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PRODUCTION ENGINEERING MEASURE

MECHANIZATION FOR .4 WATT DIODES AND
2N560 2N1051 2N1072 2N1195 TRANSISTORS

PHASE 1 FINAL REPORT
JUNE 26, 1959
TO
DECEMBER 31, 1962

CONTRACT NO.
DA-36-039-SC-81294
ORDER NO.
7641-PP-59-81-81

PLACED BY
U.S. ARMY ELECTRONICS MATERIEL AGENCY
PHILADELPHIA, PENNSYLVANIA

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MECHANIZATION FOR .4 WATT DIODES AND 2N560 2N1051 2N1072 2N1195 TRANSISTORS, PHASE 1.

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OBJECT:

1. Design and Fabricate High-Volume Production Equipment for manufacture of Transistors and .4 Watt Diodes
2. Establish Mechanized Production Lines

(15) CONTRACT ~~NO.~~ DA-36-039-SC-81294

ORDER NO. 7641-PP-59-81-81

(10) ~~Prepared~~ by M. N. REPPERT

Approved by: R. E. MOORE

ABSTRACT

This Production Engineering Measure has increased the capability to manufacture both transistors and diodes. Mechanized equipment was provided for 28 production operations between June 26, 1959 and December 31, 1962, Phase 1 of Contract No. DA-36-039-SC-81294. Mechanized production runs, performed during the last months of 1962, indicate that Phase 1 production goals were attained and that device quality was main~~tained. The~~ Efforts were directed towards increased production capability ~~is needed~~ to ensure that 2N560, 2N1051, 2N1072 and 2N1195 transistors and ten types of .4 watt diodes can be produced in sufficient quantity for the Nike-Zeus Missile Defense Network.

As integrated transistor production line provides the high-volume production capability needed for 2N560, 2N1051 and 2N1195 transistors, TO-5 devices. Seventeen machines were developed to produce these devices under this contract. Nine machines have been assigned to 2N559 and 2N1094 production since integrating the mechanized transistor production lines, ~~developed under this Contract and Contract No. DA-36-039-SC-72729.~~ Certain machines ~~of the latter Contract~~ were modified so TO-5 devices as well as the TO-18 devices of that Contract can be processed.

Production of 2N1072 transistors was augmented during this Production Engineering Measure by mechanizing two bottleneck operations of the manual production line.

The high-volume production capability for the .4 watt diodes was established by providing 10 prototype machines and 2 commercial machines. High-volume production tooling was developed for one commercial machine.

After the Data Producing Test Set is completed in 1963; process control, production control and engineering analysis will also be facilitated on the mechanized diode production line. Associated operations and the mechanized operations of this line and the integrated transistor production lines will be enhanced during 1963, thus additionally increasing the production capability during Phase 2 of the Contract.

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PURPOSE

This Production Engineering Measure provides the mechanized equipment needed to manufacture large quantities of transistors and diodes for the Nike Zeus Defense Network. Initially, the high volume equipment for transistors was only intended for the TO-5 family of devices - 2N560, 2N1051 and 2N1195 transistors. As the Mechanization Program developed, certain machines were modified to include the capability to process TO-18 transistors - 2N559 and 2N1094. Two operations for the 2N1072 transistors were also mechanized under this Contract to overcome production bottlenecks.

The mechanized equipment for .4 Watt Diodes initially mechanized only four operations; however, changes in Zeus production requirements necessitated expanding the scope of the Mechanization Program. There were 11 operations mechanized by the end of 1962, and one more will be mechanized in 1963.

A Modification to the Contract, technically accepted December 19, 1962, lists the following specific goals:

PHASE I

1.1 Provide the engineering approach to establish the capability to manufacture 2N560, 2N1051, 2N1072, and 2N1195 transistors on a mass production basis short of actual fabrication of equipment specified under Items 1.2 and 1.3 below.

1.2 Provide high volume production equipment limited to the number and types of machines, specified below, required to develop and install a limited production line directed toward a rate of 8,500 transistors, conforming to the applicable specifications, per two (2) shift, eight (8) hour, five (5) day week.

Contract Item No.	Operation and Type of Machines	Quantity of Machines
1.2.1*	Cleaning Header Lead Wire	1
1.2.2	Collector Lead to Platform Welding	1
1.2.3	Header Assembling	1
1.2.4*	Wafering	2
1.2.5	Wafer Loading (2N560-2N1051)	2
1.2.6	Wafer Screening (2N560-2N1051)	1
1.2.7*	Wafer Screening	1
1.2.8*	Wafer To Header Bonding	2
1.2.9	Wire Bonding	1
1.2.10	Can Getter Assembly	1
1.2.11	Can to Header Closure Weld	1
1.2.12*	Painting and Coating	1
1.2.13*	Coding	1
1.2.14*	Packing	1

*Denotes machines that can be used for 2N559 and 2N1094 production as well as for 2N560, 2N1051 and 2N1195 production.

1.3 Provide high volume production equipment limited to the number and types specified below. The machines shall be capable of producing parts directed toward a rate of at least 12,000 - 2N1072 transistors, conforming to the applicable specifications, per two (2) shift, eight (8) hour, five (5) day week.

Contract Item No.	Operation and Type of Machine	Quantity of Machines
1.3.1	Wafer Screening and Electrical Probe Testing	1

Contract Item No.	Operation and Type of Machine	Quantity of Machines
1.3.2	Special Test Set	1

2.1 Provide the engineering approach to establish the capability to manufacture the 1N664, 1N665, 1N666, 1N667, 1N668, 1N669, 1N673, 1N675, 1N697 and 1N701 type diodes on a mass production basis, short of actual fabrication of equipment specified under Item 2.2 below.

2.2 Provide high volume production equipment limited to the number and types of machines, specified below, required to develop and install a production line directed toward a rate of 30,000 diodes, conforming to the applicable specifications, per two (2) shift, eight (8) hour, five (5) day week.

Contract Item No.	Operation and Type of Machine	Quantity of Machines
2.2.1	Stud Lead Cleaning	1
2.2.2	Gold Bonding	1
2.2.3	Etching, Oxidizing, Cleaning and Drying	1
2.2.4	Assembling Case to Stud and Welding	1
2.2.5	Lead Straightening and Racking	1
2.2.6	Low Temperature Reverse Current Testing	1
2.2.7	Gold Plating	1
2.2.8	Coding	1
2.2.9	Coating	1
2.2.10	Final Electrical Testing	1
2.2.11	Packaging	1

PHASE 2

1.4 Modify transistor production equipment,provided during Phase 1, and interconnecting processes in accordance with advanced semiconductor technology. This task is directed toward the objective of increasing the device assembly production yield.

1.5 Design, fabricate and refine the necessary additional tooling so as to be capable of producing parts directed toward a rate of at least 12,000 transistors conforming to the applicable specifications per two (2) shift, eight (8) hour, five (5) day week.

2.3 Modify diode production equipment, provided during Phase 1, and interconnecting processes in accordance with advanced semiconductor technology. This task is directed toward the objective of increasing the device assembly production yield.

2.4 Design, fabricate and refine one Data Producing Test Set for diodes.

PHASE 3

1.6 Modify transistor processing and production equipment, provided during Phases 1 and 2, in accordance with advanced semiconductor technology to additionally increase the device assembly production yield.

2.5 Modify diode processing and production equipment, provided during Phases 1 and 2, in accordance with advanced semiconductor technology to accomplish an additional increase in the device assembly production yield.

NARRATIVES AND DATA

SECTION 1

INTRODUCTION

I Production Planning

Two mechanization programs were initiated by this Production Engineering Measure on June 26, 1959. One program was for the TO-5 family of transistors; the other, for the .4 watt family of diodes. Anticipated Nike Zeus requirements for these semiconductor devices were so great that high volume production equipment was deemed necessary. As Nike Zeus development continued, anticipated production requirements for these devices changed. Initially they increased; since 1961 they decreased. Concurrent developments under the two mechanization programs also changed overall planning for the production lines. As a result of the changes in requirements and planning, the number of machines contracted was increased from 9 to 31. All Phase 1 machines were completed by December 31, 1962. Figure 1-1 summarizes the changes in production planning made during Phase 1.

Production requirements were at their highest while Modification No. 3 was in effect. Thirteen duplicate machines were contracted at that time to avoid bottlenecks at the slower operations. Thus the output of the mechanized lines was to be balanced by providing 36 machines for 23 mechanized operations.

Two transistor production lines were being developed by the Western Electric Company prior to 1962. The transistor production line of this Contract was designed for TO-5 type transistors; the other production line was designed specifically for 2N559 and 2N1094 transistors, TO-18 devices, under Contract No. DA-36-039-SC-72729. A change in production planning eliminated the dual line concept in 1962. Certain transistor machines were modified to process TO-18 devices as well as TO-5 devices. Conversely, machines of Contract No. DA-36-039-SC-72729 were tooled to process TO-5 and TO-18 devices. The transistor machines of both Contracts were then integrated into one Mechanized Transistor Production Line.

Seventeen machines were developed under this Contract for fourteen 2N560, 2N1051, and 2N1195 operations. Three duplicate machines were provided for three operations before adopting the integrated production line concept. At two of these operations one machine was provided to process 2N560 and 2N1051 silicon transistors, and the other machine was provided for the 2N1195 germanium transistor. Two machines were also provided for one 2N560-2N1051 operation. Since adopting the integrated line concept, nine machines were assigned to TO-18 as well as TO-5 transistor production. Seven duplicate machines scheduled for two mechanized operations were deleted after production requirements decreased. Several developments were also deleted as a result of process changes or the modified production requirements. During the latter half of Phase 1, two machines were added to transistor mechanization for 2N1072 transistors. These machines are not, however, a part of the integrated line.

Production planning for the Mechanized Diode Production Line was more straightforward. Prototype machines were provided for eleven operations. At one time, two operations were scheduled to have duplicate machines. These were deleted after production requirements were reduced. Development of another mechanized operation was started under this Contract but was deleted after a commercial machine was purchased under Facility Contract No. DA-36-039-SC-26645.

II Authorization

The U. S. Army Signal Supply Agency, Philadelphia, Pennsylvania, authorized the Western Electric Company to undertake the two mechanization programs of this Production Engineering Measure June 26, 1959. Contract No. DA-36-039-SC-81294 documented the terms and condition of the programs. Modifications to the Contract increased the scope of these programs and adjusted the number and types of machines in accordance with the latest production planning and advances in state-of-the-art. A modification, technically accepted by the U. S. Army Electronics Materiel Agency, Philadelphia, Pennsylvania, December 19, 1962, was the fifth modification affecting the list of machines and overall production goals. This modification extends the Contract through 1963 (Phase 2) and 1964 (Phase 3).

III Transistor Machine Developments

Machine developments of associated Contract No. DA-36-039-SC-72729 greatly influenced transistor machine developments of this Contract. Seven mechanized operations of the two Contracts are very similar. Initial development of machines for these operations was done on the associated Contract. Design and construction of seven similar machines under this Contract were delayed sufficiently to eliminate problems encountered during construction and prove-in of the 2N559-2N1094 models. By proceeding in this manner, it was also possible to take advantage of recent advances in transistor processing.

The following transistor design changes were made during Phase 1:

1. Changed from a tubulated can to a nontubulated can containing a moisture getter.
2. Adopted a butt welded collector lead design for the TO-5

header.

3. Reduced the silicon wafer size from a .030 to a .020-inch square.

Only the third change affected machines of this Contract. The other two changes were made before mechanization of the former operation was started.

2N560, 2N1051, and 2N1195 transistors were produced by the Mechanized Transistor Production Line during mechanized production runs performed in the last months of Phase 1. Distribution of all electrical parameters indicate the quality of these devices. Several distributions of each code were slightly abnormal, but there were assignable causes in each instance. Section 2 contains distributions of all parameters tested. This section also establishes the relationship of the machines provided under this Contract to the integrated Mechanized Transistor Production Line. Individual transistor machines are described in Section 3. The following discussion reviews major developments of the transistor mechanization program.

The Wafer Breaking, Screening and Loading concept of Contract No. DA-36-039-SC-72729 could not be utilized for the silicon slices of the 2N560 and 2N1051 transistors. The silicon introduced conditions that made it necessary to manually break these slices. Manual breaking also made it necessary to re-orient the wafers with the stripe-side up prior to wafer screening. Two 2N560-2N1051 Wafer Loading Machines, Section 3.5, were then developed to supply oriented wafers to the 2N560-2N1051 Wafer Screening Machine, Section 3.6. Since the Wafer Screening Machine would receive wafers with stripes oriented randomly, a stripe orienting mechanism was developed. It rotates the wafers in accordance with the position of a 4-way switch. The operator moves this switch in accordance with a designated stripe position after completing the visual inspection. The machine orients the stripes while the wafer is transferred to a handling tray. The 2N560-2N1051 Wafer Loading and Wafer Screening Machines can not process the redesigned silicon wafers, for the wafer size was decreased after the machines were completed.

Two other wafer screening developments of this Contract incorporated features not included on the 2N560-2N1051 Wafer Screening Machine. The separate wafer loading and screening operations of the 2N560-2N1051 machines were combined on the Wafer Screening Machine, Section 3.7. This combination became feasible after a stripe sensing system and a flipping mechanism were developed. The flipping mechanism turns inverted wafers stripe-side up. The 2N1072 Wafer Screening and Electrical Probe Testing Machine, Section 3.15, also included the foregoing developments. In addition, the scope of the screening operation was increased by screening wafers electrically as well as visually.

A simplified Cleaning Header Lead Wire Machine, Section 3.1, was provided under this Contract by delaying its development. This simplification was possible because a dual purpose Header Glassing Machine was provided under Contract No. DA-36-039-SC-72729 to perform an oxidizing operation and a glassing operation. Consequently, the lead oxidizing station of the prototype lead cleaning machine of Contract No. DA-36-039-SC-72729 became obsolete. The output of the lead cleaning machine of this Contract was doubled by redesigning it and eliminating the oxidizing station.

The Wafer to Header Bonding Machine, Section 3.8, produced the most noteworthy advance of this Production Engineering Measure. It incorporates an infrared temperature detection system and an ultrasonic scrubbing system. The infrared temperature detector controls the bonding temperature, and ultrasonic scrubbing provides a sound eutectic bond at a slightly lower temperature than in the manual process. Mechanizing the Wafer to Header Bonding operation has improved the three following electrical parameters - collector voltage, collector leakage current and saturation voltage.

IV Diode Machine Developments

The diode mechanization program more than trebled in size between June 1959 and August 1961. Initial increases resulted from the increased diode requirements for Nike Zeus. The last increase followed changes in mechanization planning and diode processing. One process change increased the reliability of diodes stored or operated at high temperatures. The second change added an electrical screening operation to improve diode reliability at sub-zero temperatures. These changes increased the number of diode machines from 4 to 14. Since the last increase in August 1961, two machines were deleted from the Contract.

Fourteen mechanized operations were developed, but only 11 machines were contracted for completion during Phase 1. Following is the status of the other three developments: (1) Wafer Evaluation was deleted from the Contract because present sampling plans are adequate; (2) Wafer Preparation was deleted after ultrasonic cutting was chosen and a commercial machine was purchased on Facility Contract No. DA-36-039-SC-26645; (3) A Data Producing Test Set will be provided during Phase 2.

The Mechanized Diode Production Line is complete with the exception of the Data Producing Test Set. The absence of this test set does not affect the output of the production line. It will be used for quality control, production control and engineering analysis. All machines performed satisfactorily during the ten mechanized production runs. The quality of the ten diode types was maintained, for all distributions of electrical parameters are normal. The description of the production line in Section 4 establishes the relationship of each mechanized operation to the overall production line. Diode machines developed for this line are described and evaluated in Section 5. A review of diode machine developments follows:

The Gold Bonding Machine and the Assembling Case to Stud and Welding Machine, Sections 5.2 and 5.4, mechanize the two major assembly operations. Both machines increase the production capability significantly. The Gold Bonding Machine replaces a manual operation in which five piece parts are loaded and aligned prior to thermocompression bonding. Two design changes to the gold bonded assembly have simplified the mechanized operation. The one change eliminated two gold preforms required on the manual operation. The other change replaced a silver nail-head lead with a gold balled lead. Utilizing a balled lead has simplified internal lead forming and loading.

The Assembling Case to Stud and Welding Machine combined an assembling operation and a welding operation. Assembling involves threading a .006-inch-diameter lead into the tubulation of a diode case and then tack welding the assembly together. Internal and external lead straightness must be maintained to assure efficiency of this machine. A new welding concept has been conceived which will simplify both the assembly and the welding operations. It will be added in the early part of Phase 2.

The Etching, Oxidizing, Cleaning and Drying Machine, Section 5.3, provides control of operations formerly under complete control of an operator. By enclosing the etching and drying stations, ambient conditions are also more closely controlled. Initial tests indicate that the machine etching rate is much slower than in the manual operation. Thus, the slower etching rate provides an additional control during etching. Initial yields from the machine were lower than from the manual operation, but operating conditions were not optimized. Once the operating conditions are optimized, the machine etching yield are expected to exceed the manual operation.

Three machines were added to the Contract in August 1961 to provide the straight leads required by five of the seven operations mechanized initially. The Stud Lead Cleaning Machine and the Gold Plating System, Sections 5.1 and 5.7, replace batch-type operations in which leads were bent during handling and processing. A Lead Straightening and Racking Machine, Section 5.5, was needed to restraighten the leads after the diodes have been aged and temperature cycled.

The Gold Plating System was also needed to update diode processing on the mechanized line. A device design change was made to improve aging characteristics. As a result, the painted protective coating was replaced by a gold plate and a clear silicone varnish. The Low Temperature Reverse Current Testing Machine, Section 5.6, was also added to update the mechanized line. This machine screens out diodes that are erratic at low temperatures.

V Technical Assistance

As noted in the last two sections, changes to the transistor and diode design specifications by the Bell Telephone Laboratories influenced the scope of the mechanization program. In the actual performance of the Contract, Bell Telephone Laboratories contributed directly to the overall Western Electric Company effort by providing technical assistance to the mechanization program. This technical assistance, in the form of an engineering service during the development of the mechanized equipment, extended over the 3-1/2 year Phase 1 period of the Contract. Because the scope of this consulting service included a large number of areas, a separate narrative for the Laboratories effort is not feasible. Accordingly, the Bell Telephone Laboratories contributions have been integrated into the individual machine narratives and are not specifically identified within the mechanization development programs.

PRODUCTION PLANNING FOR THE MECHANIZED PRODUCTION LINES

TRANSISTOR

MODIFICATION NO.	DATE	WEEKLY OUTPUT MECHANIZED LINE	NO. OF MACHINES PROTOTYPES	TOTAL
0	6/26/59	2,400	5	5
2	7/26/60	12,000	15	15
3	8/19/60	24,000	16[1]	27
5	9/29/61	12,000	22[2]	23
6	1/9/62	12,000	19[2]	20
8	12/19/62[3]	8,500(Phase 1)	18[2]	19
		12,000(Phase 2)	18[2]	19

DIODE

MODIFICATION NO.	DATE	WEEKLY OUTPUT MECHANIZED LINE	NO. OF MACHINES PROTOTYPES	TOTAL
0	6/26/59	6,000	4	4
2	7/26/60	30,000	7	7
3	8/19/60	36,000	7	9
5	9/29/61	30,000	14	14
6	1/9/62	30,000	14	14
8	12/19/62[3]	30,000(Phase 1)	11	11
		30,000(Phase 2)	12	12

1. Includes one prototype machine for 2N1072 Transistor.
2. Includes two prototype machines for 2N1072 Transistor directed toward producing 12 thousand 2N1072 Transistors per week.
3. Technical acceptance date.

FIGURE 1-1

SECTION 2

MECHANIZED TRANSISTOR PRODUCTION LINE

D. H. Lockart

MECHANIZED TRANSISTOR PRODUCTION LINE

I General

The major requirement of Phase 1 of the 2N560, 2N1051, and 2N1195 mechanization portion of PEM Contract No. DA-36-039-SC-81294 is provision of high volume production equipment required to develop and install a limited production line directed towards producing 8500 transistors conforming to applicable specifications per two shift, eight hour, five day week. In addition to specific machines, this capability includes the provision of associated tooling and facilities. To meet this requirement, an integrated production line capable of manufacturing 2N560, 2N1051, and 2N1195 transistors has been designed, fabricated and installed.

A second requirement of Phase 1 of the transistor mechanization portion of the Contract is provision of high volume production equipment capable of producing parts directed toward a rate of at least 12,000 2N1072 transistors conforming to the applicable specification per two shift, eight hour, five day week. This task includes the design, fabrication and refinement of only two machines.

Normal practice requires that pilot production runs be made over manufacturing facilities to verify machine performances and line capabilities. In this case, however, pilot runs were not made a requirement under the terms of the PEM Contract for the following reason. During the period following installation and prove-in of the 2N560, 2N1051, and 2N1195 mechanized line, production requirements of these devices were sufficiently large to permit the operation of the line with regular product. Mechanized production runs were made, therefore, rather than so-called pilot runs. Some of the devices resulting from these runs were used to satisfy the data requirements of the Contract, after which they were shipped as regular product.

No 2N1072 production program was scheduled for this period. Rather then starting up the production line for the purpose of evaluating the two 2N1072 machines, the U. S. Army Electronics Materiel Agency authorized using prove-in and acceptance data to verify machine capability. As a result no production runs were made using these machines.

Those machines developed under this Contract capable of processing 2N559 and 2N1094 transistors were used in support of the 2N559 Pilot Run and the 2N1094 mechanized production run as required. Manufacturing costs for operating the production line were borne by the pilot run in the case of 2N559 production and by the product in the case of the other codes. Data collection costs were absorbed by the PEM Contract.

II Mechanized Line Operations

Phase 1 of PEM Contract No. DA-36-039-SC-81294 limited the development of high volume production equipment to specific quantities and types of machines and tooling. It was not intended that all manufacturing operations be mechanized, but that machines would be built for those operations and processes which could be made more reliable or required a high degree of skill by the operator. As a result, the limited production line is a "hybrid" line consisting of a mixture of mechanized and unmechanized equipment. In addition, the equipment developed under this Contract is integrated with the equipment developed under associated PEM Contract No. DA-36-039-SC-72729. This integration permitted the development of a single production line capable of processing 2N559, 2N560, 2N1051, 2N1094, and 2N1195 transistors. Certain equipment will handle only TO-5 or TO-18 components, but many of the production facilities can be used for both. This results in reducing the overall investment required to meet the Contract production requirements.

For purposes of this discussion the subject production line is divided into four parts, as follows:

1. Transistor Header Assembly
2. Semiconductor Material Preparation
3. Transistor Can Assembly
4. Transistor Assembly

Each part will be discussed in sufficient detail to provide an understanding of the relationship of the various items of mechanized equipment to the unmechanized operations and the production line as a whole.

The transistor header assembly portion of the production line is highly mechanized. Machines have been provided to perform most of the critical operations. A header assembly requires one platform, two electropolished leads, one cleaned lead, one piece of cut glass tubing and one piece of cut glass rod. Cleaning and drying of the platform and the cleaned lead is done by the Piece Part Cleaning Machine, an SC-72729 Contract machine. The purpose of this cleaning is to remove greases, oils, and oxides from the surfaces of the parts. Cleaning of the glass parts is done on a batch basis by manually rinsing in cleaning solutions. The two electropolished leads are processed over the Cleaning Header Lead Wire Machine, Item 1-2-1 of the Contract. This machine cleans only that portion of the leads which is involved in the glass-to-metal seal during fabrication of the header. Cleaning is accomplished by removing a layer of the lead by electropolishing. Rinsing and drying are also done by the machine.

Following cleaning and drying of the platform and the cleaned lead, they are butt-welded together in the Collector Lead to Platform

Welding Machine, Item 1-2-2 of the Contract. The lead becomes the collector lead of the transistor and the platform will subsequently support the semiconductor material used in making the transistor. The lead is welded to the underside of the platform properly positioned with respect to the platform locating tab. Following welding, the assemblies are decarburized on a batch basis in a furnace with an atmosphere of wet dissociated ammonia.

Assembly of the various header piece parts is done by the Header Assembling Machine, Item 1-2-3. Initially, the collector lead-platform subassembly is manually placed in proper orientation in a ceramic mold which will be used during the subsequent glass-sealing operation. These molds each containing 10 subassemblies are fed into the Header Assembling Machine where the base and emitter leads (the electropolished leads), and the pieces of glass rod and glass tubing are automatically fed and placed in proper position. The final station of this machine bends the emitter and collector leads of each assembly and welds all three leads together. This step is taken for the following reasons. The emitter and collector leads are bent to separate them from the center or base lead during gold plating. If the leads are too close together during this operation, a "shadowing" effect is noted, which results in little or no plate on the inner surfaces of the leads. The leads are welded together to strengthen the structure, which helps prevent bending of the leads during subsequent handling. Automatic insertion of headers into the various machines is much easier with the leads joined together.

After assembly the loaded molds are processed through the Header Glassing Machine of the SC-72729 Contract. This machine oxidizes the metal piece parts in the assembly and melts the glass parts, thereby forming a glass-to-metal seal between the glass and the platform and the glass and the leads. Annealing of the sealed header is also completed in this machine. Following glassing, parts are manually unloaded from the molds and inspected for lead location, for proper welding of leads, and for glass height above the bottom of the platform.

Assembled headers are manually fed into tooling which trims the two ungrounded leads, namely the base and emitter leads, to the proper height with reference to the bottom of the platform flange. After trimming the headers are returned to the Piece Part Cleaning Machine, previously mentioned, where oils, oxides, and excessive glass are removed. After this operation a 100 percent inspection for glass defects is made. Next the headers are chemically cleaned, polished, rinsed, and dried in batches using various tanks and commercial dryers. The purpose of this operation is to remove all oils and greases present on the headers due to handling and to prepare the metal surfaces by etching for gold plating.

After cleaning and polishing the headers are processed to the Strip Perforating and Welding Machine developed on the SC-72729 Contract. This machine punches index holes into a steel tape and welds the ends of the header leads to the tape. The tape containing the headers is wound on a reel for processing to gold plating. Plating is done by the Header Continuous Rack Plating Machine, another SC-72729 Contract machine. Reels of welded headers are unwound and the strip is drawn through various cleaning, rinsing, plating, and drying stations. Gold plated headers are then sheared from the strip in a manner not affecting the weld between the three leads. After strip plating, headers are sintered in batch quantities in a commercial furnace to level out the gold plate and to make it uniform.

Plating inspection and a final inspection of a random sample of completed headers prepares the headers for shipment to the transistor assembly area. A flow diagram of the operations entailed in manufacturing transistor headers is shown in Figure 2-1.

Preparation of semiconductor material starts with the basic raw material, polycrystalline silicon or germanium dioxide, as the case may be, and ends with inspection of completed wafers. No machines have been fabricated for processing of the basic material since most of this processing is done with large quantities. It is not until the material is ready to be broken down into wafers that mechanized equipment is utilized.

The various operations involved in material processing will not be discussed in detail. Silicon material for the 2N560 and 2N1051 transistors is purchased in polycrystalline form. A single crystal ingot is grown from a molten charge of polycrystalline silicon doped with arsenic. A properly oriented "N" type seed is used to start the growing process. The crystal is cut into slices and the resultant slices are lapped and polished. Following a clean-up etch an oxide layer is formed on the slice in an oxidation furnace. The surface is chemically cleaned and gallium is diffused into the slice. This process results in gallium diffusing through the oxide layer forming a "P" layer just under the oxide. The slices are lapped to remove the oxide and the gallium layer from the back side. After cleaning an emitter window or rectangle is formed on the face of the slice by use of ultraviolet light-sensitive material, suitable masks and etchants. After the window is formed, the oxide is removed from the slice face in precisely the area of the window. The slice is again cleaned following which phosphorus is deposited on the slice and diffused into the gallium layer. The phosphorus will not diffuse through the oxide layer, so it will be diffused only in the window area and on the back side of the slice. This will cause the formation of an "N" region in the window area and an "N+" layer on the back of the slice. The back side of the semiconductor slice is etched to remove oils, greases and other contaminants, and gold is evaporated onto this surface. The gold is diffused into the silicon material to form recombination centers which will subsequently reduce the pulse response turn-off time of the transistor.

All oxide is removed from the slice face, and aluminum emitter and base stripe pairs are evaporated and alloyed into the phosphorus rich emitter areas and the gallium rich base regions of the slice, respectively. Using masking techniques a wax coating is applied to the series of small areas of the slice each of which contains a stripe pair. A subsequent chemical etch removes material from the slice face except in the areas protected by the wax. Sufficient material is removed to eliminate the gallium "P" layer. The end result is a series of raised areas or "mesas". Each one of these mesas will become the active area of a transistor wafer. Each active area will contain one stripe pair, and it will be only slightly larger than the space occupied by the stripe pair itself. This completes the processing of the semiconductor material and the silicon slice is now ready for scribing.

Material for the 2N1195 transistor, germanium dioxide, is reduced to germanium metal, zone refined and zone leveled. Zone leveling provides for the introduction of doping alloys and for the growing of a single crystal. The single crystal bar is cut into slices, and the resultant slices are lapped and etched on both sides and mechanically polished on one side. Polished slices are transported to the gaseous diffusion process where the semiconductor junction is formed.

The "P" type germanium slice used in manufacturing the 2N1195 transistor is diffused with antimony to form an "N" skin on its surface. Since the "N" skin is formed on all external surfaces it must be subsequently removed from the unpolished side by etching. After a clean-up etch a copper backing is evaporated onto the unpolished side of the slice. Following an additional clean-up etch, gold and aluminum base and emitter stripe pairs are evaporated onto the polished side of the slice. The aluminum emitter stripes are permitted to alloy into the germanium slice forming a "P" region in the "N" skin.

The active area of the 2N1195 transistor wafer is surrounded by a moat deep enough to penetrate through the "N" skin into the "P" region. This moat is formed while the material is still in the slice form by use of an ultraviolet light-sensitive material, suitable masks and etchants. This process forms a physically undamaged active area with the evaporated stripe pair in the center.

The germanium slice is now ready for scribing. Operations on silicon slices for the 2N560 and 2N1051 and germanium slices for the 2N1195 are essentially the same from this point to the completion of material processing. Slices are scribed for subsequent breaking into wafers by the Wafering Machines, Item 1-2-4 of the Contract. Scribe lines are cut with a diamond point on .020-inch centers in both X and Y directions. The scribed slices are manually broken into wafers over the sharp edge of a steel block. The wafers are then cleaned to remove chips, dust and other contaminants.

The next two operations, Wafer Loading and Wafer Screening, were to be performed by machines developed under the Contract. During the development period the size of the wafers was changed from .030-inch square to .020-inch square rendering the machines temporarily unusable. It is anticipated that these machines will be modified during Phase 2 of the Contract to adapt them to the smaller wafer size. These operations were performed manually during the mechanized production runs; however, this description will assume the machines can be used

Following wafer cleaning, silicon wafers are loaded from bulk into wafer trays with the active element in view by the Wafer Loading Machines, Item 1-2-5. The Wafer Screening Machine, Item 1-2-6, processes silicon wafers from the loaded wafer trays to a viewing station for operator acceptance or rejection. Acceptable wafers are oriented with respect to the base and emitter stripes by operator control during reloading into wafer trays. Germanium wafers after cleaning are separated from bulk and oriented stripe-side up for visual inspection in a viewing station by the Wafer Screening Machine, Item 1-2-7. Acceptable wafers are then oriented with respect to the base and emitter stripes under operator control during transfer to a wafer tray. The loaded trays form one of the inputs to the transistor assembly portion of the mechanized line. A flow diagram showing silicon material processing is given in Figure 2-2 and a diagram for germanium processing is given in Figure 2-3.

The metal can used to enclose the assembled transistor is formed on a punch press using tooling developed under the PEM Contract. After proper cleaning to remove oils, greases and oxides, cans are fed into the Can Getter Assembly Machine, Item 1-2-10. This machine has two main sections. The Can Loading section loads the cans into pallets and then places a measured amount of nickel powder into each can. A powder leveling component levels the nickel powder in the cans and places the loaded pallets on a moving belt of a sintering furnace. Following sintering the pallets are fed into the Getter Loading section which removes any loose particles of sintered nickel, adds a moisture seeking getter and melts the getter and permits it to flow into the pores of the sintered nickel powder where it solidifies. The can getter assemblies are then processed through an activating furnace just prior to use. This furnace drives off the moisture present in the getter. Assemblies are stored in dessicator flasks under vacuum until used. The flow diagram of the operations affecting the can is included with the transistor assembly flow diagram, Figure 2-4. This diagram is valid for 2N560, 2N1051, and 2N1195 transistors.

The first transistor assembly operation is accomplished on the Wafer Bonding Machines, Item 1-2-8. Here the semiconductor wafer is intimately joined to the transistor header through the medium of a gold-germanium or gold-silicon eutectic bond depending on the device processed. Wafers are loaded into the machine in trays, each holding 100 oriented wafers. Headers are manually loaded into the machine during the dwell period of the operating cycle. Wafer bonded headers are automatically unloaded following which they are manually placed in magnetic handling racks for further processing. The wafer-header subassemblies are screened for bonding defects following which acceptable subassemblies are spray-cleaned to prepare the stripes for wire bonding. Both the screening and the spraying operations are performed with the wafer bonded headers in the handling racks. The Wire Bonding Machine, Item 1-2-9, attaches gold wire to the aluminum wafer stripes and to the portions of the transistor external leads extending above the header platform. The gold wire used for silicon transistors is .001 inch in diameter and is attached to the stripes and leads using a thermal compression principle. One span of wire is attached to the base stripe and the base lead. A second span of wire is attached to the emitter stripe and the emitter lead. The 2N1195 germanium transistor uses .0005-inch-diameter gold wire. Following wire bonding, loose ends of gold wire extending beyond the external leads are manually trimmed.

The next operation after gold wire trimming is emitter etching. Wire bonded silicon transistors are lightly etched with a mixture of hydrofluoric and nitric acids, rinsed and cleaned with deionized water and dried in a hot air drying station. Wire bonded germanium transistors are lightly etched with hydrogen peroxide, rinsed with deionized water, partially dried with a methanol dip and completely dried in an infrared chamber. The purpose of the etching operation is to clean the transistor active area of greases and foreign particles. Immediately after etching, the devices are placed in a baking oven. This bake passivates the surface of the semiconductor material and stabilizes the electrical characteristics of the device. Following the bake, a protective coating of SiO_2, silicon dioxide, is applied to the top surface of the transistor and header. The purpose of this coating is to protect the transistor junctions from foreign particles. All devices after coating go into a pre-weld bake. This bake drives out any gases which may have been trapped by the silicon dioxide coating and also dries the coating itself by driving off moisture.

After completing the pre-weld bake the devices are processed to the Can to Header Closure Weld Machine, Item 1-2-11. In this machine the metal cans containing the moisture seeking getter are welded to the transistor headers in an atmosphere consisting of a mixture of nitrogen and helium for the silicon transistors and nitrogen, oxygen and helium for the germanium. The helium is used as a tracer element during the next operation, helium leak detection. In this operation minute leaks through the weld, through the can or through the glass-to-metal seals can be detected by sensing the presence of helium in the atmosphere surrounding the device. Devices which pass this check are given an oven bake. This bake rapidly drives any moisture remaining inside the can into the getter.

Following the bake, devices are placed in a container filled with alcohol. The purpose of this operation is to allow the alcohol to penetrate any large leaks which may be present in the device. The presence of alcohol in the device is detected at D-C Screen by the failure of the unit to meet leakage current specifications. The alcohol soaking operation is necessary since large magnitude leaks are not detected by the helium leak check. In this case, the helium is exhausted by the time the check is made.

Just prior to testing, the transistor leads are cut to final length. The weld holding the three external leads together is removed by this trimming. The completed transistors are then processed to D-C Screen where all Group A D-C tests in the applicable specification are made on a go no-go basis. Good units after testing are centrifuged at a speed which applies a force equivalent to 20,000 times the force of gravity. This operation, done only on silicon devices, checks the strength of the wafer and wire bonds made during previous operations. Good devices after centrifuge are subjected to a 600-milliwatt power age for 12 hours to determine the failure rate of the transistor lot on this parameter. If the lot is acceptable after power age evaluation, it is processed to the next operation.

Good units at this stage are cleaned to remove oils and greases following which the external leads are coated with solder. After a second degreasing, the devices are processed to the Painting and Coating and Coding Machines. Units are manually loaded into magnetic handling trays which are automatically fed into the Painting and Coating Machine, Item 1-2-12, for painting. Following this operation, the devices are baked and then processed to the Coding Machine, Item 1-2-13. Following coding, the devices are baked a second time and then processed to the Painting and Coating Machine again for varnish coating. A third bake follows coating. Devices remain on the magnetic handling trays throughout all of these operations.

All remaining devices are tested manually on all Group A parameters. Good transistors passing this series of tests are submitted to a final inspection which is done on a sample basis. The various samples are submitted to electrical and environmental tests as determined by the applicable specification. All electrical tests required by this inspection are performed by the Data Handling System developed on the SC-72729 PEM Contract.

If the transistor lot passes final inspection, the individual transistors are packaged on the Packing Machine, Item 1-2-14 of the Contract. This machine automatically places completed transistors in a sealed polycell (polyethylene and cellophane) strip for shipment. A flow diagram of all transistor assembly operations is shown in Figure 2-4.

The two machines developed for processing 2N1072 transistors are the Wafer Screening and Electrical Probe Testing Machine, Item 1-3-1 of the Contract, and the Special Test Set, Item 1-3-2. The first machine takes individual silicon wafers from bulk and orients them, stripe-side up, for visual inspection and testing at a screening and probing station. Wafers are visually screened by an operator and accepted or rejected. Accepted wafers are probed in order to make BV_{CES} and BV_{EBO} electrical tests following which good wafers are automatically loaded into wafer trays.

The Special Test Set mechanically tests completed 2N1072 transistors, after manual loading, on all Group A parameters with the exception of C_{ob} performed at 10 kilocycles. Six D-C tests and two pulse response tests are made.

Complete resumes of the operations performed on the 2N1072 transistor are not included in this report. Processing of this device is similar to the processing of other silicon transistors. The relationship of the two machines discussed to the other processes involved can be easily correlated by referring to the processing of the 2N560 and 2N1051 transistors.

III Material Handling

Several unique material handling components were provided to support the various items of mechanized equipment developed under the PEM Contract. These components are used to support transistor elements either during the time they are in the machines, or during storage periods between operations or both. They are also used to maintain orientation of elements, to make handling easier and to protect the elements from physical damage.

In this sub-section all material handling components developed under the Contract will be described in detail. Illustrations have been included to help clarify these descriptions. The relationships of these various components to the contract machines will be emphasized.

The first material handling components used in header assembly are the ceramic molds used for receiving the header piece parts during assembling and for holding these parts during glass-to-metal sealing. These molds each have 10 cavities into which platform-lead subassemblies are manually loaded. A locating slot receives the tab on the header platform to provide proper orientation. At the base of each cavity two holes are drilled to receive the base and emitter leads as they are fed through holes in the platform by the Header Assembling Machine. A third hole is provided for possible automatic unloading of the molds after glassing. V-shaped slots are provided on one side of the molds for locating during header assembly. Each slot is relieved on one edge to provide for indexing the molds. The mold used for the TO-5 header is shown in Figure 2-5.

The next material handling component used in header assembling is the strip to which the headers are welded by the Strip Perforating and Welding Machines. The strip itself is made of steel and is used as a means of supporting the assembled transistor headers during gold plating. It also forms the electrical contact to the headers during plating. The headers are welded onto the strip on 1/2-inch centers using approximately the extreme 3/32-inch portion of the leads. The three leads have been previously welded together on the Header Assembling Machine. Indexing holes are punched into the strip by the Strip Perforating and Welding Machine. These holes mate with the teeth in the drive wheels of the Header Continuous Rack Plating Machine. The strip is pulled and guided through the Plating Machine by the various drive wheels, thereby providing a means for passing the headers through various cleaning and plating solutions, rinsing stations and dryers. A picture of strip-mounted headers is shown in Figure 2-6.

Wafer trays and magazines were developed to support transistor wafers during the period of storage between the Wafer Loading, Wafer Screening and Wafer Bonding Machines. Wafers are loaded into the trays automatically by the first machine, processed by the second machine and automatically unloaded from the trays by the third machine. During storage eight trays can be placed in one magazine. The trays have the capability of supporting the individual wafers, maintaining their orientation during reasonable handling, and providing some protection for the extremely small, brittle wafers. The magazines provide some protection from dust and contaminants settling directly on the surface of the wafers.

Each wafer tray holds 100 wafers of the .020 by .020-inch size, the size used for all contract codes except the 2N1072. The wafers are held in square slots just slightly larger than the individual wafers. The wafer tray and magazine are illustrated in Figure 2-7. The wafer slots are the series of small squares along the centerline of the tray. The raised fins along the near side of the tray are used for indexing the tray during loading and unloading.

During the assembly of the transistor can and the moisture seeking getter in the Can Getter Assembly Machine, a metal pallet is used for supporting the transistor cans. This pallet is actually the handling medium of the machine itself. The first operation performed by the machine is the loading of 66 cans into each pallet. The cans remain in the pallets during all subsequent operations and are only unloaded after the operation is complete and the can getter assemblies are stored in dessicator flasks under vacuum. Between operations the pallets are stockpiled in pallet magazines, each magazine holding 18 pallets. The pallet with its accompanying magazine are shown in Figure 3.10-2.

The major handling component used in the transistor assembly line is a magnetic handling tray and magazine combination. This combination is first used as an output of the Wafer Bonding Machine. The wafer bonded headers are loaded into the magnetic tray and they remain in the tray during wafer bond inspection and spray cleaning. The trays are then used as the input to the Wire Bonding Machine. This machine automatically unloads the headers from the tray, performs the Wire Bonding operation and returns the headers to the tray. Following wire bonding the headers are removed from the magnetic trays for further processing. Header tray magazines are used throughout the above mentioned processes as storage for the loaded trays. They offer support and limited protection for the easily damaged devices.

Magnetic trays are used for input to the Painting, Coding and Coating operations. Trays are automatically removed from the magazine; devices are mechanically removed from the trays; the operation is performed, and the devices are replaced in the trays and the trays in the magazines. These steps are essentially repeated three times -- once for each operation.

The magnetic trays each hold 30 units on 3/8-inch centers. The devices are held by attraction between the magnets and the metal external leads of the transistor. They are oriented so that the emitter and collector leads of the transistor rest against the magnet. In the normal position, the bottom of the transistor platform rests against the stainless steel plate which acts as a frame for the tray. For the Wire Bonding operation, the headers are pushed from beneath by a force applied on the welded lead ends raising the devices above the stainless steel plate. The leads remain in contact with the magnet and are guided by slots cut in the plate.

Each magazine holds 20 trays for a total of 600 devices. Locks are provided to prevent the trays from sliding out of the magazines during handling. Trays and magazines are illustrated in Figure 2-8.

During Phase 2 of the Contract, material handling will be further evaluated to possibly extend it to other operations. Effort will be applied to eliminate manual loading of material handling components.

IV Mechanized Production Runs

As stated earlier in this report, no pilot runs as such were required under the terms and conditions of the PEM Contract. Instead mechanized production runs were made using all available machines developed under the SC-81294 Contract and its associated Contract, SC-72729, when applicable. 2N560, 2N1051, and 2N1195 transistors were processed in varying numbers. Good transistors resulting from these runs were shipped as regular product.

The mechanized runs were made during the last quarter of 1962. Semiconductor slices and transistor header elements were earmarked for the production runs, and instructions were issued to process these components over the mechanized equipment. Some of the good transistors resulting from the runs were used for data collection purposes to meet the data requirements of the Contract. The production runs also permitted a thorough evaluation of the manufacturing equipment developed with contract funds.

Several normal and anticipated problems arose and were met during the mechanized runs. Operators of the various items of mechanized equipment required training over and above that given during shop trial and/or production trial phases. Machines experienced periods of down-time due to maintenance requirements and due to the need for minor changes and adjustments. Variations in semiconductor material and piece parts were found which adversely affected the operation of some of the mechanized equipment. As anticipated, all transistor elements must be made with as little variation as possible, since the mechanized equipment will not accept wide fluctuations in parameters.

In general, the results of the mechanized production runs met all expectations. Operators developed fast and became very skilled in operating the equipment. Operator errors did occur on occasion, but, fortunately, they were limited in number. No problems arose during the runs which could not be solved within a reasonable period of time.

V Test Data

The PEM Contract requires that test data be provided from a mix of one thousand 2N560, 2N1051, 2N1072, and 2N1195 transistors. Test data from 2N1072 transistors was not provided, however, due to the lack of a production program. Since it was inadvisable to produce devices for the sole purpose of data collection, USAEMA engineering personnel agreed that the 2N1072 data requirement of the Contract be waived. Test data from a mix of one thousand 2N560, 2N1051, and 2N1195 transistors was provided instead. The number of transistors from which data was accumulated and the number of parameters involved are listed below:

Device Type	Number of Devices	Number of Parameters
2N560	364	10
2N1051	316	9
2N1195	320	11

The applicable military specifications for these devices are listed next:

Device Type	Applicable Specification
2N560	MIL-S-19500/73A dated 29 July 1960
2N1051	MIL-S-19500/216(NAVY) dated 9 November 1961
2N1195	MIL-S-19500/71C dated 17 January 1961

In order to make the raw test data more understandable, distributions of parameter values were plotted. The total number of devices as shown above for each code were used in determining the distributions.

The distributions of the various parameter values are shown in Figures 2-9 to 2-38 inclusive. The device type, the test parameter, bias conditions, specified maximum and/or minimum test values, and the number of devices in the distribution are given for each figure.

The ordinate of each distribution shows the central values of the cells selected for plotting the distribution. For example, the I_{CBO} distribution for the 2N560 transistor, Figure 2-9, lists values of .0002, .0007, .0012, etc. The first cell includes values from .0000 to .0005, the second cell includes values from .0005 to .0010, and so on. The mid-values or central values are .00025 and .00075 respectively, however, since the fifth digit is not significant in this particular distribution, it is dropped. In the event a reading is obtained which coincides with the boundary value between two cells, for example .0005, this device will be counted in the lower valued cell, the .0002 cell.

Cell widths and the number of cells used have been selected on the basis of providing the most meaningful distributions. In doing this, it became impractical to list all the cells required to show the position of all units since the test values on certain devices show considerable departure from the norm. HI and LO categories were added to pick up these devices. These categories do not indicate "out-of-spec" devices, since all units used in accumulating the data met the applicable specifications.

It should be noted that leakage current (I_{CBO}) distributions for the 2N560 and 2N1051 contain several devices with readings of .0000 µAdc. The actual test values are not zero but are smaller than the minimum readout capability of the test equipment used in generating the data. These devices fall in the LO cell for that particular parameter.

Transistors are stockpiled after Group A final testing and submitted to final inspection on a lot basis. The final inspection organization takes random samples of the device lots and subjects them to the various Group B tests. In certain cases the test is an examination of the physical characteristics of the sample. A check of the dimensions of the completed transistors is an example of this case. In other tests, the sample is subjected to certain environmental conditions, following which the devices in the sample are subjected to end point electrical tests. Moisture resistance evaluation is an example of this latter type of Group B test.

The mechanized production lots from which the 2N560, 2N1051, and 2N1195 transistors used for data collection were taken were submitted on a sample basis to Group B inspection. The results of these inspections are given in Figures 2-39, 2-40 and 2-41.

VI Evaluation

Evaluation of the degree of success obtained in providing a mechanized production facility meeting the terms and conditions of the PEM Contract can best be made by considering the results of the mechanized runs. These runs essentially represented an opportunity to evaluate the performance of the individual machines, the contributions of the unmechanized processes to the various device parameters, the ability of the various material handling components to perform their particular functions, and the results of testing and final inspection of the completed transistors.

All runs made were basically successful. While many problems arose, none were of sufficient magnitude to require complete termination of production. The experience of these runs, however, dictates that certain safeguards be established to insure that transistors can be manufactured at the required production rate. These safeguards are listed below:

1. Skilled operators with the ability to use good judgment

should be used. These operators should be thoroughly familiar with the operation of their machines or equipment.

2. Quality control measures should follow all operations which affect the product in any way. High capacity production lines are particularly vulnerable to variations caused by machine maladjustments or operator error.

3. Critical operations, whether mechanized or partially mechanized, should be controlled automatically, whenever possible, rather than being placed under operator control.

4. Special efforts should be made to insure that all piece parts meet specifications consistent with mechanized production. Effort should also be applied to insure that all variables are covered by specifications.

These safeguards are not unique, since they should be a part of any production line. It is important, however, that they be enforced and continually checked for improvement, particularly when applied to high-volume production lines.

Most of the mechanized equipment developed under the PEM Contract was operated for the duration of the pilot and mechanized production runs. The performance of these machines is discussed in detail in the various individual machine reports. In summary, a list of the machines developed under this Contract together with the Western Electric Company drawing numbers and the operating and maintenance specification numbers for the machines is given in Figure 2-42.

The distributions of the electrical test values for the various transistor codes shown in Figures 2-9 to 2-38 are normal bell-shaped distributions for the most part. Those distributions which depart from normal are discussed in the next few pages.

The BV_{CES} distribution for the 2N560 transistor, Figure 2-10, shows a sharp drop on the upper end of the distribution. This drop is due to the inherent characteristics of the silicon material. The diffused collector to base junction breakdown voltage limits the upper value of BV_{CES}. The spreading of the lower values of the distribution shows the effect of emitter alloying. This spreading is a function of the variation in effective base width which is inversely proportional to emitter depth. The h_{FE} distribution for the 2N560 transistor, Figure 2-14, shows a sharp cutting away of the lower values. Devices which normally would occupy the low valued cells were rejected on pulse response tests. This eliminates them from the gain distribution since only devices good on all parameters have been used.

Figure 2-15, which shows the pulse response turn-on time values for the 2N560, exhibits the phenomenon of "operator favorite value". While the distribution is normal, certain values of turn-on time are favored by the operators taking visual readings from a meter. This results in certain cells containing a disproportionate number of devices while adjacent cells contain fewer than normal devices. Other distributions will exhibit this phenomenon when manual test readings are taken.

The BV_{CES} distribution for the 2N1051 transistor, Figure 2-21, shows the same sharp drop on the upper end as the 2N560 distribution for this parameter due to the inherent limiting effect of the silicon material. In addition, another effect is noted. The distribution is bimodal which is caused by oscillations in a portion of the transistors tested. These oscillations produce a reduced BV_{CES} reading. The oscillations are caused by the external circuitry providing a feedback loop. Since these devices were tested, a special socket has been designed which eliminates this problem.

Several distributions for the 2N1195 transistor require comment and evaluation. Figure 2-31 which shows the h_{fb} distribution peaks near the high specification limit and then drops off very sharply. This is due to the fact that electropolished germanium slices were used to fabricate the wafers used during the mechanized run for this device. Mechanically polished slices result in a normal distribution for this parameter. Figure 2-32, the C(dep) distribution for the 2N1195 is cut off very sharply by the maximum limit of 1.5 $\mu\mu$f. During the mechanized production run, over-size slice moating masks were inadvertently used which resulted in larger than normal active areas. This condition directly affects this parameter. The problem has been corrected and C(dep) distributions are now normal.

The REh_{ie} distribution for the 2N1195, Figure 2-36, is cut away on its upper side by the 80-ohm specification limit. The diffusion cycle for this transistor is peaked to give a better BV_{EBO} distribution, Figure 2-30, which has this detrimental effect on REh_{ie}. The BV_{CEO} distribution for the 2N1195, Figure 2-38, is cut away on its lower-valued end by the specification limit of 20 volts. This is due to the use of electropolished slices as mentioned earlier. Use of mechanically polished slices causes this distribution to peak 2 to 3 volts higher.

All distributions which depart from normal can be attributed to assignable causes. Yields which resulted from the various mechanized production runs are not discussed in this report since they are considered proprietary data by the Western Electric Company. These yields, however, were normal for this type of operation.

Evaluation of Group B inspection results indicates that all lots tested behaved in normal fashion. In no case were the allowable number of failures exceeded for any examination or test. In only one case were the allowable number of failures equaled. 2N1051 lot number 82 showed two failures on Subgroup 2. This was a result of an inadvisable change in the shop testing limits for this device. During the period that lot 82 was being processed, a new semi-automatic test set was introduced which was set up with test limits closer to the specification limit than formerly used. The two failures were just barely outside the specification limit for the subgroup.

While the mechanized production line is a reality and has been operated in production, it is not claimed that all machines are problem-free or that all processes are optimized. Considerable effort is planned for Phase 2 of this Contract to update certain machines and to refine certain processes. Additional mechanized production runs will be made at the end of 1963 to evaluate the progress made during this phase.

VII Conclusions

The following conclusions are gathered from this report:

1. A mechanized production line consisting of prototype machines and associated tooling and facilities with a capacity meeting contract requirements has been provided.
2. 2N560, 2N1051, and 2N1195 mechanized production runs were made on the mechanized line. These runs resulted in an output of good transistors meeting the applicable specifications. As proved by these runs, the line can be operated and will produce good product.
3. Distributions of test parameter values for all codes are normal with certain exceptions for which there are known assignable causes.

HEADER ASSEMBLY OPERATIONS

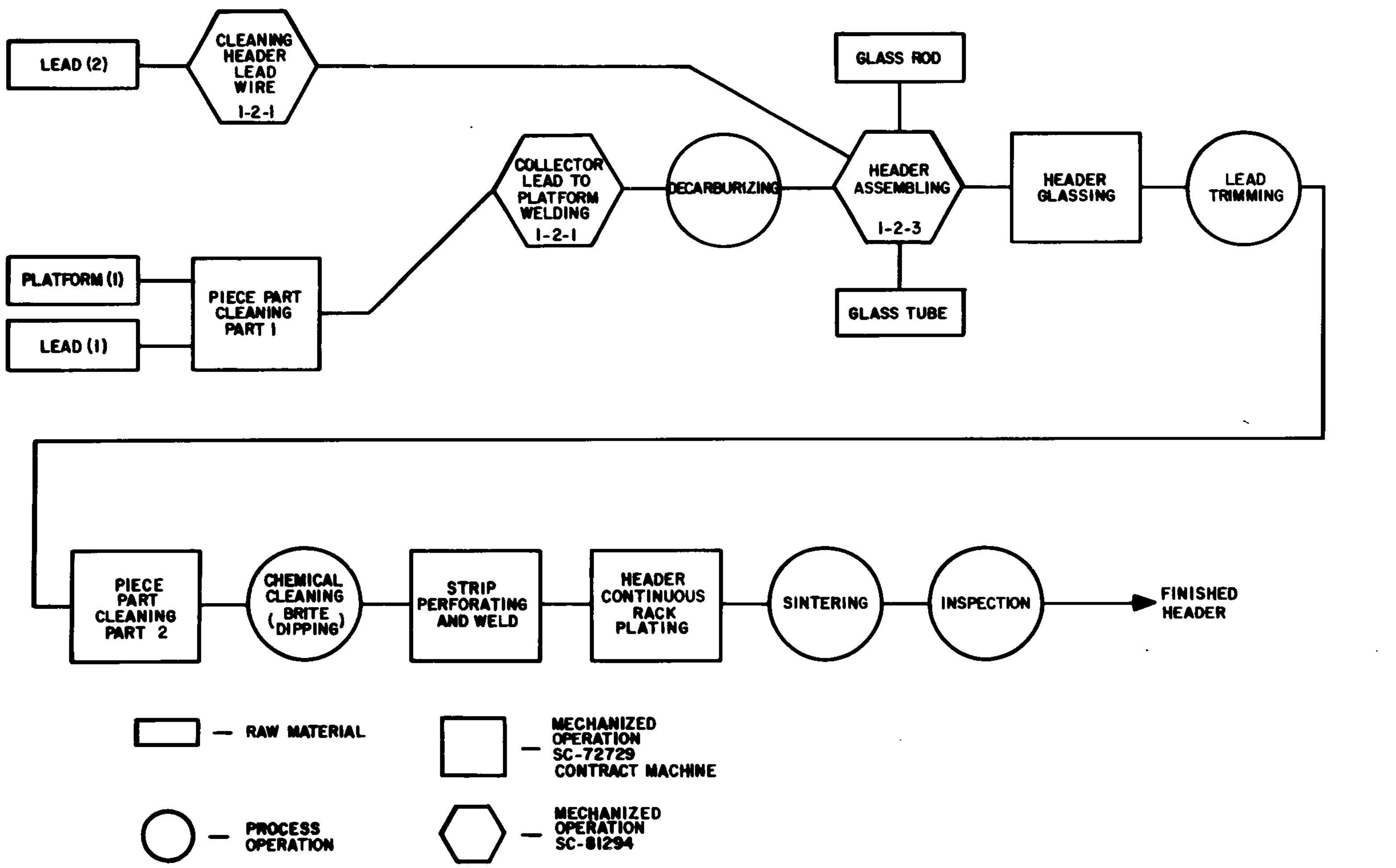


FIGURE 2-1

SILICON MATERIAL PROCESSING (2N560-2N1051)

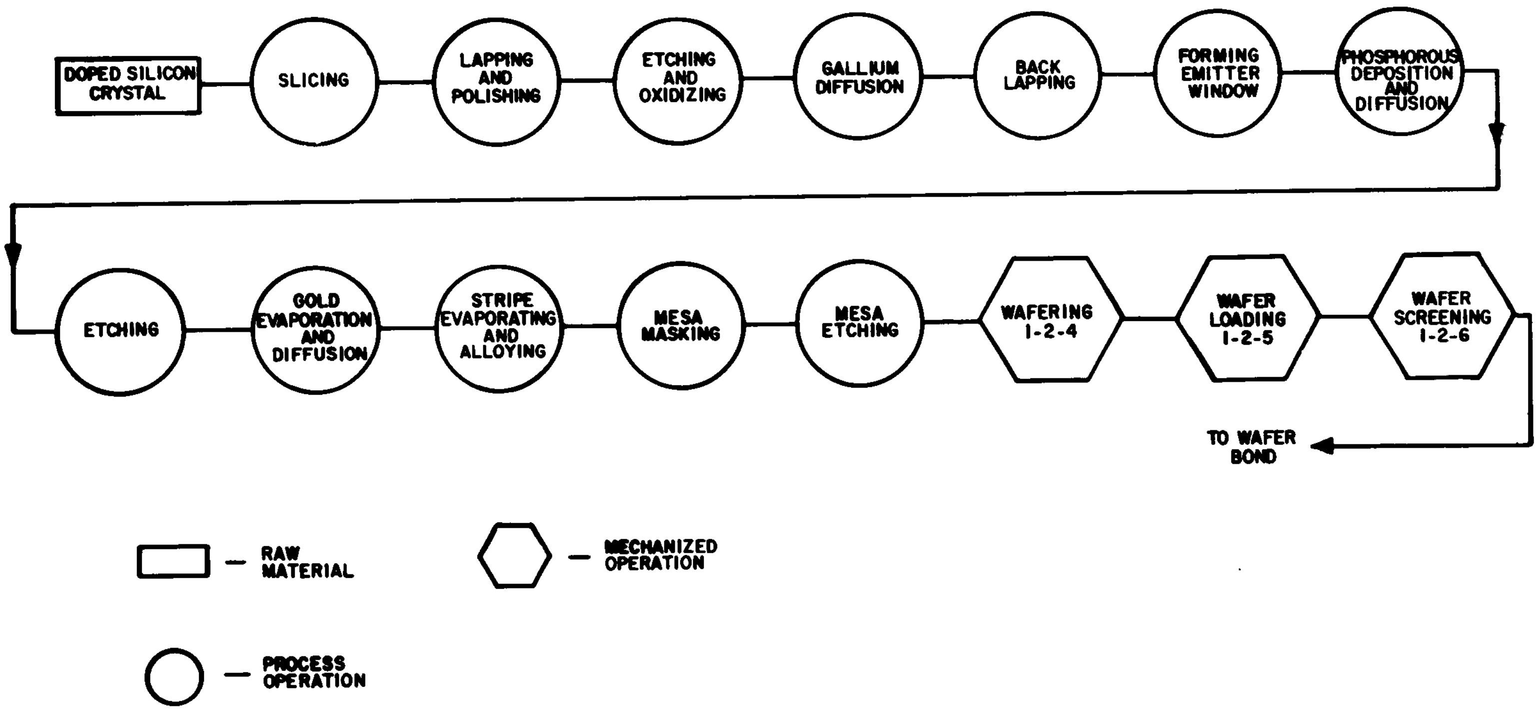


FIGURE 2-2

GERMANIUM MATERIAL PROCESSING (2N1195)

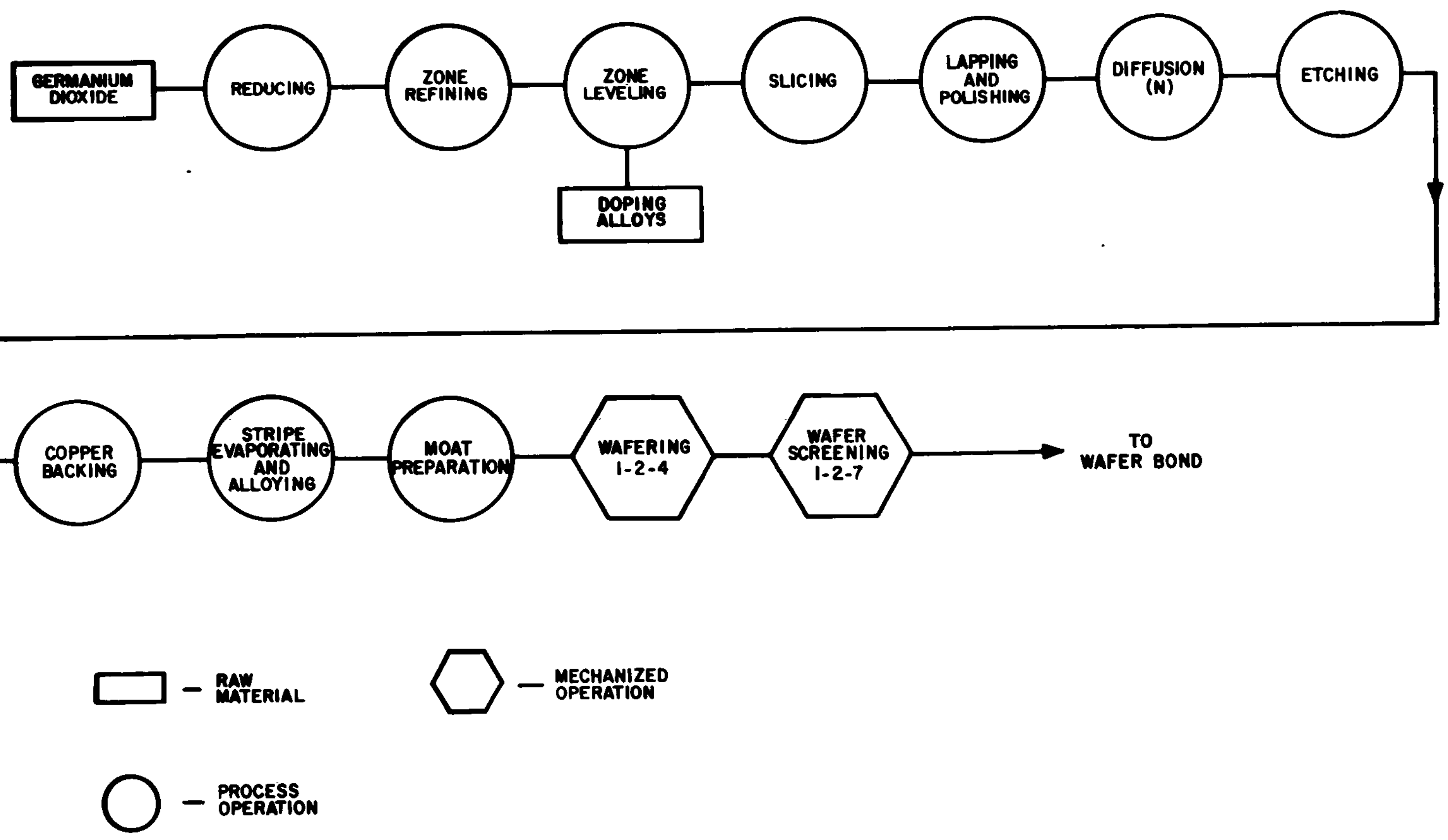


FIGURE 2-3

TRANSISTOR ASSEMBLY OPERATIONS

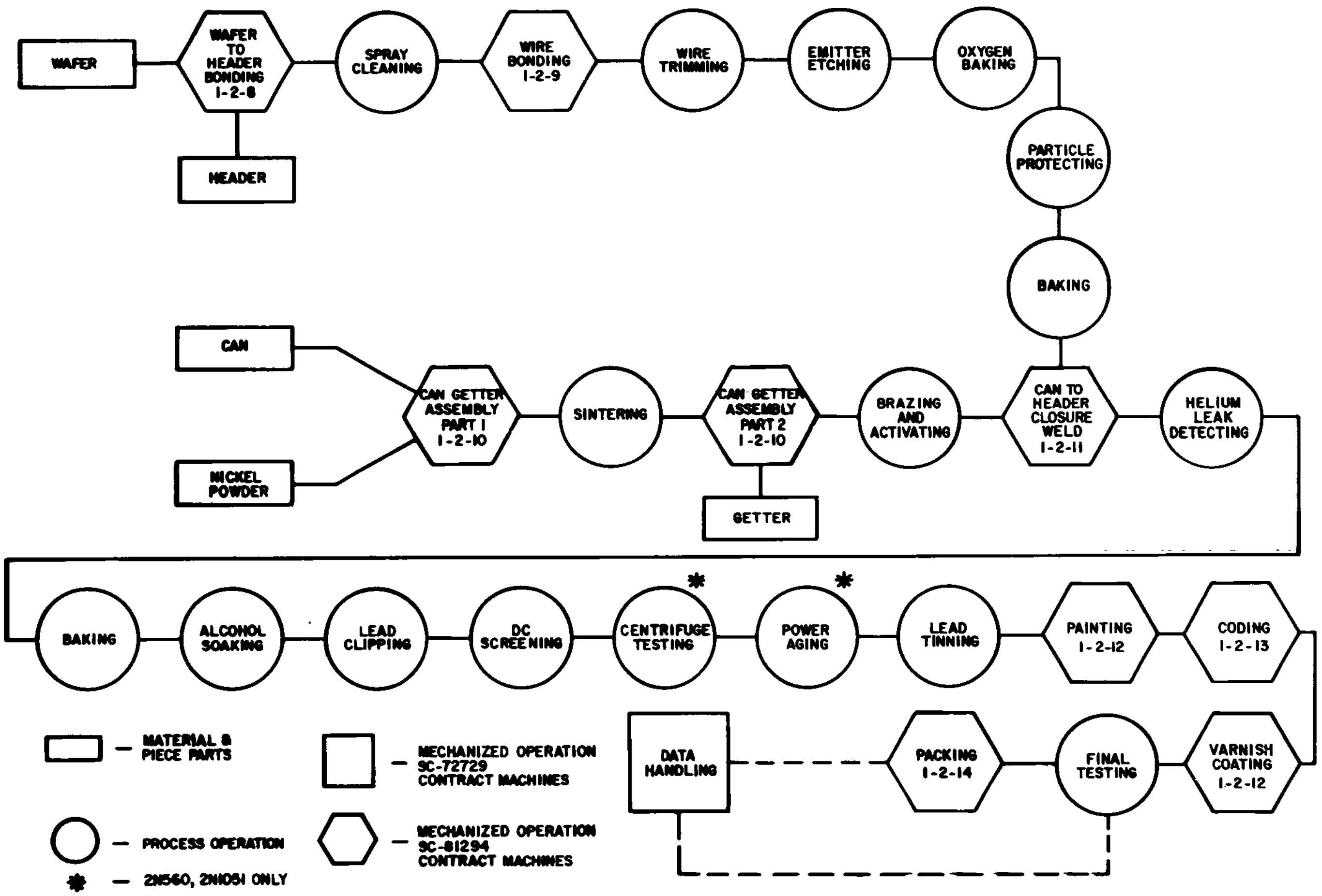
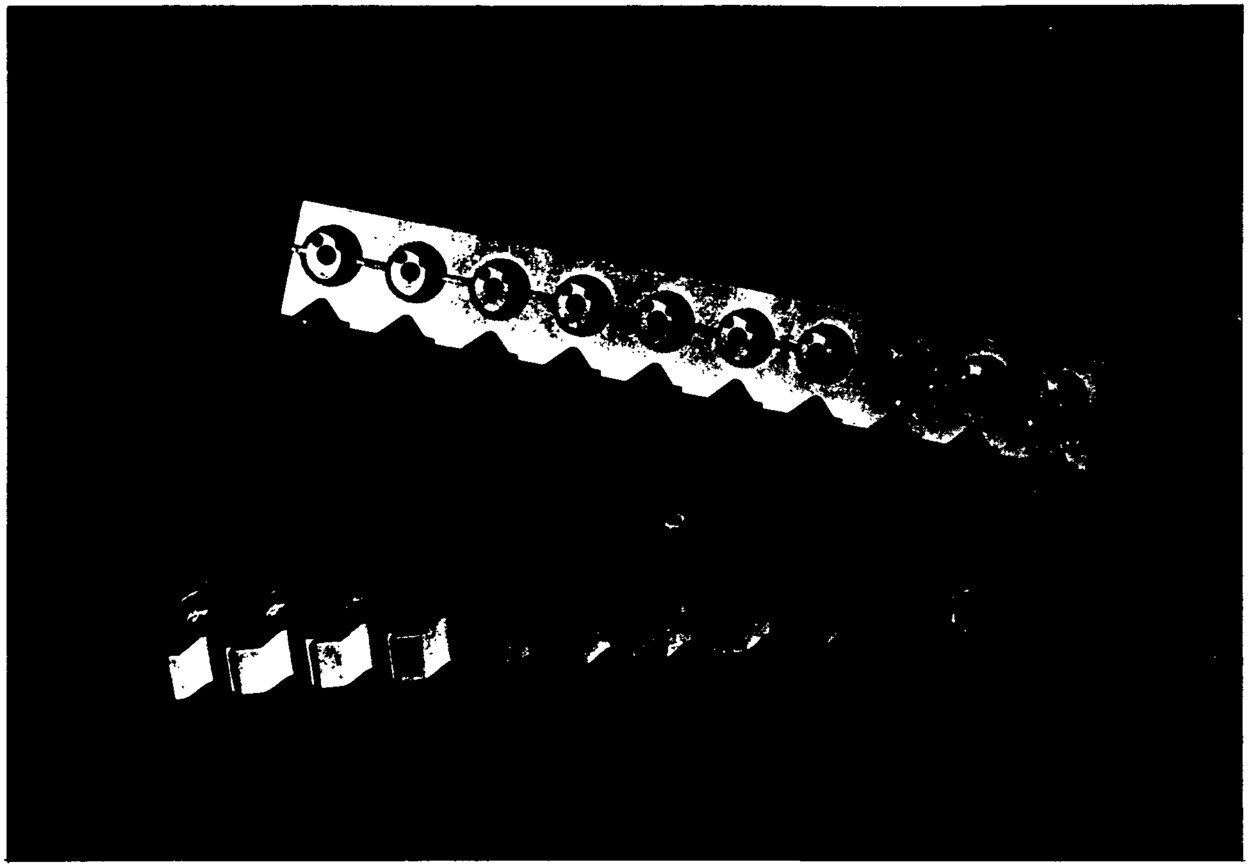
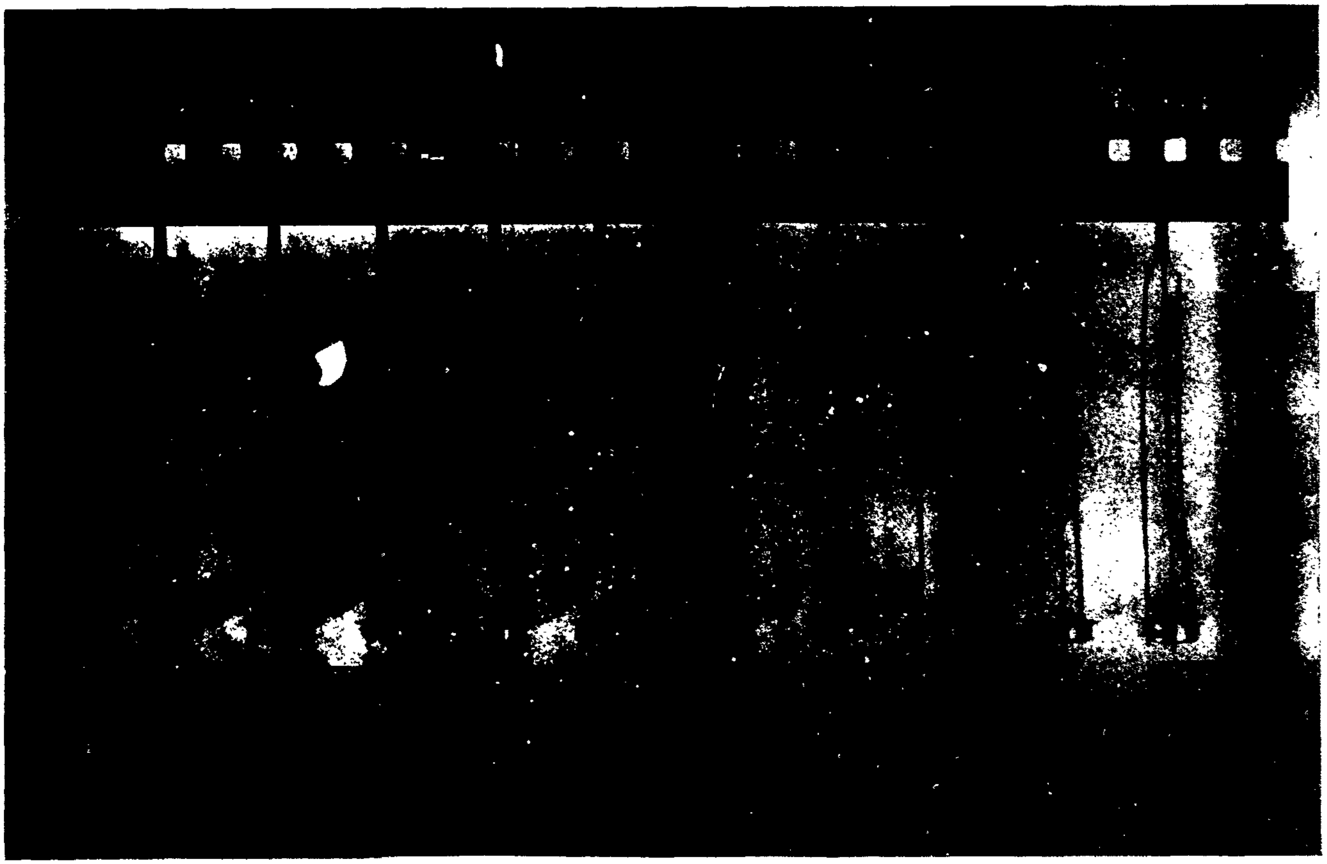


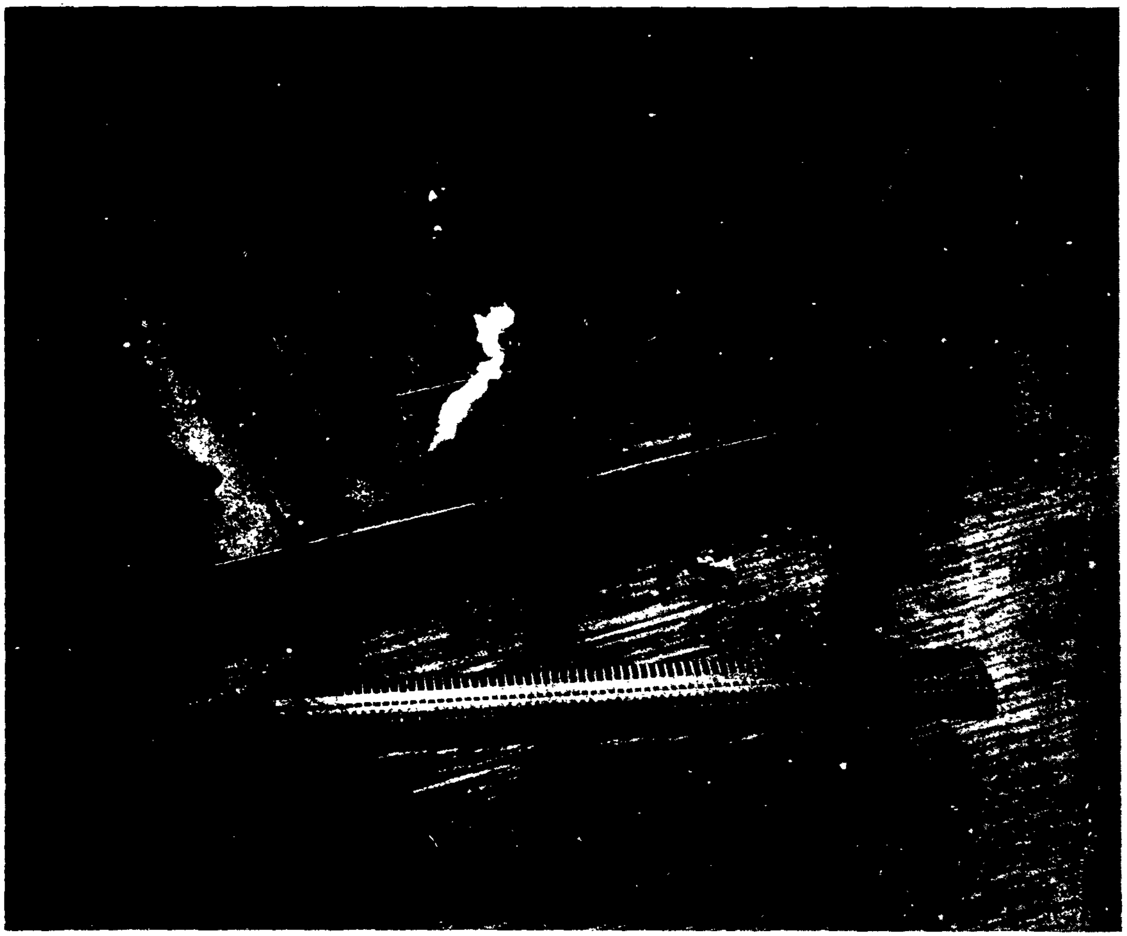
FIGURE 2-4



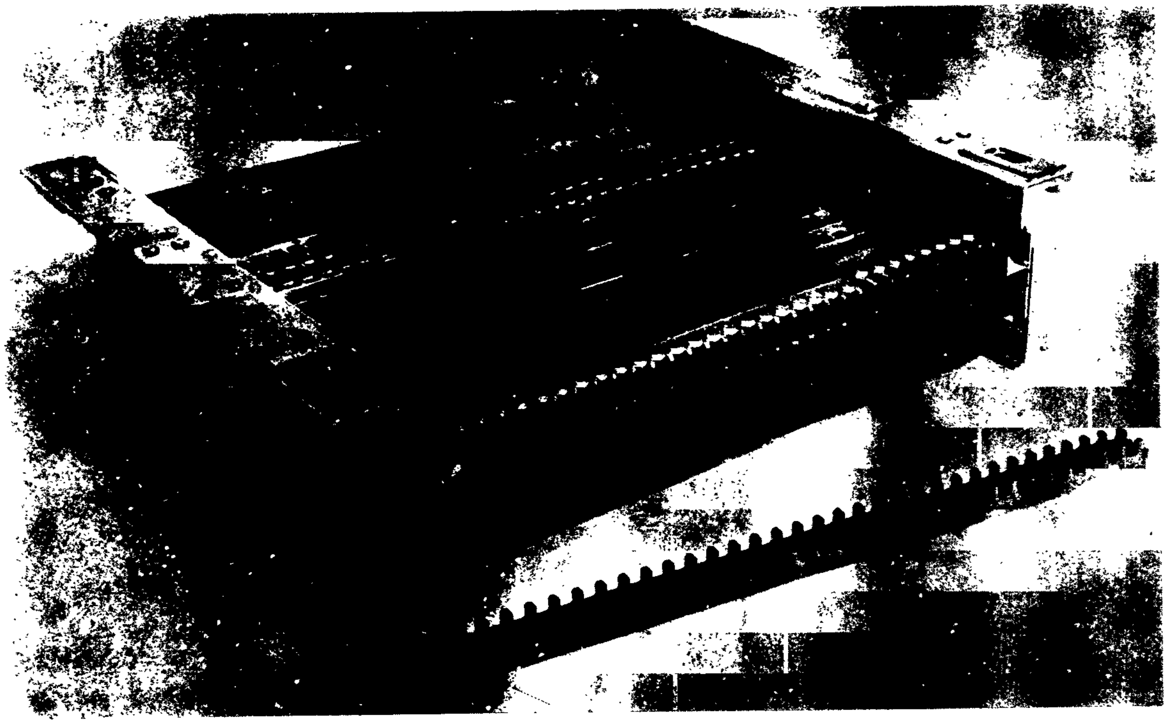
GLASSING MOLDS FOR TO-5 HEADERS
FIGURE 2-5



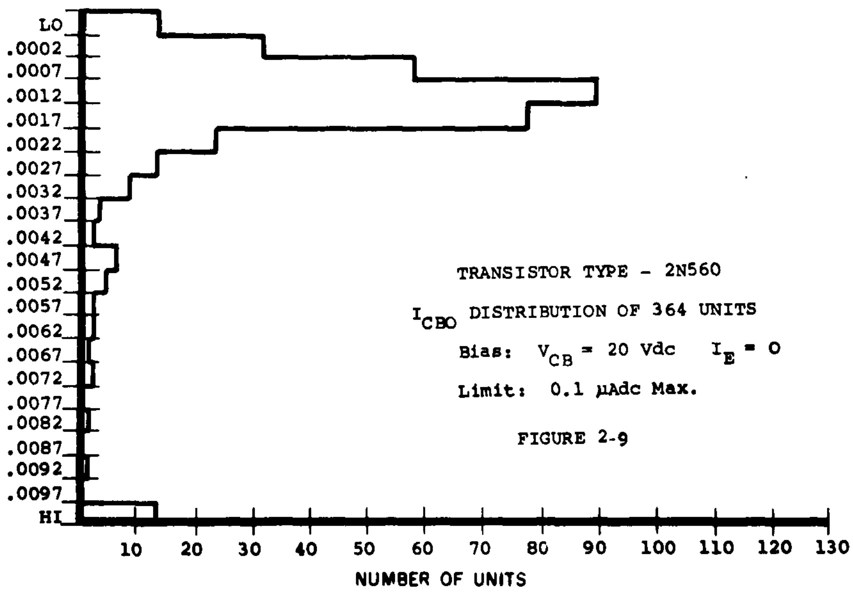
TO-5 HEADERS MOUNTED FOR GOLD PLATING
FIGURE 2-6



WAFER TRAY AND MAGAZINE
FIGURE 2-7



TO-5 HEADER TRAYS AND MAGAZINE
FIGURE 2-8



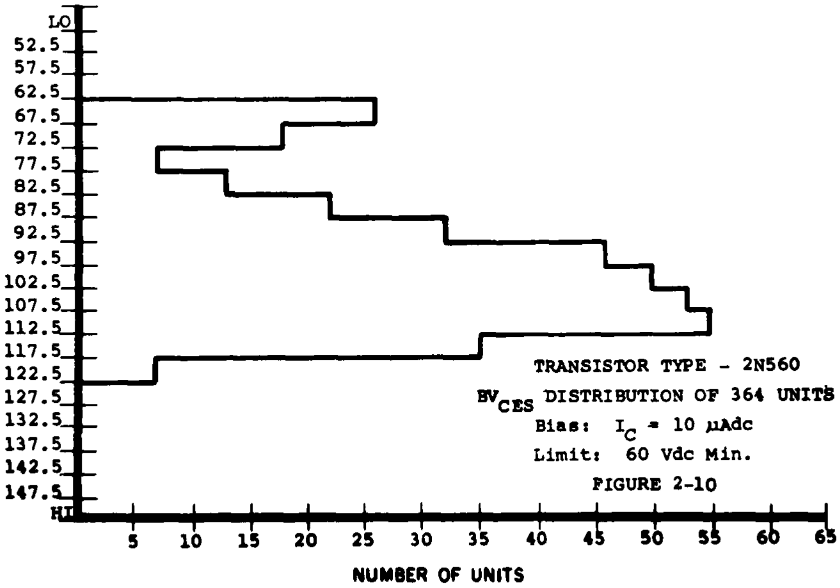
TRANSISTOR TYPE - 2N560

I_{CBO} DISTRIBUTION OF 364 UNITS

Bias: V_{CB} = 20 Vdc I_E = 0

Limit: 0.1 μAdc Max.

FIGURE 2-9



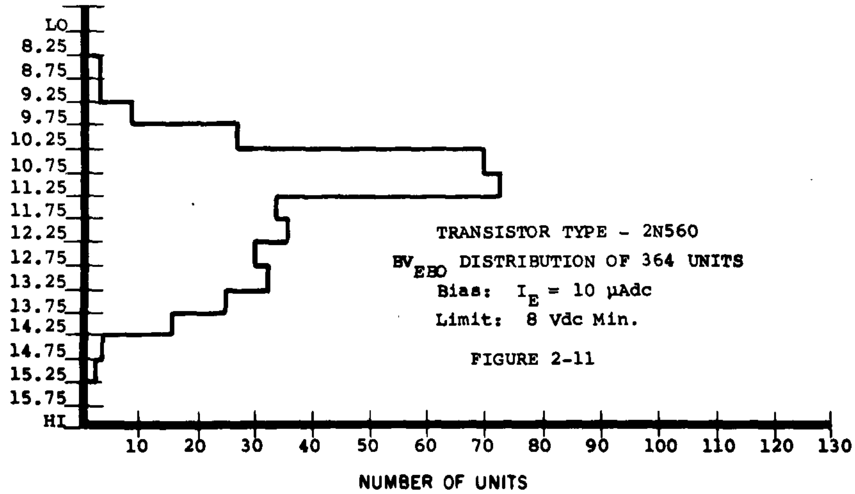
TRANSISTOR TYPE - 2N560

BV_{CES} DISTRIBUTION OF 364 UNITS

Bias: I_C = 10 μAdc

Limit: 60 Vdc Min.

FIGURE 2-10



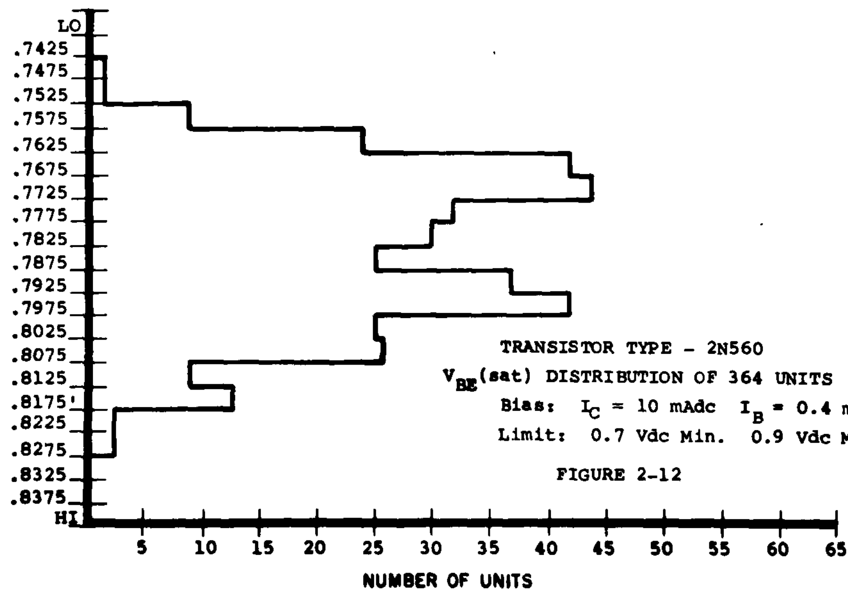
TRANSISTOR TYPE - 2N560

BV_{EBO} DISTRIBUTION OF 364 UNITS

Bias: I_E = 10 µAdc

Limit: 8 Vdc Min.

FIGURE 2-11



TRANSISTOR TYPE - 2N560

V_{BE}(sat) DISTRIBUTION OF 364 UNITS

Bias: I_C = 10 mAdc I_B = 0.4 mAdc

Limit: 0.7 Vdc Min. 0.9 Vdc Max.

FIGURE 2-12

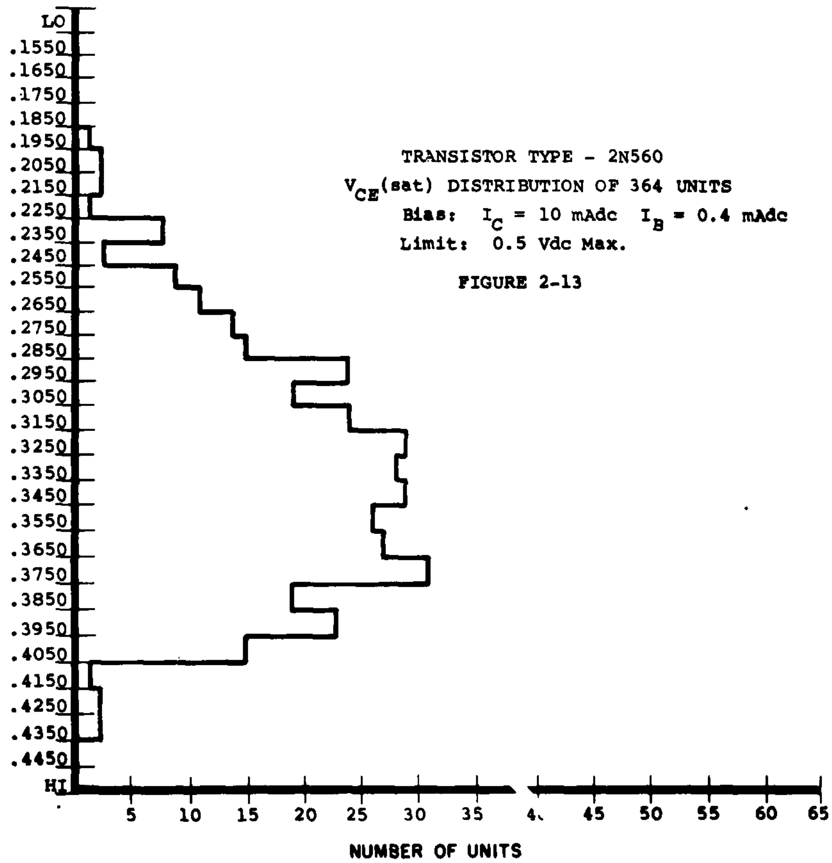


FIGURE 2-13

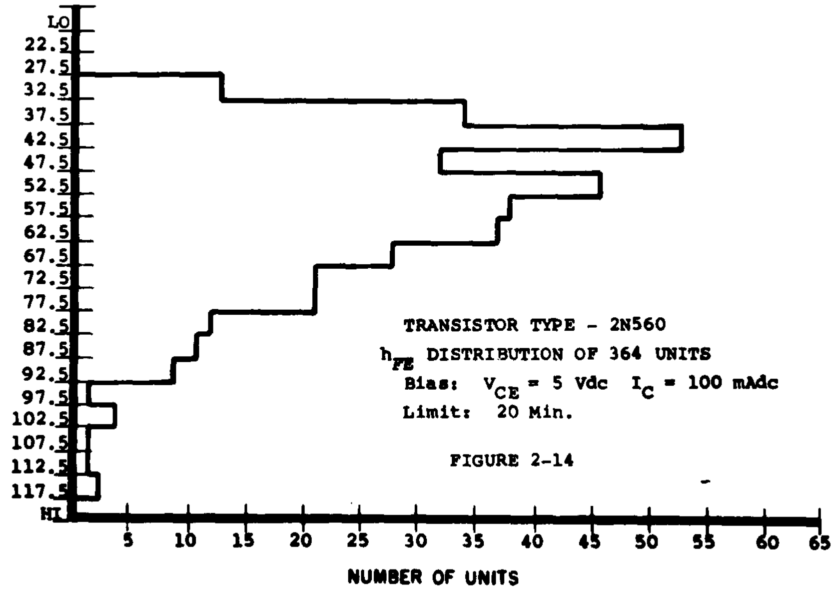


FIGURE 2-14

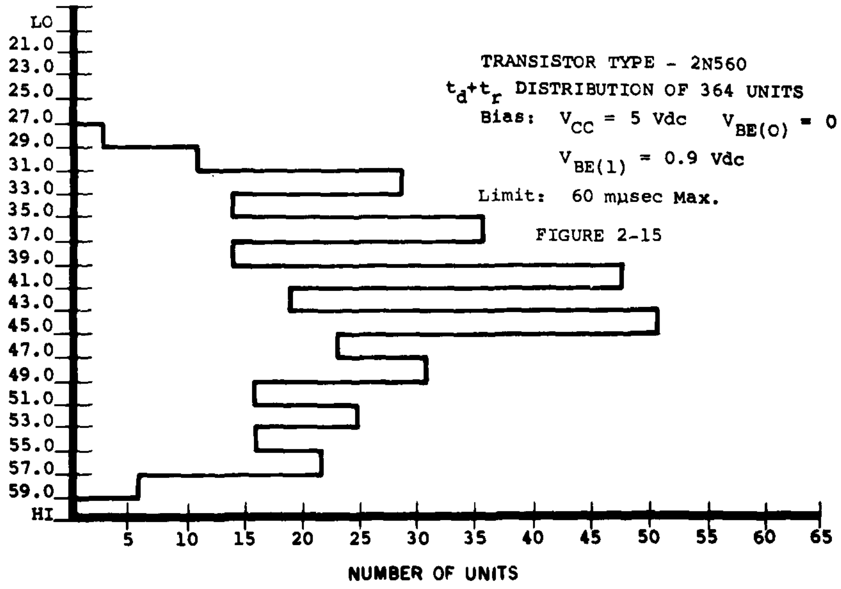


FIGURE 2-15

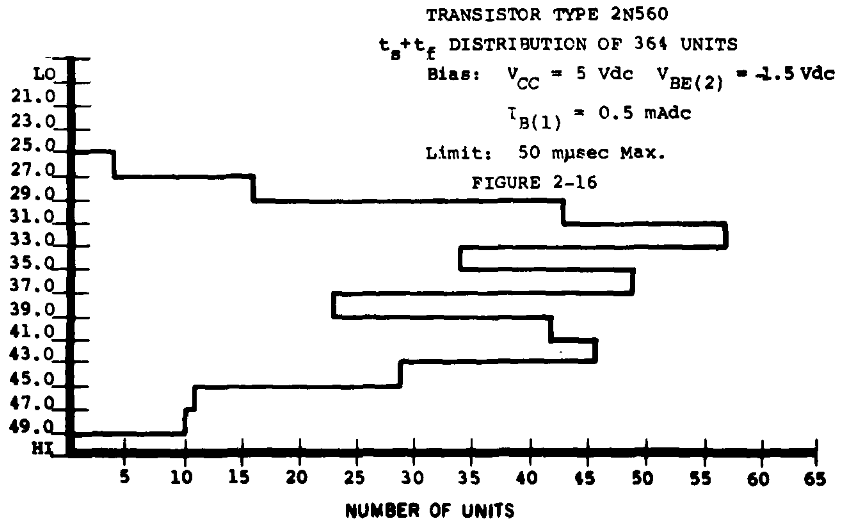
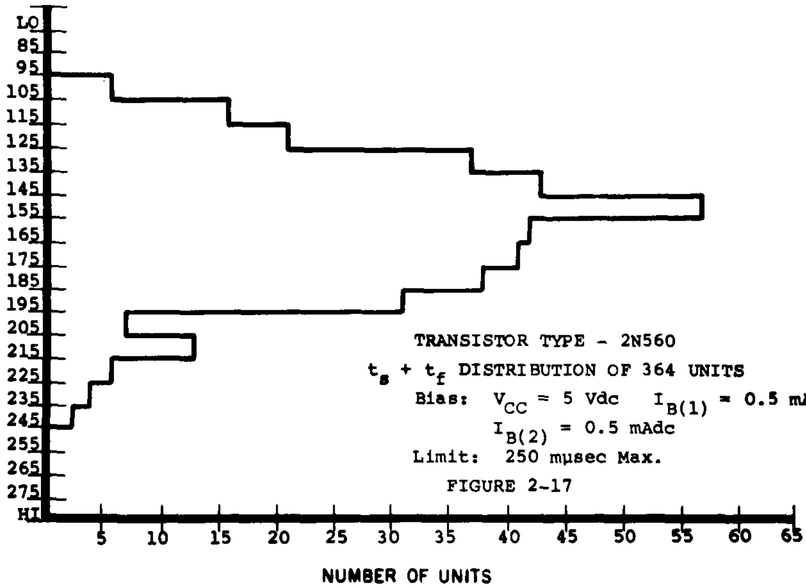


FIGURE 2-16



TRANSISTOR TYPE - 2N560

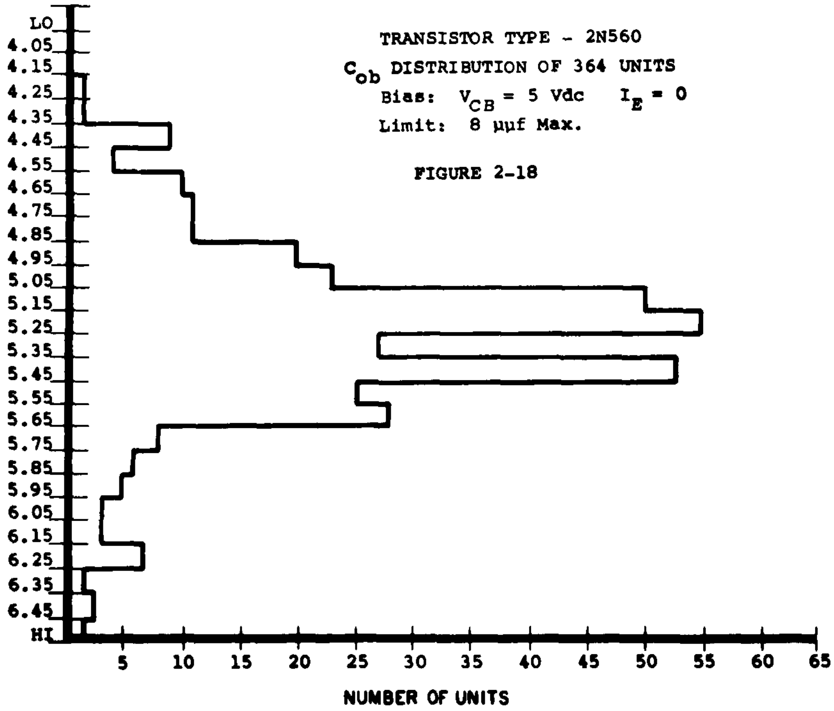
$t_s + t_f$ DISTRIBUTION OF 364 UNITS

Bias: $V_{CC} = 5$ Vdc $I_{B(1)} = 0.5$ mAdc

$I_{B(2)} = 0.5$ mAdc

Limit: 250 mμsec Max.

FIGURE 2-17



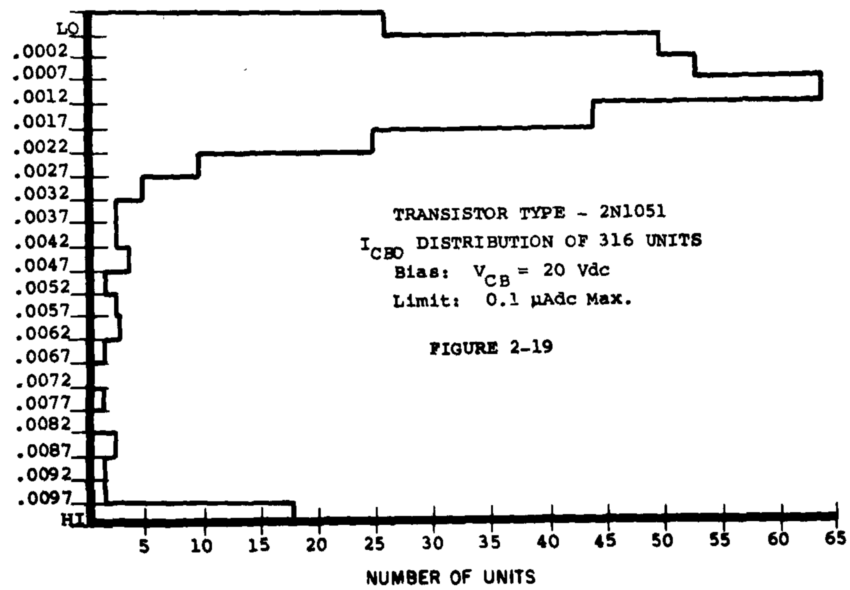
TRANSISTOR TYPE - 2N560

C_{ob} DISTRIBUTION OF 364 UNITS

Bias: $V_{CB} = 5$ Vdc $I_E = 0$

Limit: 8 μμf Max.

FIGURE 2-18



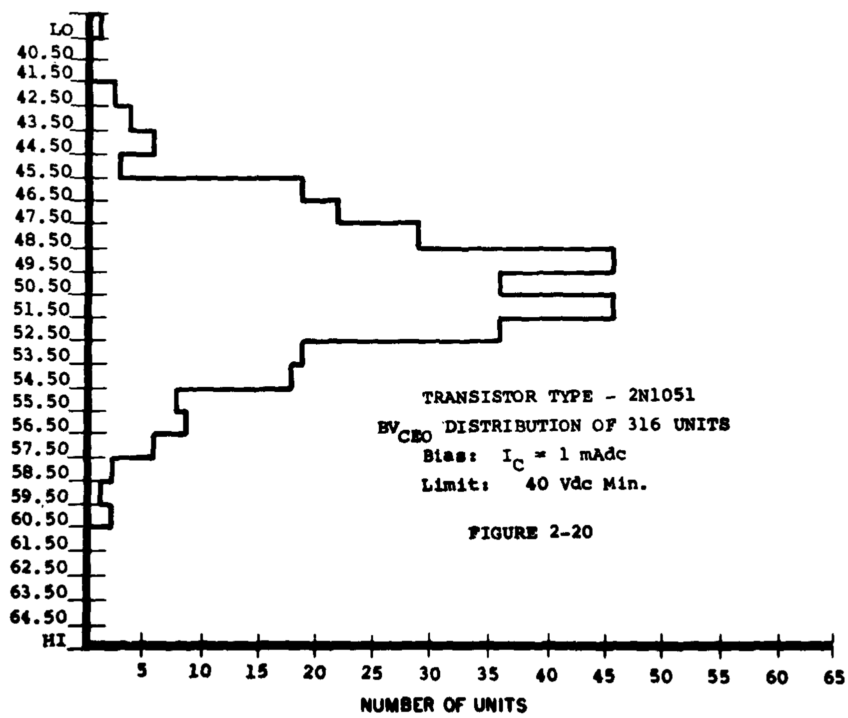
TRANSISTOR TYPE - 2N1051

I_{CBO} DISTRIBUTION OF 316 UNITS

Bias: V_{CB} = 20 Vdc

Limit: 0.1 μAdc Max.

FIGURE 2-19



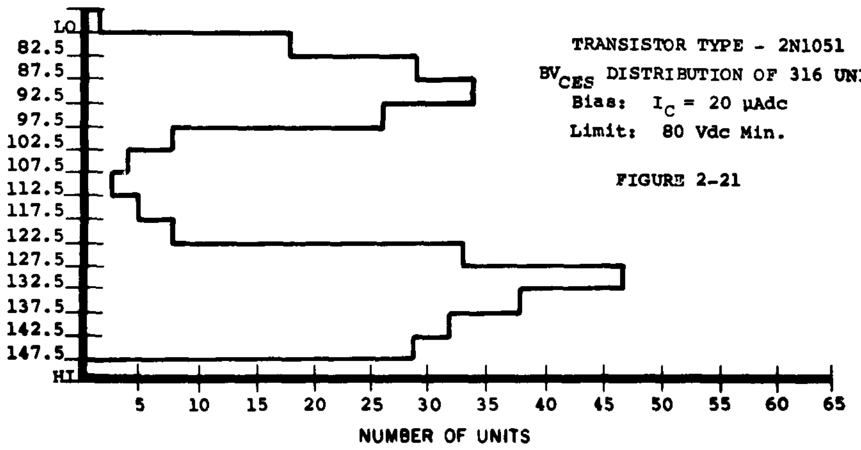
TRANSISTOR TYPE - 2N1051

BV_{CEO} DISTRIBUTION OF 316 UNITS

Bias: I_C = 1 mAdc

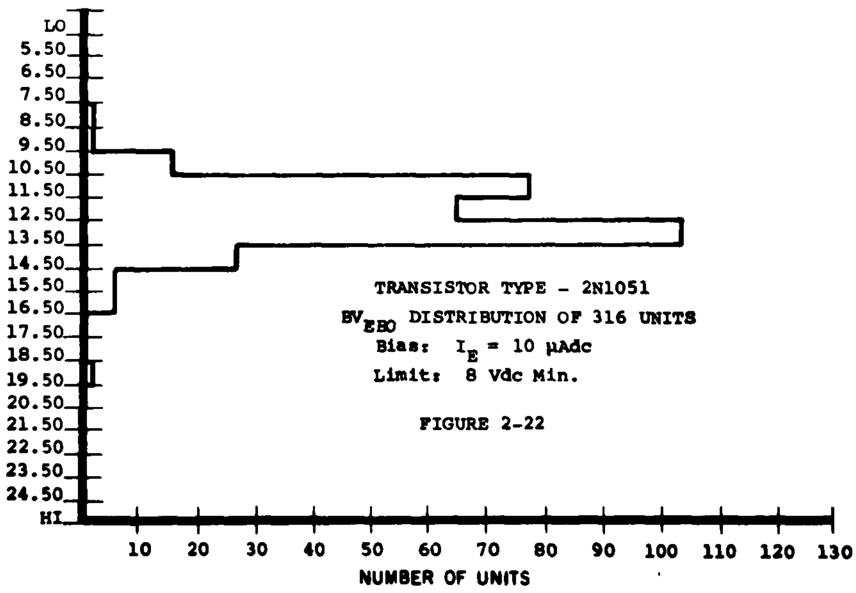
Limit: 40 Vdc Min.

FIGURE 2-20



TRANSISTOR TYPE - 2N1051
BV_{CES} DISTRIBUTION OF 316 UNITS
Bias: I_C = 20 µAdc
Limit: 80 Vdc Min.

FIGURE 2-21



TRANSISTOR TYPE - 2N1051
BV_{EBO} DISTRIBUTION OF 316 UNITS
Bias: I_E = 10 µAdc
Limit: 8 Vdc Min.

FIGURE 2-22

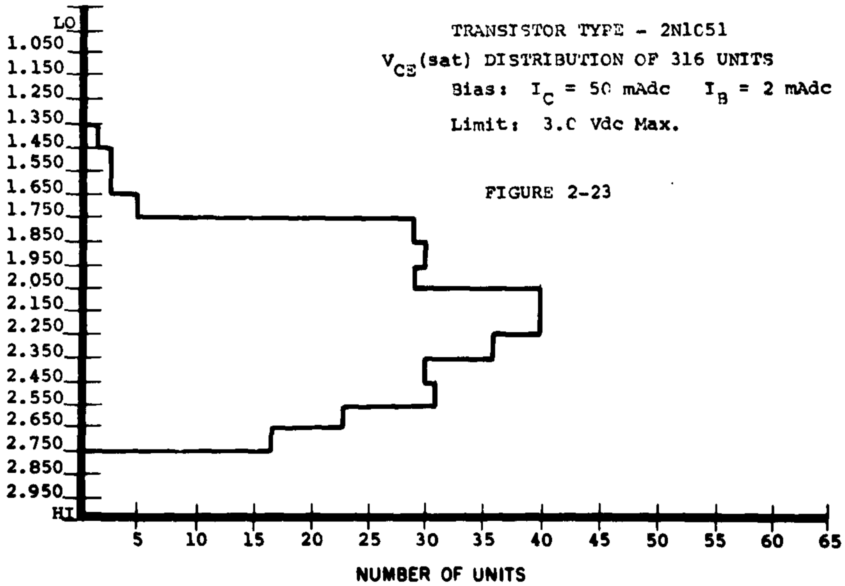


FIGURE 2-23

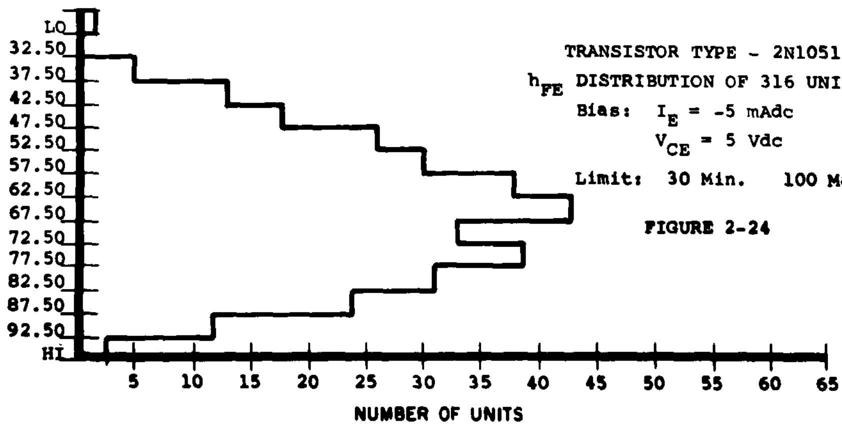


FIGURE 2-24

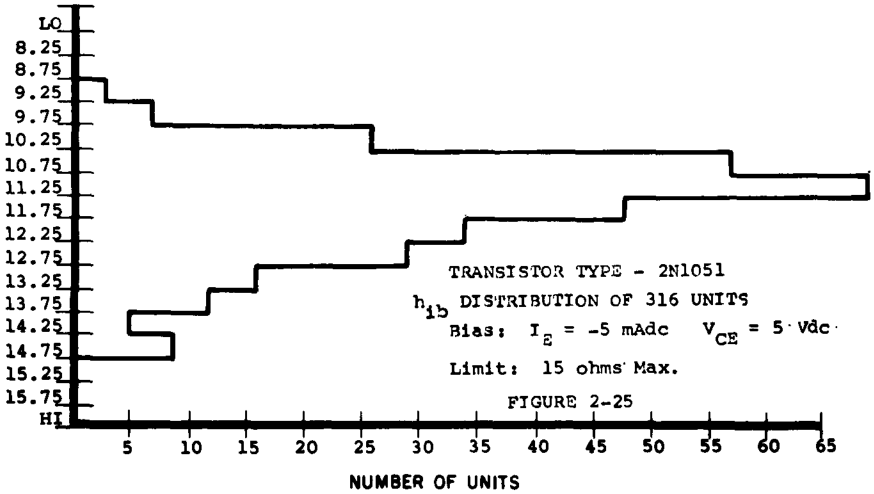


FIGURE 2-25

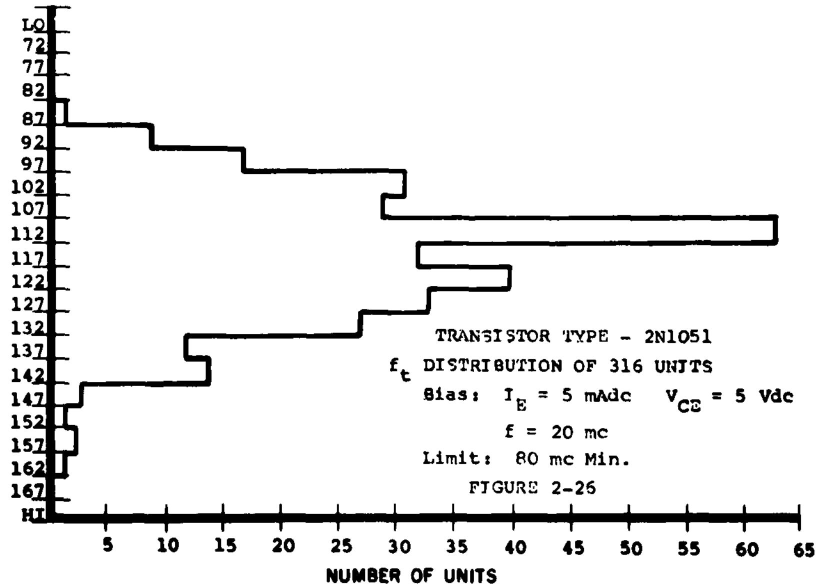


FIGURE 2-26

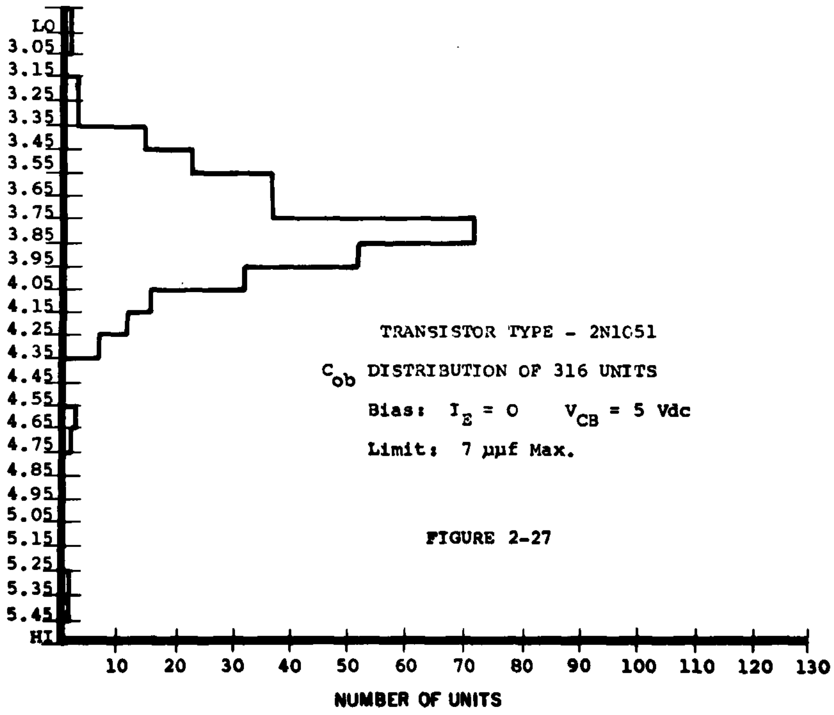

LO
3.05
3.15
3.25
3.35
3.45
3.55
3.65
3.75
3.85
3.95
4.05
4.15
4.25
4.35
4.45
4.55
4.65
4.75
4.85
4.95
5.05
5.15
5.25
5.35
5.45
HI
10 20 30 40 50 60 70 80 90 100 110 120 130
NUMBER OF UNITS
TRANSISTOR TYPE - 2N1051
C_{ob} DISTRIBUTION OF 316 UNITS
Bias: $I_E = 0$ $V_{CB} = 5$ Vdc
Limit: 7 µµf Max.

FIGURE 2-27

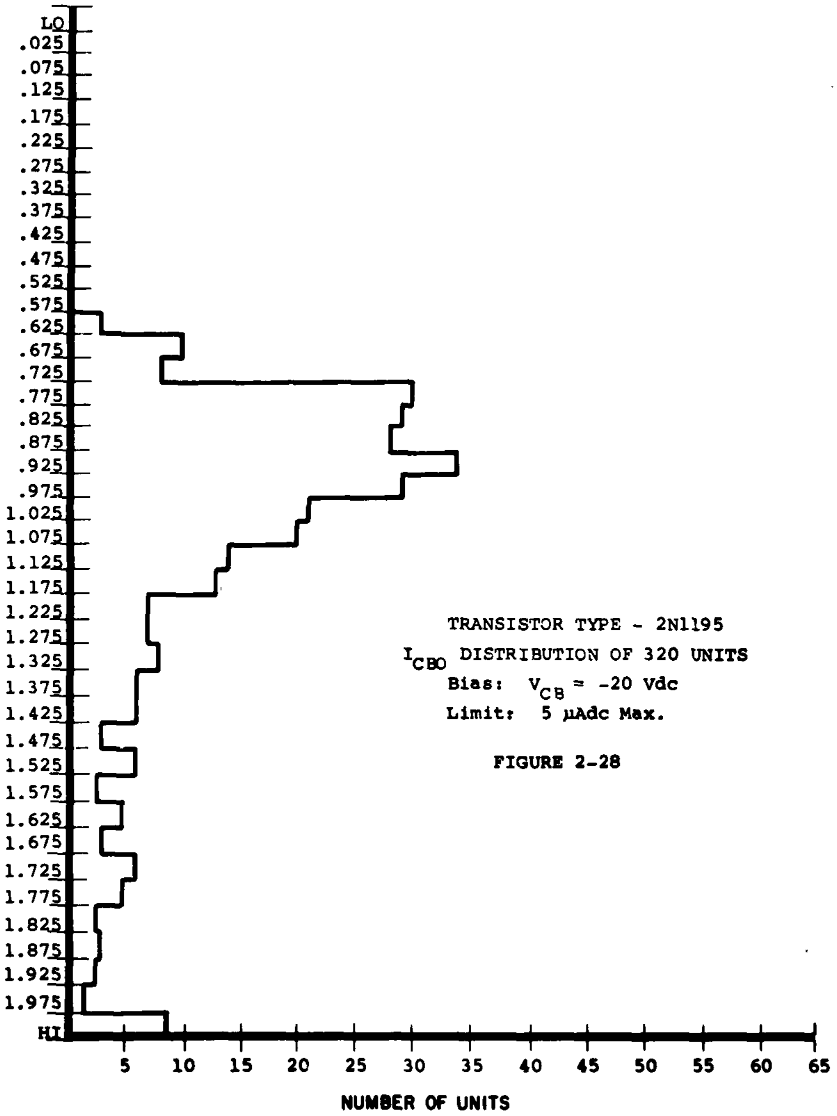
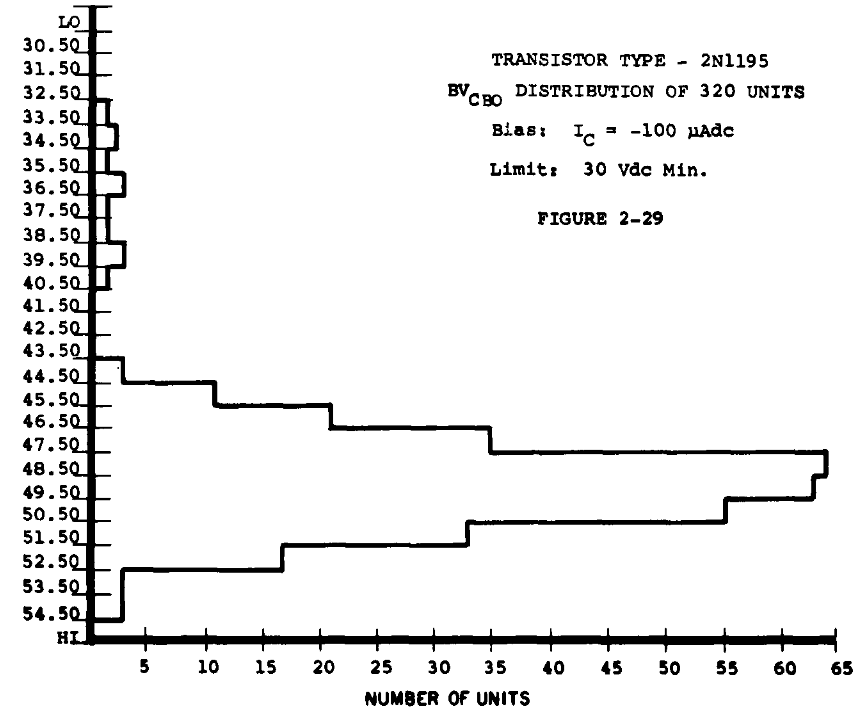

TRANSISTOR TYPE - 2N1195
I_{CBO} DISTRIBUTION OF 320 UNITS
Bias: V_{CB} = -20 Vdc
Limit: 5 μAdc Max.
LO
.025
.075
.125
.175
.225
.275
.325
.375
.425
.475
.525
.575
.625
.675
.725
.775
.825
.875
.925
.975
1.025
1.075
1.125
1.175
1.225
1.275
1.325
1.375
1.425
1.475
1.525
1.575
1.625
1.675
1.725
1.775
1.825
1.875
1.925
1.975
HI
5 10 15 20 25 30 35 40 45 50 55 60 65
NUMBER OF UNITS

FIGURE 2-28



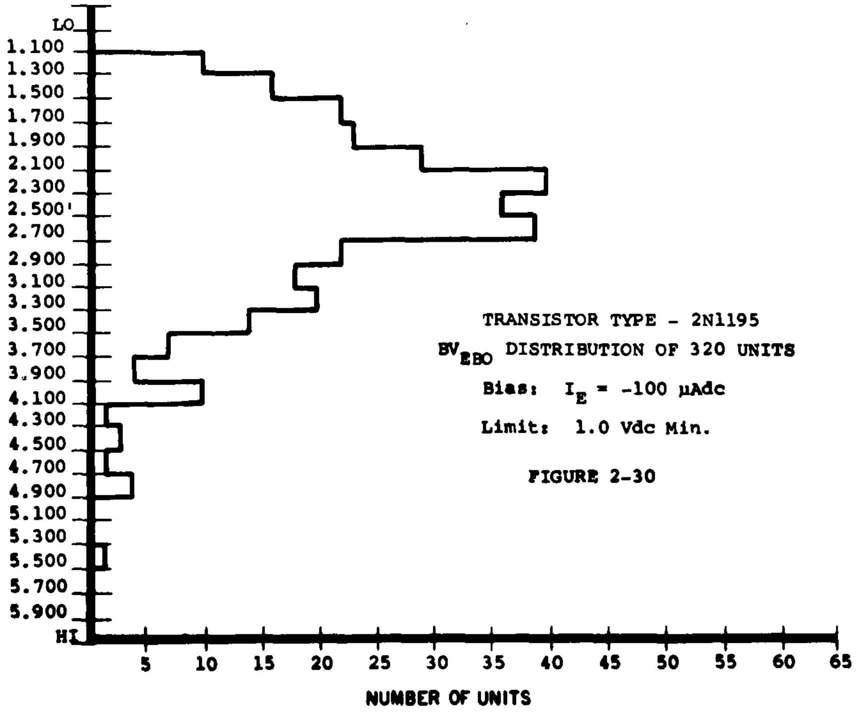
TRANSISTOR TYPE - 2N1195

BV_{CBO} DISTRIBUTION OF 320 UNITS

Bias: I_C = -100 µAdc

Limit: 30 Vdc Min.

FIGURE 2-29



TRANSISTOR TYPE - 2N1195

BV_{EBO} DISTRIBUTION OF 320 UNITS

Bias: I_E = -100 µAdc

Limit: 1.0 Vdc Min.

FIGURE 2-30

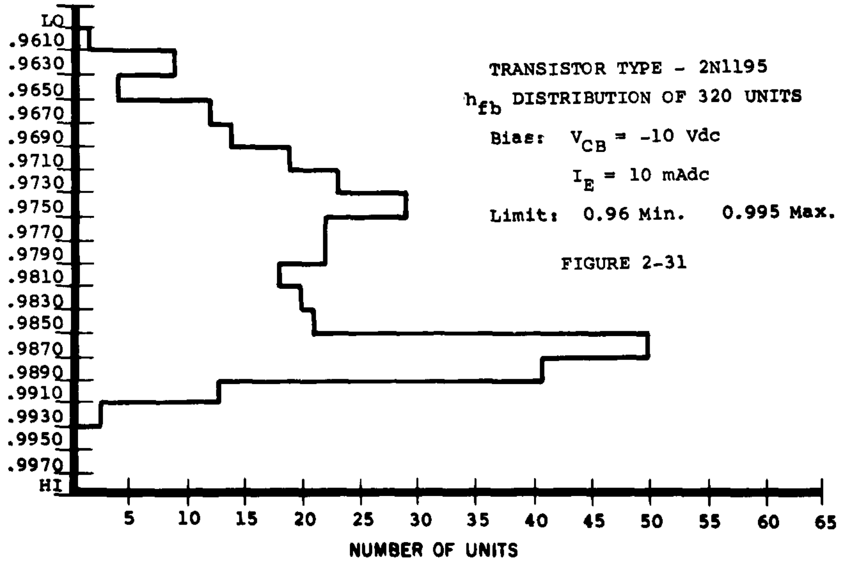


FIGURE 2-31

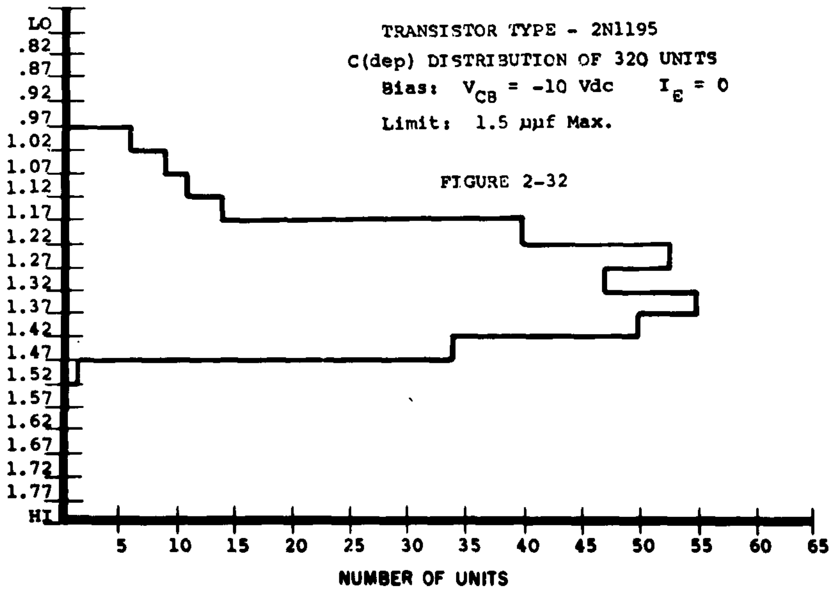


FIGURE 2-32

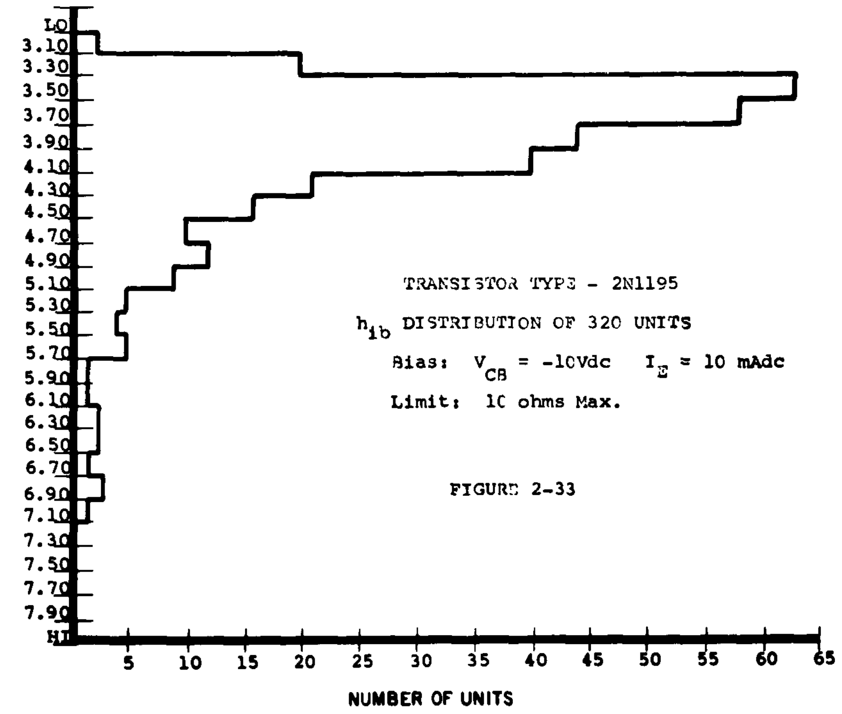


FIGURE 2-33

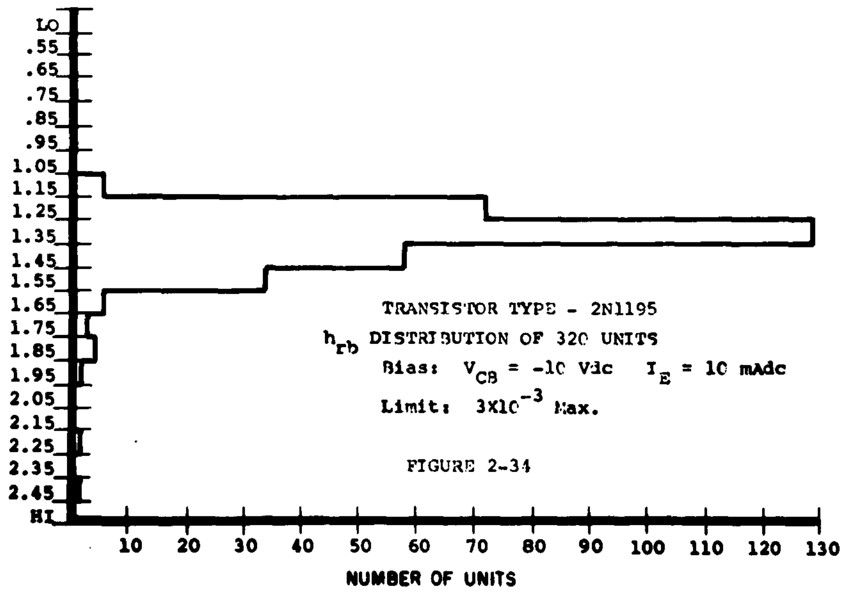


FIGURE 2-34

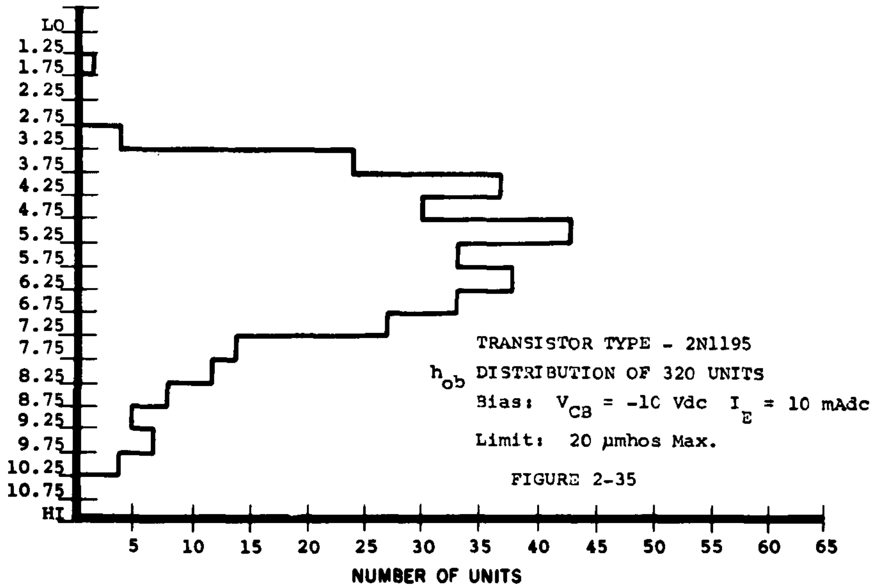


FIGURE 2-35

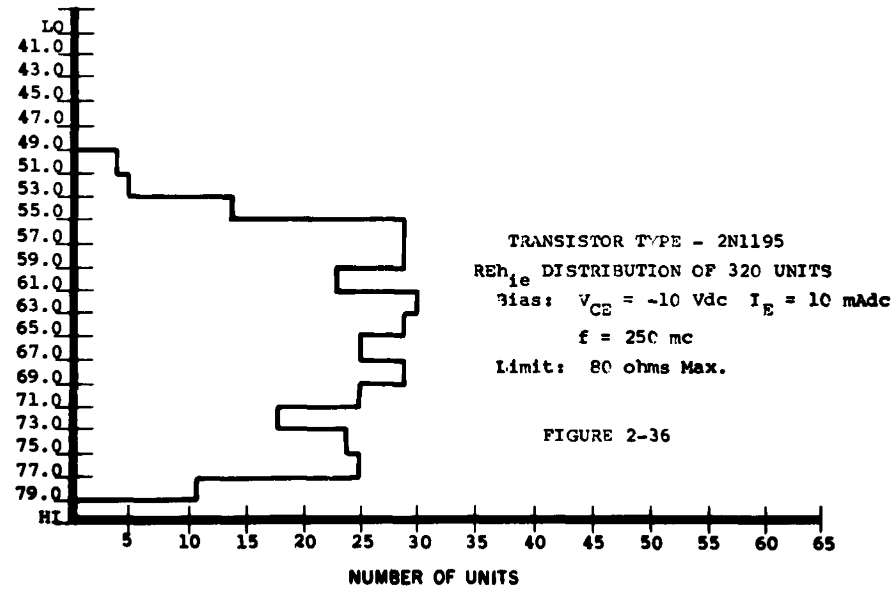


FIGURE 2-36

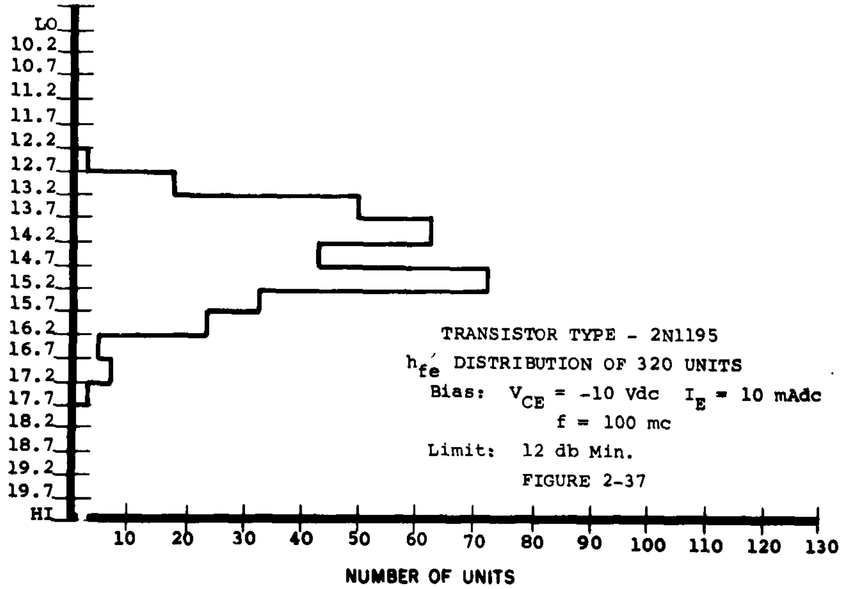


FIGURE 2-37

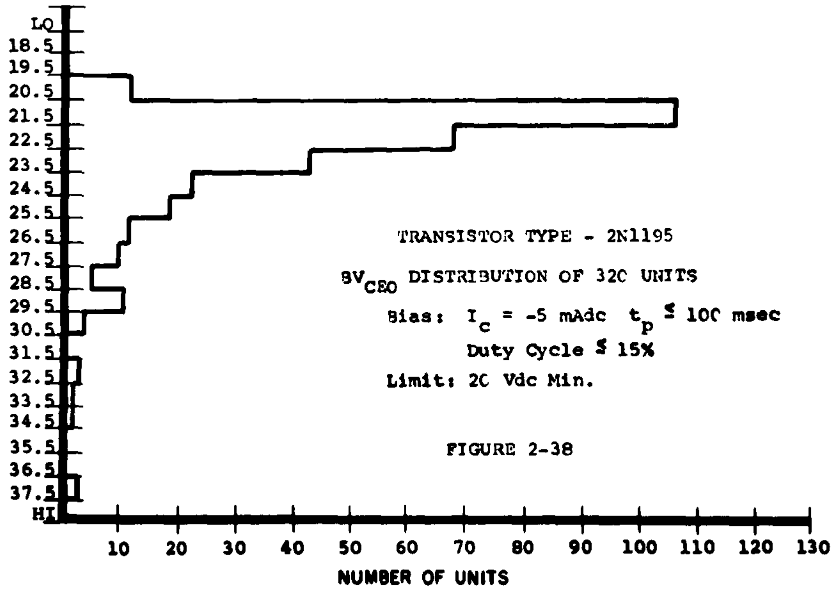


FIGURE 2-38

SUMMARY OF 2N560 MECHANIZED RUN GROUP B INSPECTION

Lot No. 206 - 10,000 Devices

EXAMINATION OR TEST	End Point Tests	No. in Sample	No. of Failures	Failures Permitted
Subgroup 1				
Physical Dimensions	None	52	0	83*
Subgroup 2				
Soldering Temperature Cycling Thermal Shock Moisture Resistance	I_{CBO} $V_{CE(sat)}$ BV_{CES}	32	0	3
Subgroup 3				
Shock Constant Acceleration Vibration Fatigue Vibration, Variable Frequency	I_{CBO} $V_{CE(sat)}$ BV_{CES}	32	0	3
Subgroup 4				
Lead Fatigue	None	32	0	3
Subgroup 5				
Storage Life	I_{CBO} $V_{CE(sat)}$ BV_{CES}	105	0	2

* Demerits Permitted

FIGURE 2-39

SUMMARY OF 2N1051 MECHANIZED RUN GROUP B INSPECTION

Lot No. 82 - 2,350 Devices

EXAMINATION OR TEST	End Point Tests	No. in Sample	No. of Failures	Failures Permitted
Subgroup 1				
Physical Dimensions	None	52	0	83*
Subgroup 2				
Low Temperature Operation	h_{fe}	52	2	2
Subgroup 3				
Soldering Temperature Cycling Thermal Shock Moisture Resistance	I_{CBO} h_{fe} BV_{CES}	52	0	2
Subgroup 4				
Shock Constant Acceleration Vibration, Fatigue Vibration Variable Frequency	I_{CBO} h_{fe} BV_{CES}	52	0	2
Subgroup 5				
Lead Fatigue	None	52	0	2
Subgroup 6				
Storage Life	I_{CBO} h_{fe} BV_{CES}	105	0	2

* Demerits Permitted

FIGURE 2-40

SUMMARY OF 2N1195 MECHANIZED RUN GROUP B INSPECTION

Lot No. 160 - 2,000 Devices

EXAMINATION OR TEST	End Point Tests	No. in Sample	No. o Failures	Failures Permitted
Subgroup 1				
Physical Dimensions	None	52	0	87*
Subgroup 2				
Soldering Temperature Cycling Thermal Shock Moisture Resistance	I_{CBO} h_{fb}	32	0	3
Subgroup 3				
Shock Constant Acceleration Vibration Fatigue Vibration Variable Frequency	I_{CBO} h_{fb}	32	0	3
Subgroup 4				
Lead Fatigue	None	32	0	3
Subgroup 5				
Storage Life	I_{CBO} h_{fb}	52	0	2

* Demerits Permitted

FIGURE 2-41

TRANSISTOR MACHINE REFERENCE NUMBERS

PEM CONTRACT DA-36-039-SC-81294

CONTRACT ITEM NO.	MACHINE	WECO DRAWING NUMBER	OPERATING & MAINTENANCE SPEC. NO.
1-2-1	Cleaning Header Lead Wire	C-281634	21953
1-2-2	Collector Lead to Platform Welding	C-281580	21943
1-2-3	Header Assembling	C-281653	21935
1-2-4	Wafering #1	C-281615	21910
	Wafering #2	C-281654	21910
1-2-5	Wafer Loading (2N560-2N1051) #1	C-281618	21947
	Wafer Loading (2N560-2N1051) #2	C-281618	21947
1-2-6	Wafer Screening (2N560-2N1051)	C-281616	21917
1-2-7	Wafer Screening	C-281673	21949
1-2-8	Wafer to Header Bonding	SID-308244 C-281614	21944
	Wafer to Header Bonding	SID-308244 C-281633	21945
1-2-9	Wire Bonding	C-281617	21961
1-2-10	Can Getter Assembly	C-281665	21956 21958
1-2-11	Can to Header Closure Weld	C-281680	21950
1-2-12	Painting & Coating	C-281636	21918
1-2-13	Coding	C-281637	21919
1-2-14	Packing	C-281692	21920
1-3-1	Wafer Screening & Electrical Probe Testing	SID-306394 C-281670	21966
1-3-2	Special Test Set	SID-306314 C-281643	21916

FIGURE 2-42

SECTION 3

MECHANIZED TRANSISTOR OPERATIONS

This section contains narratives on the 16 mechanized operations developed during Phase 1 of the Contract for high-volume production of transistors. Each narrative contains a description of the prototype machine provided as well as a review of its development, operational problems and performance. The narratives on Wafering, Wafer Loading, and Wafer to Header Bonding also review development of a second machine.

A contract modification, technically accepted December 19, 1962, indicates the 9 machines provided under this Contract that are capable of processing 2N559 and 2N1094 transistors. These machines are identified in the Purpose. The following machines of associated Contract No. DA-36-039-SC-72729 are also capable of processing 2N560, 2N1051, and 2N1195 transistors or components thereof:

Operation	No. Machines
1. Cleaning Header Lead Wire	1
2. Piece Part Cleaning	1
3. Piece Part Gold Plating	1
4. Header Glassing	1
5. Strip Perforating and Welding	2
6. Header Continuous Rack Plating	1
7. Slice Scribing	1
8. Wire Bonding	2
9. Data Handling	1

Tooling must be changed on the two Strip Perforating and Welding and two

Wire Bonding Machines to handle TO-5 header (200-mil pin circle) before 2N560, 2N1051, and 2N1195 subassemblies can be processed. These changes are necessary because the above machines were originally provided for high volume production of 2N559 and 2N1094 transistors which are assembled on TO-18, one hundred-mil pin circle headers.

The technically accepted contract modification also deleted two mechanized operations: Emitter Etching and D-C and Switch Testing (2N560-2N1051). (Development effort on these machines is reviewed in Section 6, Discontinued Developments.) It also returned Collector Lead to Platform Welding to this Contract from Contract No. DA-36-039-SC-72729; therefore, a narrative on this development is included in this report.

The original Contract provided for Initial Engineering Approach Studies of 15 operations. All mechanized and deleted operations were included in these studies except (1) Collector Lead to Platform Welding, (2) Wafer Loading, (3) Can Getter Assembly (4) Wafer Screening and Electrical Probe Testing (2N1072) and, (5) Speci ˈ Test Set (2N1072). These operations were added as a result of transistor design changes and changes in overall planning.

The original Contract specified that prototype machines should be built for the following operations:

1. Wafering
2. Wafer Screening
3. Wafer to Header Bonding
4. Wire Bonding
5. Gold Wire Preparation

Development of a mechanized operation for Gold Wire Preparation was never started. It was postponed until the Wire Bonding operation was developed.

Then, Gold Wire Preparation was no longer needed for the mechanized Wire Bonding operation would be designed to feed gold wire continuously.

The narratives in the following subsections cover transistor production machinery completed by December 31, 1962 as required by the latest contract modification.

SECTION 3.1

CLEANING HEADER LEAD WIRE

R. W. Ingham

CLEANING HEADER LEAD WIRE

I General

The concept, design and requirements of the Cleaning Header Wire Machine were based on the work performed approximately two years earlier on a similar machine developed under Contract No. DA-36-039-SC-72729. Experience gained during operation of the earlier machine and process changes made either for product improvement or higher volume output have been incorporated. The machine serves as a source of straight, burr-free leads for the mechanized Header Assembly operation described in another section of this report.

The block diagram, Figure 3.1-4, graphically illustrates the changes in the operations resulting from the introduction of the Cleaning Header Lead Wire Machine. In addition to these changes, the inability of the manual processes to maintain the degree of straightness required for subsequent operations prompted the design and construction of the Cleaning Header Lead Wire Machine.

II Description of the Machine

The machine is a single turret, multistation, continuous motion machine (Figure 3.1-1).

A 1/2-horsepower motor fitted with a spring loaded variable speed pulley drives a 600 to 1 speed reducer by means of a belt. The output of the speed reducer drives the lead load station (Figure 3.1-2). The diameter of the slotted feed drum and the driving pulley are matched so that there is no relative movement between the leads and the clamping belt which serves as the drive for the main turret.

The main turret transports the leads through the various operations with the leads held in a vertical position. Electrochemical and physical processing is only performed on the lower portion of the leads. The electrochemical cleaning is done in a double tank fitted with weirs for level control and a pump for recirculation of the chemicals. Rinsing is done in two steps: (1) A dip rinse and (2) a spray rinse. Water is heated to a minimum of 140°F to improve the effectiveness of the rinse.

After rinsing, the leads move into the drying chamber where dry air is blown over the leads to remove droplets and provide a source of dry air to complete the drying by means of evaporation. Heat in this chamber is supplied by several infrared heat lamps.

As the main turret rotates, the leads are moved past a switch where they are counted. At the next station the leads are unloaded by lifting the belt from the surface of the turret and allowing the lead to fall via gravity through a chute and into a glass container for transportation and storage.

The controls and electrical equipment necessary for the operation of the machine are housed in a separate control cabinet or console located as shown on Figure 3.1-1. The rectifier that supplies the direct current for the electrochemical cleaning is located in the lower section of the console. The rectifier capacity is 150 amperes at 18 volts. Directly above the rectifier and mounted in the center panel are the pushbuttons and parts per hour counter. The single button for each control is illiminated when the circuit is in the "On" mode. A master button located above the others operates the control circuits and serves as an emergency cut-off of the entire machine. The three meters located in the upper panel indicate the output voltage of the rectifier, the amount of cleaning current flowing, and the temperature of the acid in the cleaning tank. An electrical impulse, manual reset counter above the meters provides a continuous count of the leads cleaned by the machine. All wiring and relays are mounted on a panel easily accessible from the rear of the cabinet.

III Machine Development

Development of the Cleaning Header Lead Wire Machine involved the incorporation of modifications required to correct minor operating problems encountered in the Cleaning Header Lead Wire Machine developed for Contract No. DA-36-039-SC-72729. These modifications consisted of (1) increases in the length and volume of the acid tank to provide for the increased output and (2) increases to the capacity of the drying chamber to insure that the leads were completely dry before unloading. These changes were made without changing the overall dimensions of the machine because the oxidizing station of the prototype was no longer required.

IV Operational Problems

During both the shop trial period and the initial production runs, leads occasionally had cut-off burrs that were within specification, but would not feed from the loading station without almost constant attention. This problem was quickly rectified by the departments responsible for furnishing the cut leads. The training of operating personnel was quickly and smoothly carried out.

One problem encountered caused several interruptions before it was identified and corrective action was taken. The rectifier is convection cooled and the manufacturer had installed a thermocouple between the rectifier plates to protect the unit against overheating. This thermocouple was not shown on the wiring diagram furnished with the rectifier. Before this thermocouple was discovered it opened the protective circuit and the rectifier lost voltage on several occasions. An exhaust fan was installed in the wall of the cabinet and the lower panel was replaced by a grill to improve the cooling.

The life of the infrared heat lamps has been reduced to about one-half of the average life expectancy because of the severe operating conditions. To prevent operation with burned out lamps, they are checked at the beginning of each shift and replaced as required.

V Pilot Run Performance

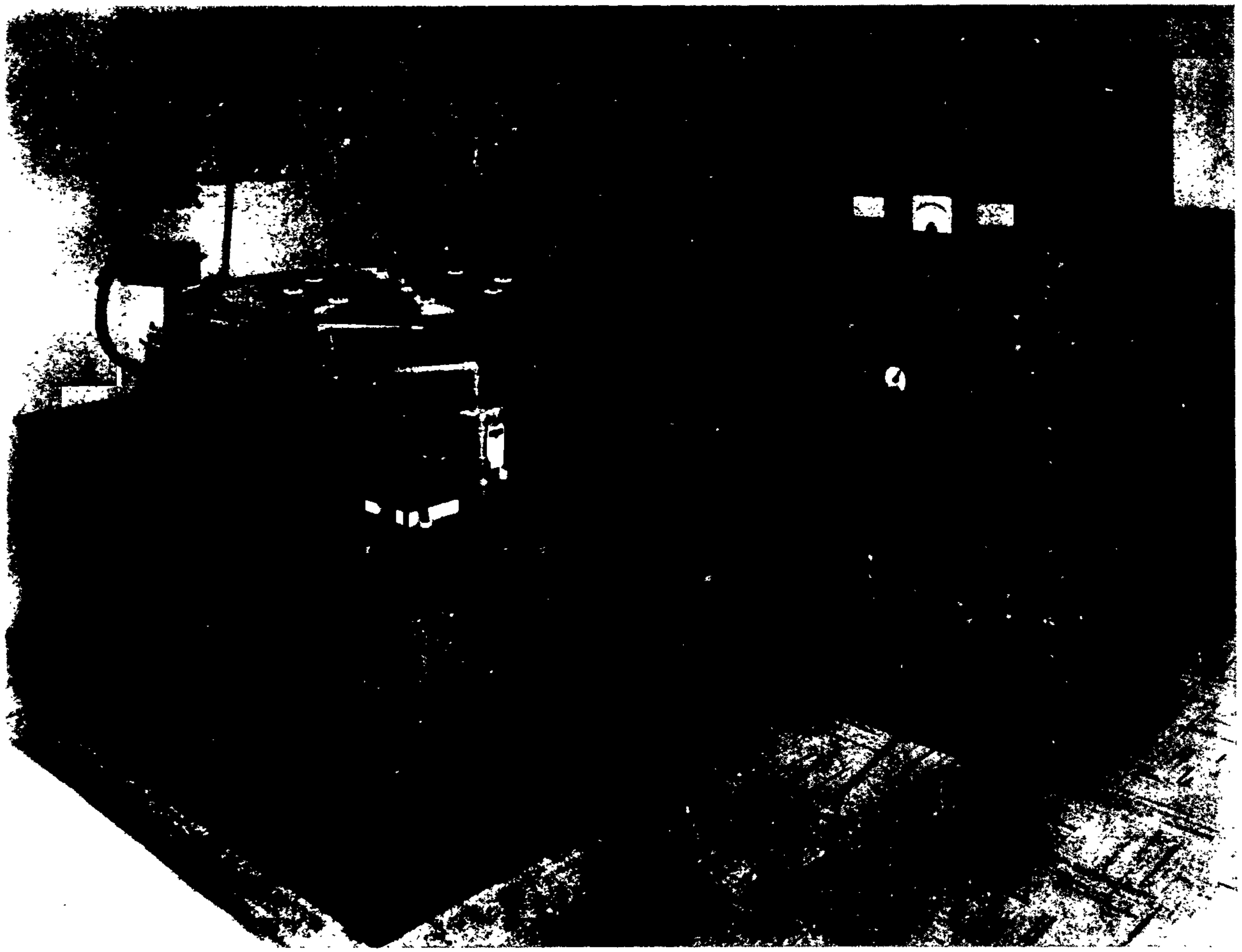
The pilot run was made over a three-month period during which time 1,500,000 leads were processed at an average net rate of 8,000 leads per hour.

The machine has been operated on a 5-day single shift basis and has furnished all of the leads required by the TO-18 and TO-5 headers during the pilot run. Maintenance has been confined to periodic lubrication and tightening of fittings to control acid leaks. The Cleaning Header Lead Wire Machine has provided clean leads capable of being handled by the mechanized Header Assembly operation.

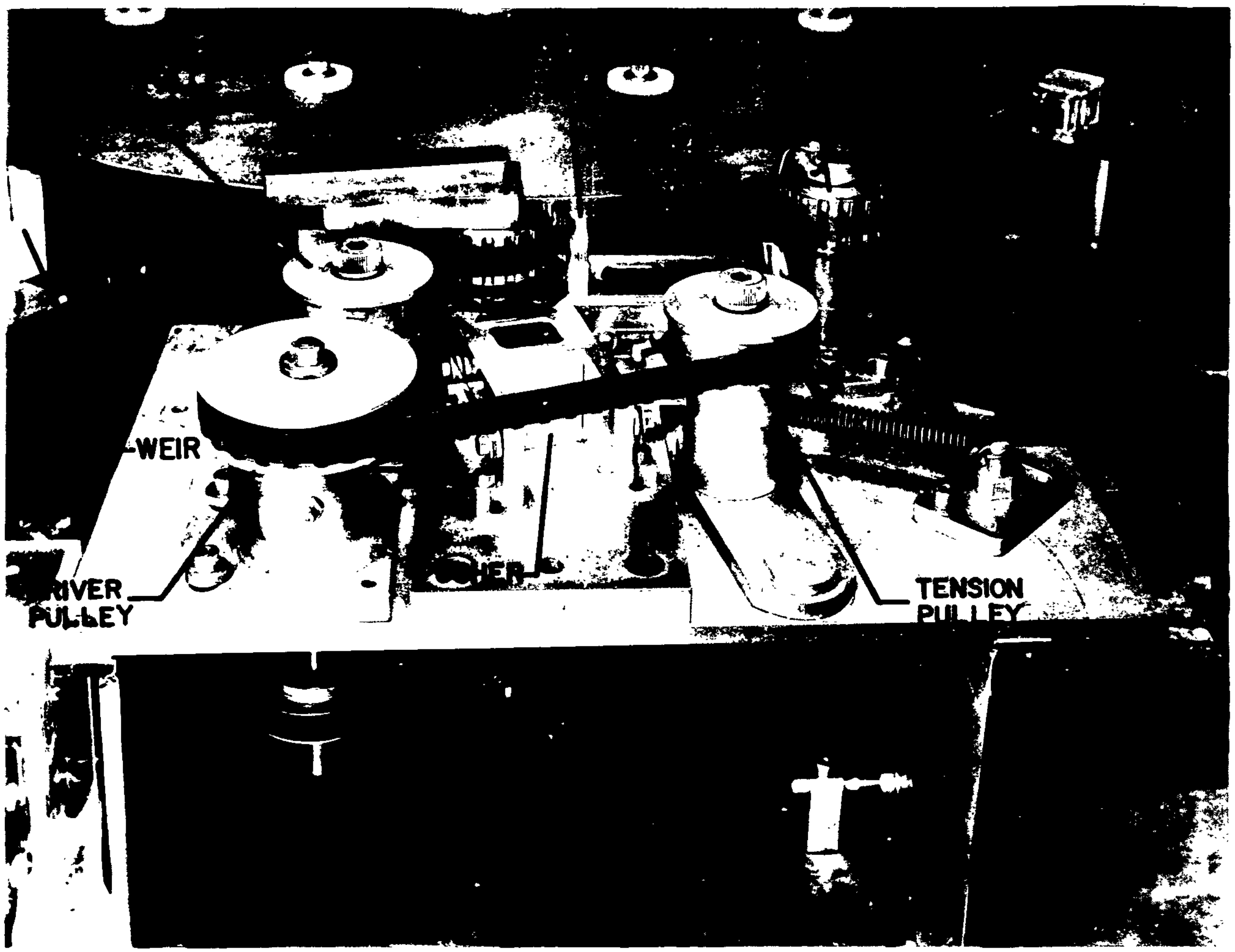
VI Evaluation and Conclusion

The basic requirements set for the machine have been fulfilled. The ability to furnish leads suitable for mechanized header assembly has increased the capacity of the transistor production line. Uniformity of the leads furnished by the machine has matched original expectations. The machine has also served to maintain uniformity of lead diameter by varying the amount of metal removed on the basis of the average diameter of the wire being used.

Operation of the machine on a production basis has indicated some modifications that might improve the operation and reduce maintenance. One of these is to coat the inside of the tank with "Teflon" and provide a separate cathode. Operating history indicates that it would not be practical to increase production simply by increasing the size of the machine. The machine has demonstrated that it is capable of producing large quantities of parts compatible with the manufacture of high reliability semiconductors.



CLEANING HEADER LEAD WIRE MACHINE
FIGURE 3.1-1



LEAD LOAD STATION OF CLEANING HEADER LEAD WIRE MACHINE
FIGURE 3.1-2

FEEDING AND CLAMPING LEADS ON THE CLEANING HEADER LEAD WIRE MACHINE

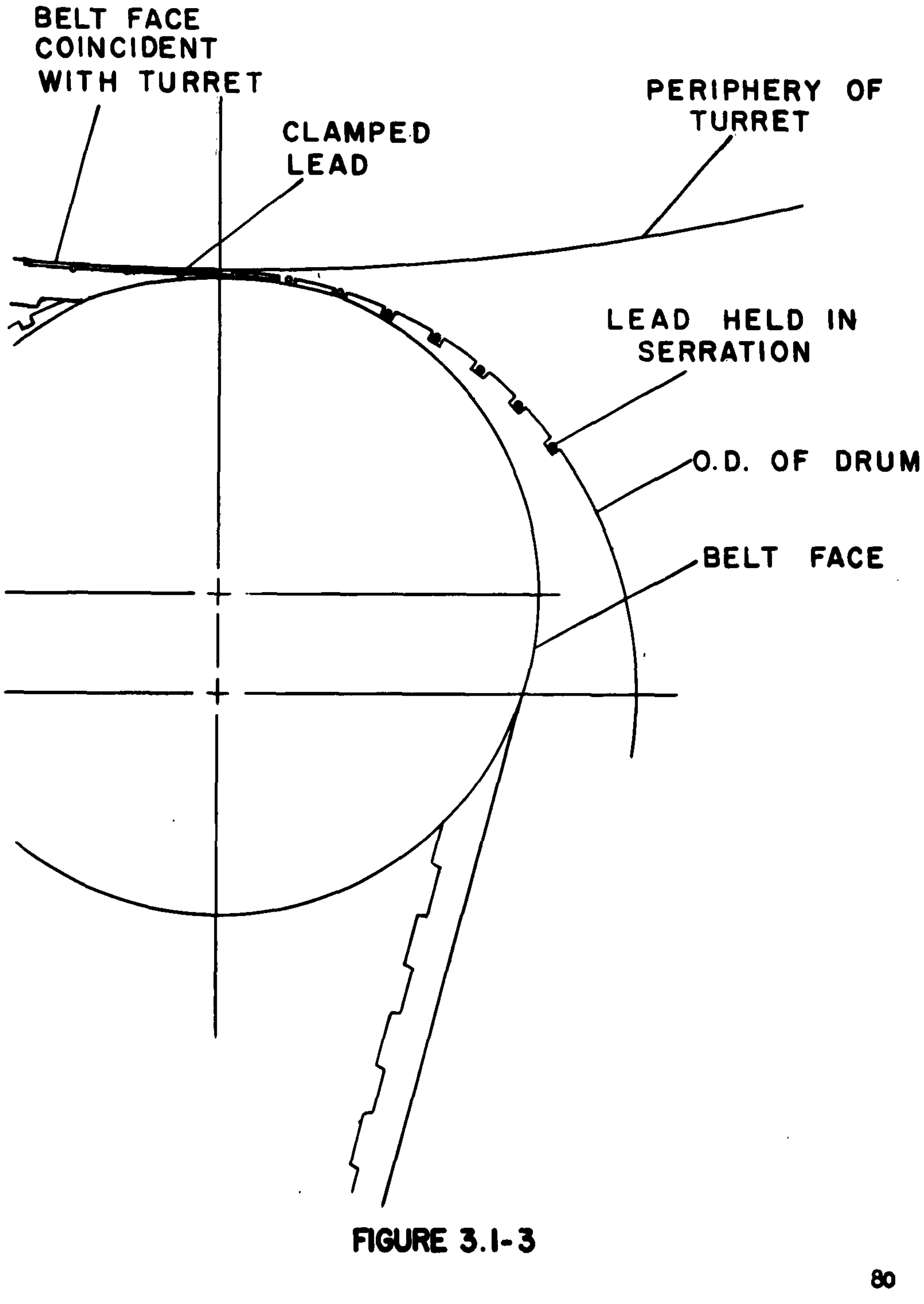


FIGURE 3.1-3

LEAD CLEANING PROCESSES

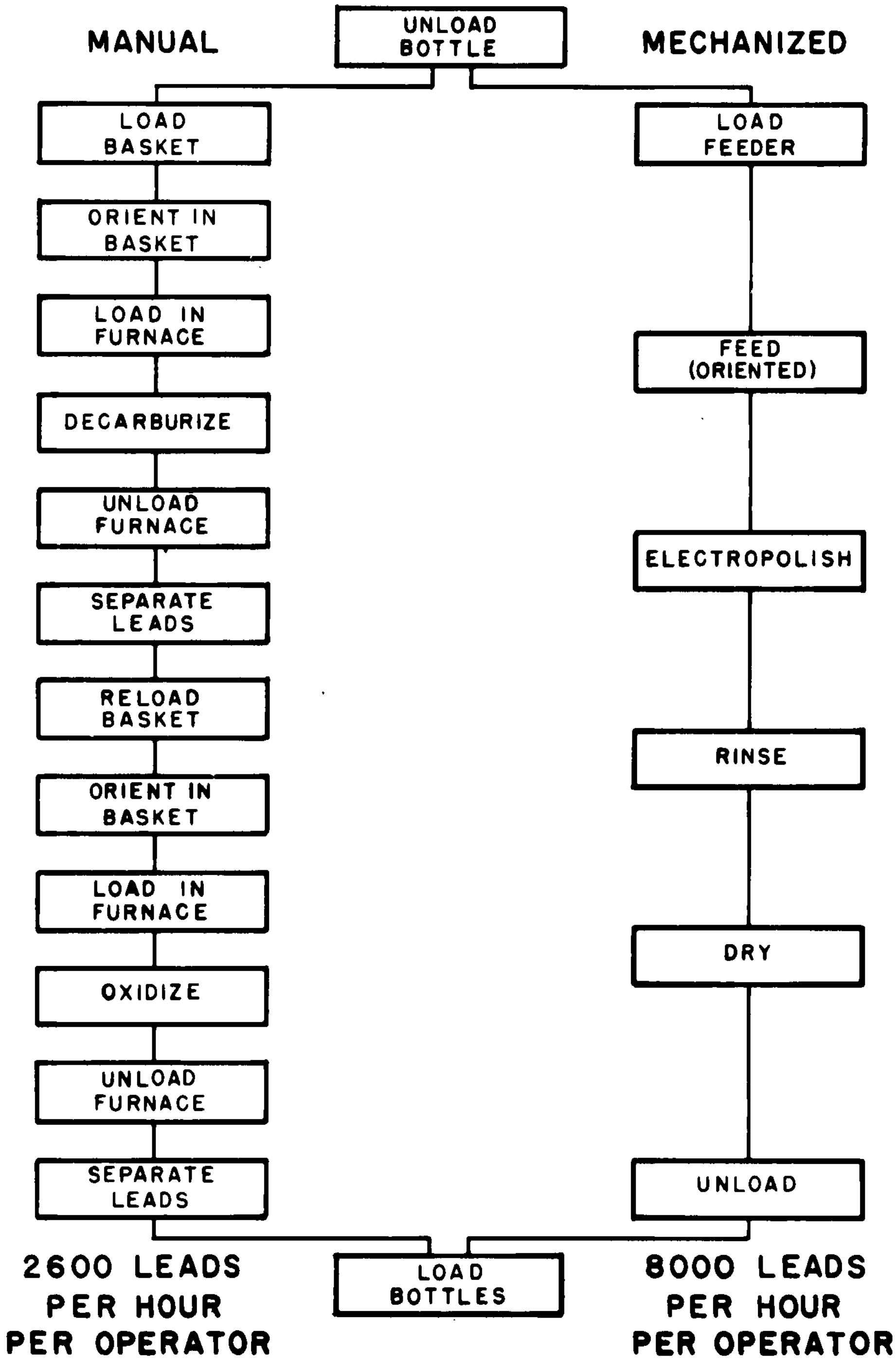


FIGURE 3.1-4

SECTION 3.2

COLLECTOR LEAD TO PLATFORM WELDING

R. P. Loeper

F. J. Reinhard

COLLECTOR LEAD TO PLATFORM WELDING

I General

The Collector Lead to Platform Welding Machine assembles a collector lead and platform by welding the two parts together at the rate of approximately 1200 units per hour. It produces assemblies with accurately positioned leads perpendicular to the base of the platform without any sharp bends along their entire length. It is a semiautomatic machine consisting of four stations with an independent fixture at each station and requires three operators. Accurate nest alignment of the parts before welding and uneven heat balance at the individual fixtures were the main problems encountered during prove-in. Complete interchangeability of all main components on the fixtures and ease of maintenance are principal features. If further development on this machine is desired, it will encompass automatic platform and lead loading, and possibly automatic collector lead assembly unloading.

II Description of the Machine

This machine will assemble a collector lead and platform by welding with the lead positioned within $\pm$ .005 of the nominal position and perpendicular to the platform within two degrees. It covers an area 4 foot square and utilizes a Ferguson Intermitter as the basic component. This is a four station turret type indexing table of cast construction with an integral drive. Four completely independent fixtures which are positioned on the indexing table revolve about a stationary center column. Cams which control all fixture movements are mounted on this column. Directly above the cams is the stored energy power pack for the welding station.

Accurate alignment of the parts at welding is obtained by a die set type aligning fixture. The base of the aligning fixture has aligning pins which accurately guide the moving upper part of the fixture. The lower electrode is mounted in the center of a steel nest which locates the platform in the aligning fixture. The steel nest is mounted on a pair of thin steel cantilever springs which are deflected to provide the welding force and follow-up needed after making the weld. This steel nest assembly is mounted on a cam operated cross-slide guided on the main base. This cross-slide in the forward position places a locating screw under the upper electrodes for positioning the lead wire with the proper length exposed. In this same forward position, the steel nest is also in position providing access for removing the welded assembly and for loading another platform. At the welding station the cross-slide is in the retracted position free of the cam, and an adjustable stop accurately aligns the platform with the collector lead. The top electrode is mounted on another slide which provides vertical travel. A partly slotted copper electrode is mounted on this vertical slide. The slotted part of the electrode is sprung open automatically, and a small cam lock forces it together. This cam permits the slot to assume three positions: fully open, lead load or semi-closed, and clamped. The cross-slide of the lower electrode, the cam lock for the upper electrodes, and the upper electrode height control operate automatically as the fixtures revolve around the cams mounted on the stationary center column.

Three of the four stations require an operator at all times. At the first station a platform is hand loaded; at the second station a lead is hand loaded; at the third station the assembled lead and platform are welded together; at the fourth station the welded unit is hand unloaded. Each index of the machine produces a completed unit. Since all operations are either loading or unloading, no special operator skills are required.

Normal maintenance consists mainly of replacing electrodes. The top electrodes are held in place by four flat head screws and the lower electrodes are screwed into the bottom of the nests. If necessary, by removing five screws, a complete fixture including the transformer can be removed in minutes, allowing production to continue while the trouble is corrected. Figure 3.2-1 shows a complete fixture in detail and Figure 3.2-2 shows an overall view of the machine.

III Development

The development work associated with this machine was done in association with the Platform Lead Welding Machine under P.E.M. Contract No. DA-36-039-SC-72729 and, consequently, will not be discussed in this report. Except for the dimensional changes required due to the larger size of the TO-5 platform, this machine is an exact duplicate of the 2N559 machine.

IV Operational Problems

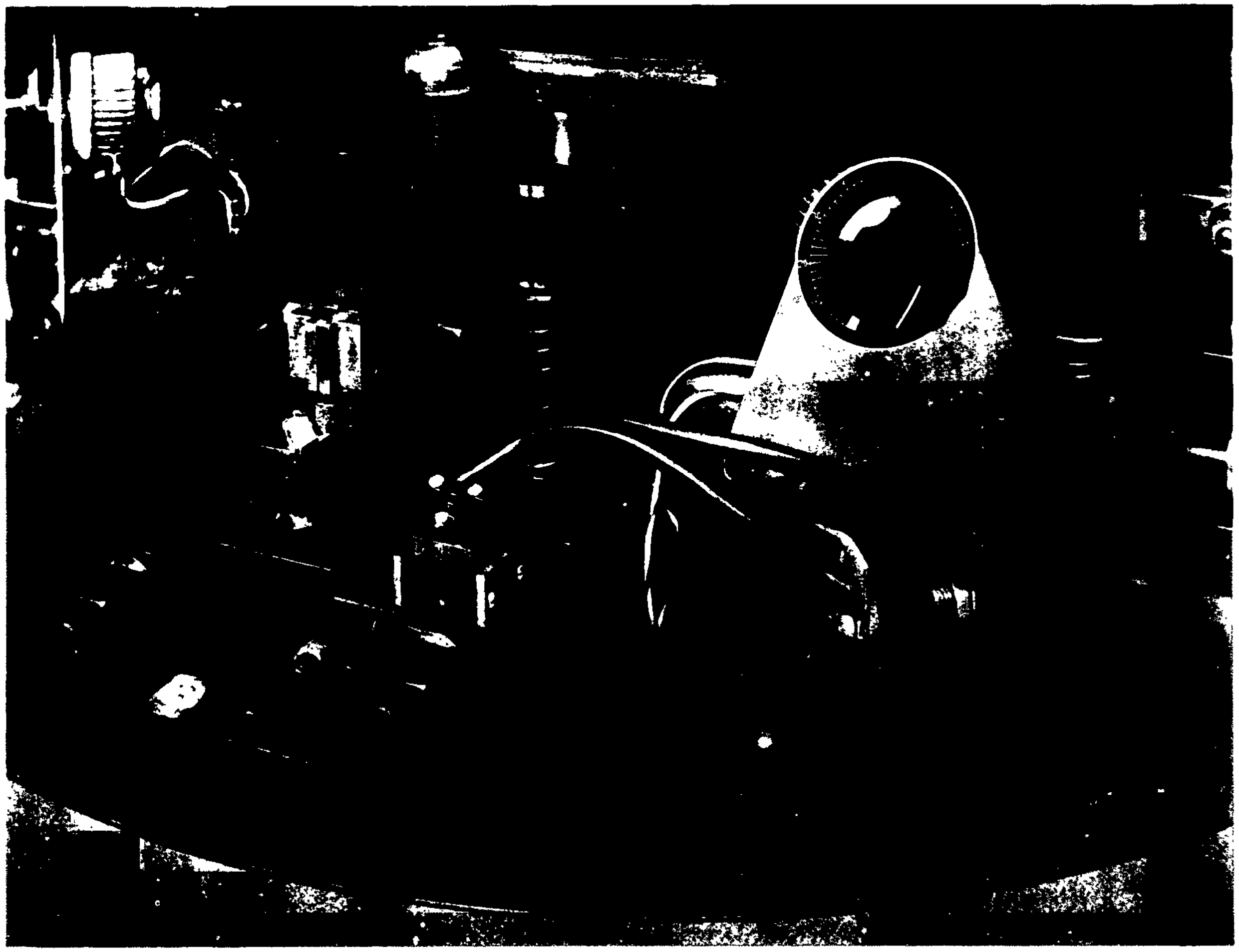
During prove-in of the machine, problems concerning indexing, welding heat balancing, and welded subassembly removal were experienced. The indexing problems were traced to the drive mechanism and the timer furnished with the machine. Since this was a standard drive and the timer was provided with the Ferguson Intermitter, the troubles experienced were quite unexpected. The first time the machine started to index erratically, it was traced to the clutch which was originally designed to disengage electromagnetically during the dwell phase of the index cycle; however, even with the clutch disengaged electromagnetically, the armature was so heavy that it stayed in contact with the field facing during dwell causing excessive wear of the clutch armature and field magnet facing. To correct this condition, the clutch was modified by adding small springs to lift the clutch armature while it was disengaged electromagnetically. The cam which controls the clutch and brake activation was also modified to obtain better results. Continued erratic indexing was traced to the timer supplied by Ferguson.

A heat balancing problem, or obtaining equal welding heat on each of the four fixtures from the welding power supply, was solved by placing a rheostat, to vary resistance, on the primary side of the individual transformers. In this way the welding heat was balanced and uniform welds were obtained.

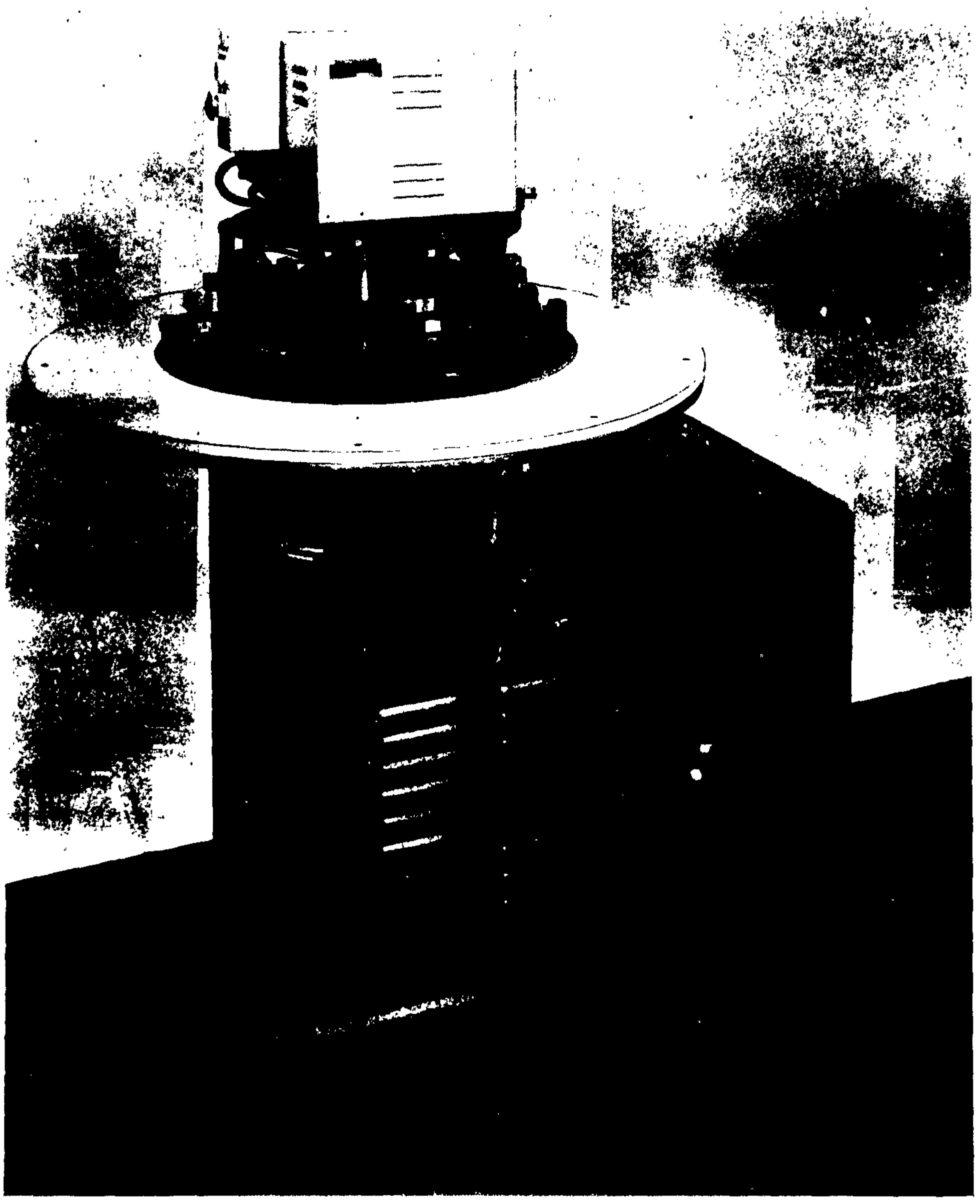
Removal of the welded assemblies normally is a quick hand operation; caution must be used, however, to keep from disturbing the perpendicularity of the welded collector lead. Occasionally, assembled units stuck to the bottom electrode with the result they were difficult to remove. Since the dwell time is less than two seconds, the machine had to be stopped resulting in production interruption. Also, many of the collector lead assemblies were usually bent or damaged in the process of removing them. The nest holding the platform was redesigned to recess the opposite sides of the nest and a tool was then fitted into the recess to free the stuck assemblies with a prying action. This method proved successful and is the one now in use.

V Conclusion

Since a prototype machine had already been built on the DA-36-039-SC-72729 Government Contract, the design was utilized and the machine was built with minor changes. It produces a butt welded assembly with the collector lead positioned in the platform. It has been operated on a two-shift, six-day week basis and has reached our estimated net hourly output of 1200 platform collector lead assemblies per hour. After the machine was in production, it was observed that lead location was not held as accurately as desired. Further nest changes are anticipated to correct this condition.



ALIGNING FIXTURE OF COLLECTOR LEAD TO PLATFORM WELDING MACHINE
FIGURE 3.2-1



COLLECTOR LEAD TO PLATFORM WELDING MACHINE
FIGURE 3.2-2

SECTION 3.3

HEADER ASSEMBLING

J. H. Blewett

HEADER ASSEMBLING

I General

The Header Assembling Machine mechanizes the piece part assembly of the TO-5 headers in preparation for the glassing operation. The machine is of the continuous, straight-line type having separate stations for automatically inserting two additional non-oxidized leads, a glass ring and a glass slug into the collector lead-platform subassemblies which are contained in ceramic stick molds. It also has a crimp and weld station which forms and welds the three lead ends together. This welding operation is required to permit the glassed headers to be tack welded to strips for gold plating in the Header Continuous Rack Plating Machine and also to keep the leads from bending during the processing on subsequent automatic machines.

The assembly operation is performed automatically at a net rate of 1440 subassemblies per hour. In addition to high production, low unit cost, and uniformity of product, the machine retains the cleanliness required to produce an acceptable glassed header.

II Description of the Machine

The machine occupies a floor space 30 inches wide by 96 inches long with a working area 30 inches wide in front and 24 inches wide in the rear and at both ends. The weight is approximately 1,500 pounds, and the only plant facility required is 440-volt A-C, 3-phase power. Vacuum and pressure are provided by a self contained Gast oil-less pump. An over-all view is provided in Figure 3.3-1. A 1/2-horsepower motor drives the machine through a Boston variable speed belt drive which can be varied from 20 to 40 revolutions per minute with the optimum speed being 30 revolutions per minute or 1800 subassemblies per hour.

The Header Assembling Machine is of the straight-line continuously operating type which feeds the glassing molds from a loading magazine on the left end of the machine, through a guided track to an unloading magazine at the right.

The TO-5 collector lead-platform subassemblies are hand loaded into ceramic stick-type molds containing ten cavities. The loaded molds are indexed through the machine by a ratchet type pawl bar which advances the entire line of molds 1/2 inch during the first quarter of each revolution of the main drive shaft.

All piece parts consisting of wire leads, glass rings and glass slugs can be loaded into their respective magazines or hoppers while the machine is running. As the molds are indexed across the machine, they successively pass the lead feeding station, glass ring and glass slug stations, and finally the crimp and weld station. The stations that feed piece parts operate only when a mold is at that particular station. This allows gaps in the line of molds or the running of a single mold without missing or feeding additional parts. Figure 3.3-2 shows the arrangement of the stations and indexing mechanism.

The lead feeder depends on gravity for dropping the leads from the magazine to the mold. The .018-inch-diameter by 2.234-inches-long leads are horizontally loaded into two magazines with the cleaned end toward the back of the machine. The bottom of each magazine is enclosed by an oscillating segment containing a slot just large enough to accept one lead. As the two segments oscillate, they peel one lead off the bottom of the magazine and rotate 90 degrees so that the leads can be dropped into a chute. This chute guides them downward to a vertical position and delivers them into an insertion mechanism which applies pressure to the leads as it forces them down into the cavities of the mold. As the insertion mechanism approaches the bottom of the stroke, it opens and frees the leads allowing the molds to index to the next position.

Glass rings, .64 inch diameter by .100 inches high, are fed from the hopper of a "Syntron" vibratory feeder, down a track in a horizontal position where they are picked up one by one on a vacuum finger and indexed to a position directly over the top of the leads. The three leads are gathered together by two V-guides which are cam operated from the main drive shaft. This ring is then released by interrupting the vacuum and dropped down over the leads.

Glass slugs, .183 inches diameter by .110 inches high, are also fed from the hopper of a "Syntron" vibratory feeder and down a confined track which delivers them to an insertion bar standing on edge rather than on the base. The bar peels one slug at a time off the bottom of the column and, by means of a vacuum, transfers it across the mold, and deposits it between the three leads maintaining the edgewise position.

Since there are no piece parts fed at the form and weld station, it is geared directly to the drive shaft and operates at all times when the machine is running. The welding power is turned "off", however, when there is no mold in the welding position. At this station, the three leads are combed and clamped together in a straight line across the center of the unit. While in this position, two forming dies come in from the sides and bend the two outside leads in against the center lead. A pair of electrodes then move in over the benders and weld the three wires together. After the benders and electrodes retreat, the molds are then indexed to the right end of the machine, pushed out of the track and stored in an unloading magazine for removal to the glassing furnace. Figure 3.3-3 illustrates the successive operations in the assembly process as the mold indexes through the machine.

The electrical system on the TO-5 Header Assembling Machine operates at 110 volts and the main drive motor is 440 volts. Using the 110-volt system permits the use of switches and solenoids which are easily obtained and is also compatible with the normal voltage used for the lights, "Syntron" vibratory feeders and Gast Vacuum Pump. The clutches which connect the lead feed and two glass feed stations to the main drive are released by energizing solenoids, so that when the machine is running continuously, springs hold the clutches in the engaged position and no power is required.

Two pushbuttons control the entire machine. To start the machine, a yellow pushbutton is depressed to energize the drive. This button remains depressed and is illuminated until it is pushed the second time when it releases and interrupts the power to the motor, stopping the machine. When the loading trolley is brought all the way back and locked, it depresses a limit switch which stops the machine. After the trolley is released, the second button which is an illiminated white RELEASE button must be pressed to restart the motor drive. Similar limit switches are located on the unload station to prevent the molds from over-running the end of the unload magazine. If this occurs, a warning bell rings and the machine is stopped.

The operator must work from the front of the machine and watch for missing leads, jams and broken glass. She must also load the molds into the magazine and make sure an adequate supply of piece parts are in the hoppers for feeding at each station.

The limit switches mentioned earlier prevent mold breaking which, in turn, results in inconvenience to the operator. For added safety, all drives, gears and clutches are enclosed inside the machine. The sides of the machine base are removable for access all around. In case an emergency stop is required, there is a regular switch or an additional limit switch that can be reached by the operator from any position around the machine.

Maintenance is minimized by keeping all motions simple. Since the weights of piece parts handled are insignificant, no strain is imposed on the machine while running. The only parts that need regular attention are the welding electrodes which must be dressed periodically.

III Machine Development

Early development of the machine followed the original TO-18 Header Assembling Machine, developed under Contract No. DA-36-039-SC-72729, as closely as possible. This was done to keep the Header Assembling Machines similar both from a maintenance and an operating standpoint. The basic size and shape were retained, but refinements and improvements were made to the drive, clutches, indexing method and the electrical system.

The use of the butt welded collector lead-platform subassembly caused the major change in the handling of piece parts for this operation. This required a lead feeder which would feed two, instead of three, leads into a mold which already contained the collector lead-platform subassembly. Several studies and considerable development were done in this area with two approaches being investigated: the reciprocating bar feed and the oscillating segment type feed.

The reciprocating bar feeder picked up a lead in a slot cut on each side of a bar which moved back and forth between the lead magazines and a position directly over the mold. This method fed two leads at a time and the total lead drop was approximately 3 inches. The short drop time is important because of the shorter work cycle possible, thus a higher rate of output for the machine. While this method was fast, the reciprocating motion presented a wear and vibration problem when operating at high speeds. However, the main drawback was the need to stop the machine while loading the leads. The oscillating segment overcomes these drawbacks and has a much smoother drive train. The one disadvantage over the bar feeder is that the lead must drop about 9 inches and be turned from a horizontal to a vertical position. This limits the cycle time of this station; however, it has satisfactorily fed as many as 2500 pair of leads per hour.

One of the problems introduced by the butt welded collector lead-platform subassemblies was the springing of the subassembly after the welding operation. A great deal of experimenting and development was done to keep the subassembly and the assembled piece parts properly seated in the mold when the lead forming and welding are being performed.

The original concept for feeding both the glass rings and slugs was to feed them down through a tube between the vibratory feeder and the insertion mechanism. Various materials were used for the tubing and the one that worked best was made of stainless steel. Exhaustive experiments were run utilizing this through-feed method and while this arrangement worked, it had the disadvantages of clogging up on an oversize piece part. Since this type feeder is entirely enclosed, it required tearing apart and considerable work to loosen a jam. This downtime on a machine could not be tolerated. It was, therefore, decided to go to an open track feed which could be opened and cleared while the machine was operating.

IV Operational Problems

One of the early prove-in problems encountered with the TO-5 Header Assembling Machine was the indexing arrangment. In order to prevent a mold from being returned by the indexing pawls, spring loaded ball detents were placed in the back of the track to place a drag on the mold and prevent it from returning. This enabled a single mold to be indexed through the entire machine. However, when the machine ran continuously, the accumulative drag on all the molds was too great to be overcome by the indexing spring and the machine did not index. The solution was to remove the detents and add stationary spring steel stops between the indexing pawls which utilized the same notches in the molds. This not only assured positive indexing, but also eliminated the grooves that the detents were wearing into the backs of the ceramic molds.

The original chute on the glass slug feeder was covered with a plexiglas cover. While this cover afforded a good visual check on the supply of slugs in the chuts, it also wore from the constant sliding of the glass. A stainless steel cover was then designed which covered about three-fourths of the track opening. This modified cover resisted the wear better and also afforded tweezer access to remove any jams that were caused by oversize parts.

From the start of the prove-in period, difficulty was experienced in keeping the platform seated in the mold and the tab in the slot during the forming and welding operation. Since the piece parts were so light and set in shallow cavities of the mold, they offered no resistance to the lifting and twisting actions that resulted when the upper ends of the leads were being formed and welded. To keep the platform subassembly and the glass parts snugly in the mold while going through this station, a sail-like arm was mounted directly before the comb and clamp of the welder. At the bottom of this arm, a thin finger projects forward under the clamp and comb and holds the entire subassembly down in the mold by pressing on the glass slug. This accomplished the task of keeping the subassembly down while welding, but since it was fixed, oversize or tilted glass slugs would jam under the finger causing a failure in the indexing of the molds. This also caused broken glass which, when melted in the furnace, ruined the molds. To combat this problem, the arm was spring loaded so that any excessive height or tilting of the glass slugs will merely raise the finger and allow the unit to pass through without jamming. This also has the advantage of keeping uniform pressure on each unit as it is welded.

As in all mechanized equipment which duplicates a series of operations with a high legree of accuracy, the process can be successful only if the piece parts that it processes are to specification. The first piece part which causes concern on the Header Assembling Machine is the butt welded collector lead-platform subassembly. Straightness and location of the welded lead in the platform caused the most trouble during the prove-in period. When the lead is not straight and perpendicular to the platform it is difficult to gather the leads at the glass ring loading and the welding stations. Since the collector lead is welded rigidly to the platform, the platform tends to tilt in the mold when the lead is moved. Also, when the collector lead is welded too close to the inside edge of the platform, there is not sufficient clearance for the glass ring to fit into the space between the lead and and platform. This condition causes glass breakage at the glass slug loading station and also uneven glassing, in the furnace.

The lead feeder requires straight wires without burrs on either end. If the leads are bent, they fail to drop into the slot properly and jam the oscillating segment so that it can not feed a lead. The reliability of the lead feeder depends to a large degree on the straightness and cleanliness of the leads being fed.

The glass piece parts are not as critical as the leads; however, the glass rings are fragile and any mishandling will break them. Broken rings cause jams either in the feeder track or in the insertion mechanism. The slugs are solid and have a far less tendency toward breakage. Any oversize slug will, however, block the track and interrupt slug feeding.

Training of operators posed no particular problems. The machine was slowed down so that they could become accustomed to monitoring the operations and picking up missed leads or glass parts at all the stations. At the normal operating rate of one assembly every two seconds, it is essential that the operator monitors each station because large numbers of header assemblies may be incomplete if a station jams or runs out of piece parts.

V Performance

During the initial prove-in period, lack of adequate ceramic glassing molds prevented running full time. There was, however, a set of 75 new molds at our disposal and with these, two runs were made daily. Complete data was kept on the condition of the molds as well as results of the product processed. It was found that starting with new molds, 23 runs were made through the Header Assembling Machine and the Seal-Ox

(Header Glassing) furnace before they required cleaning. After cleaning, they ran an additional 22 runs until they again required cleaning. The hourly outputs of the machine during these short runs was between 1,000 and 1,500 units per hour depending on condition of molds, piece parts, and machine malfunctions. The three causes for rejects which can be charged to the machine usually are: First, excessive bubbles in the glass which may result from dirty leads or piece parts. Second, bad welds at the welding station deform the leads and make it impossible to weld the lead ends on the strip for plating. Third, another defect that is directly attributed to the welding station is bad lead location which is due to the platform subassemblies pulling out of the mold during crimping and welding or excessive devormation of the leads.

Actual results of the above defects taken from 60 runs on this set of 75 molds resulted in about 1 per cent defective welds, 5 to 6 per cent lead location defects and a gradual build-up of bubbles as the machine becomes dirty. The dirt problem can be easily controlled by daily cleaning procedures which have been put into effect.

VI Evaluation

The Header Assembling Machine introduces no new processing techniques into the operation of assembling the headers into the molds; however, it does increase the speed at which these assemblies can be produced. The addition of a forming and welding station after the assembly of the piece parts is required for strip plating and use in handling of the units on subsequent machines.

Shop trial runs during the first full month of production when the machine ran two shifts per day, six days per week produced up to 6,500 units on the day shift and 7,100 units on night shift. Hourly rates are difficult to determine from these total figures in that they do not establish accurately what portion of the downtime can be charged to machine malfunction, dirty molds, or operator and process delays. The best figures available indicate a maximum day to day production rate, under present operating conditions, of approximately 1,000 units per hour.

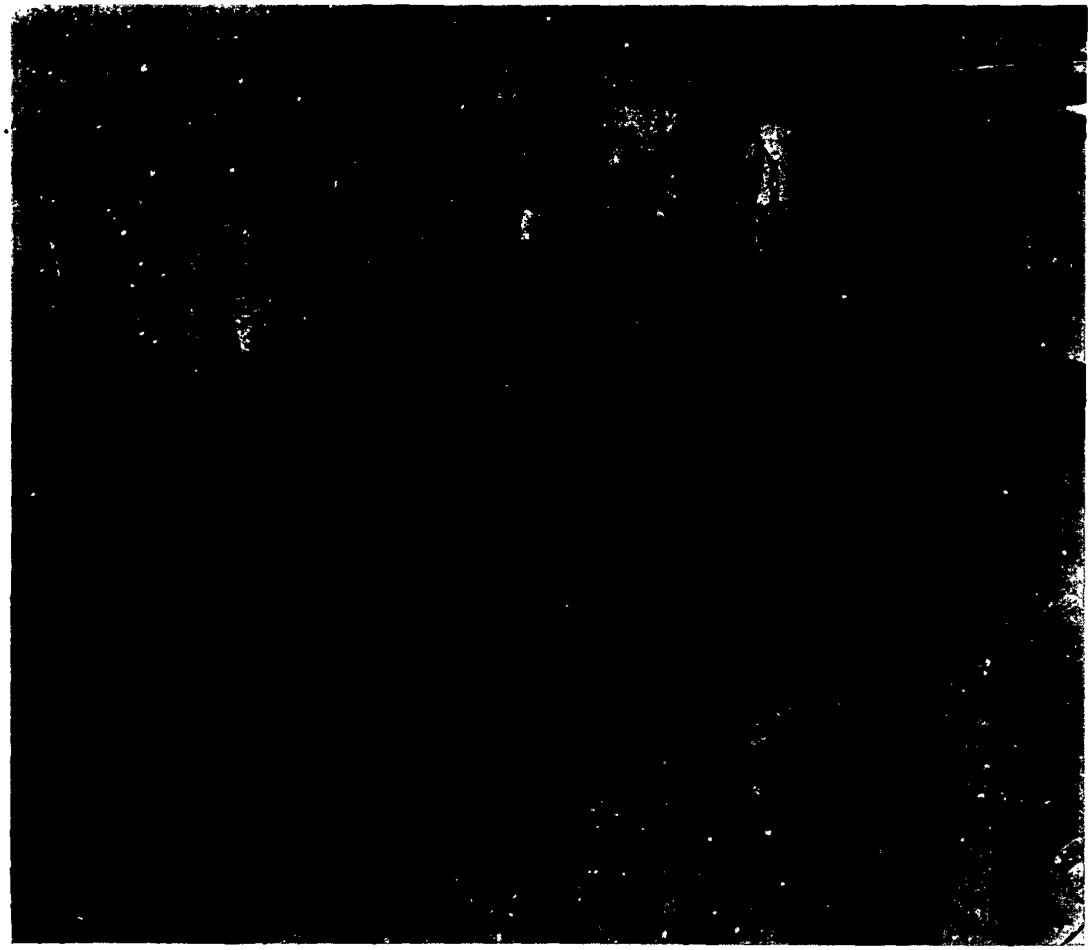
The one factor which contributes most to the erratic operation of the machine is the condition of the ceramic molds. Build up of oxides in the mold cavities and in the holes holding the leads, prevents proper seating and alignment.

VII Conclusion

With clean molds, straight leads, glass piece parts that are within the specifications and straight lead-platform subassemblies, the Header Assembling Machine will consistently produce 1,500 subassemblies per hour with a lead location rejection rate of approximately 6 percent.

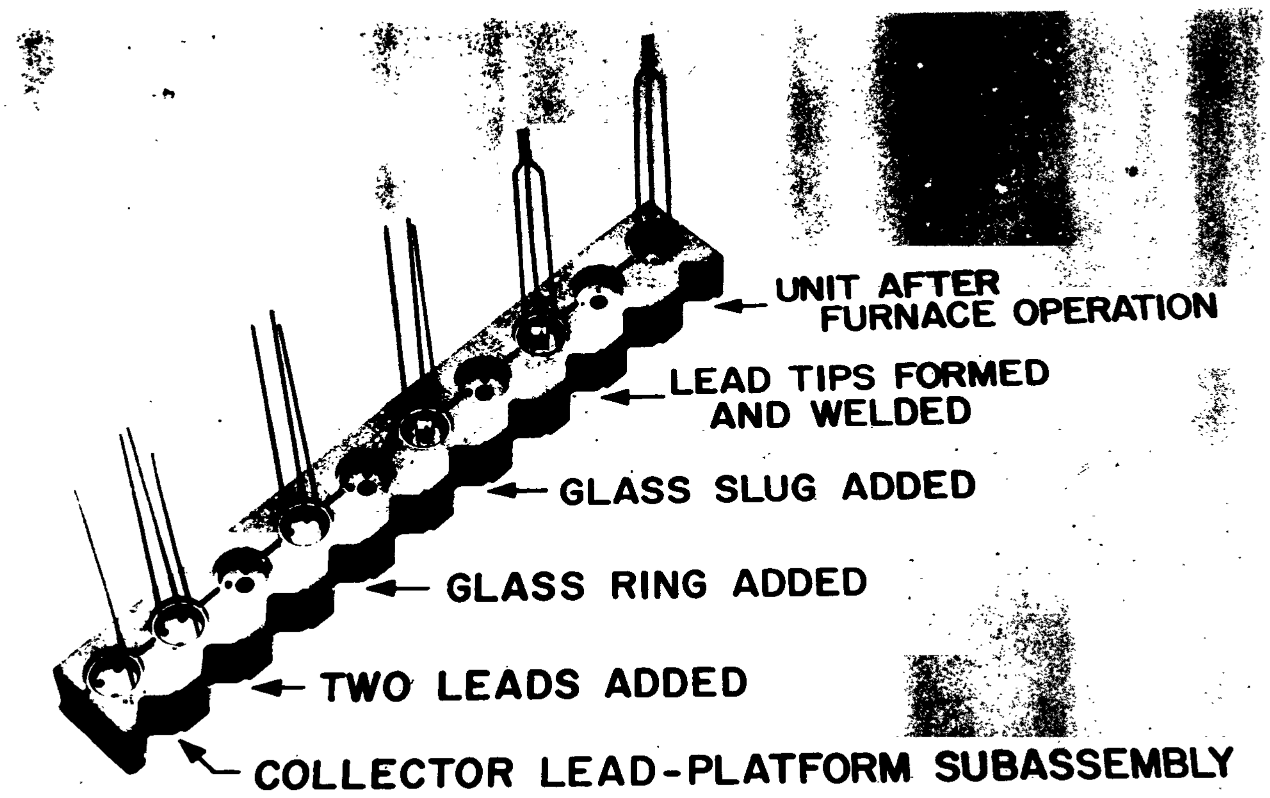
Work is still being carried on to alleviate the problem of lead location, and minor modifications have been made to reduce the tendency to break glass piece parts as they are inserted into the molds.

The efficiency of the overall Header Assembling process is reduced due to the need for the hand loading of the butt welded collector lead-platform subassemblies. The efficiency would be greatly improved if an automatic method of preloading were developed. This is being considered as a Phase 2 project.



TO-5 HEADER ASSEMBLING MACHINE
FIGURE 3.3-1

LOADING AND WELDING STATIONS OF HEADER ASSEMBLING MACHINE
FIGURE 3.3-2



TO-5 CERAMIC GLASSING MOLD ILLUSTRATING
PROGRESSIVE STEPS IN HEADER ASSEMBLING
FIGURE 3.3-3

SECTION 3.4

WAFERING

R. H. Morrow

H. K. Naumann

WAFERING

I General

The 2N560-2N1051 and 2N1195 Wafering Machines were built to mechanize manual scribing operations, to reliably maintain wafer tolerances, to improve wafer breaking through improved scribing, and to increase operator output. These machines can scribe on .020, .030, .040, or .050-inch centers and maintain an accuracy of ±.0002 inch.

The machines, patterned after the one built to scribe the 2N559 wafers under PEM Contract No. DA-36-039-SC-72729, were built to provide the wafering capacity contemplated for high volume Nike Zeus production and provide the accurately sized wafers needed for mechanized wafer and wire bonding.

Because of the experience gained on the 2N559 Slice Scribing Machine, little difficulty was encountered with these two machines.

II Machine Description

The Wafering Machines consist of four major assemblies. They are: (1) an indexing and locating mechanism (Assembly A, Figure 3.4-3) which provides the desired indexing and locating; (2) a scribing mechanism (Assembly B, Figure 3.4-3) which provides the relative motion between the scribing tip and the slice; (3) a precision cross-stage slide and a rotatable vacuum chuck (Assembly C, Figure 3.4-2) and (4) a monocular microscope (Item 1, Figure 3.4-3) used for viewing the slice during scribing and while aligning the slice prior to scribing. Mechanized indexing of the slice is accomplished through a solenoid controlled single revolution clutch, modified for half revolution indexing, driving a 50-pitch precision lead screw. A locating device was provided to insure proper locating after each index. Variation in the indexing increment is obtained by controlling the number of half revolutions made by the clutch. A single revolution of the clutch produces a 20-mil index, one and one-half revolutions produce a 30-mil index and so on. Selection of the index increment is accomplished by shifting the selection lever (Item 2, Figure 3.4-2) to the appropriate position.

To compensate for the variation in stripe spacing common to germanium slices, a compensating device has been built into the machine. This device permits the operator to reduce the scribing increment .0015 inch maximum. A micrometer has been incorporated into the machine to measure each slice prior to scribing. Correction to the index increment is made by adjusting the expanded scale (Item 3, Figure 3.4-2) to the predetermined setting. Adjustment is made by turning the adjusting knob (Item 4, Figure 3.4-2) in the clockwise direction. The scribing increment is reduced with no change to the index increment by setting the lead screw, drive motor, clutch and locating mechanism askew to the normal indexing axis.

The scribing and lifting action of the scriber tip is cam controlled and independently driven by Assembly B, Figure 3.4-3.

Indexing of the vacuum chuck and table assembly takes place during the return stroke of the scribing tip and is controlled by a limit switch and cam arrangement (Item 5, Figure 3.4-3). The operational sequence of this machine is as follows: (1) the scribing tip drops to contact the slice, (2) the slice moves relative to the fixed scriber tip to produce scribing action, (3) the scriber tip raises, (4) the slice returns to the initial position and is indexed one increment.

After approximately 35 scribing passes, the lead screw and cross-stage slide are automatically reset to the start position. After scribing has been completed parallel to the stripes and the machine has reset to the start position, the vacuum chuck and slice are manually rotated 90 degrees and scribing is resumed.

The operator's duties consist of mounting the slice, aligning the slice, measuring the stripe evaporation error, making the necessary error correction, setting the slice to the start position, starting the scribing action, and rotating the vacuum chuck 90 degrees after completing scribing in one direction.

III Machine Development

A typical manual scribing tool used prior to mechanized scribing is depicted by Figure 3.4-4. Indexing and scribing motions are individual operations performed by the operator. Before the slice could be mounted to the scriber head, each slice was mounted in wax on a glass slide. The limited accuracy and quality of the scribe lines produced by this method of scribing did not lend itself to mechanized wafer screening and bonding operations. The hourly output for manual scribing was 2.75 slices per hour. Mechanized scribing resulted in approximately a 400 percent increase over manual methods with an estimated hourly output of 12 to 15 slices.

Studies conducted in connection with this machine included investigating the possibility of holding the slice directly to a vacuum chuck and of making an indexing increment correction to compensate for variation in stripe placement from one slice to another. Studies were also conducted to establish the most desirable scribing velocities, to obtain maximum scribing tool life, and to provide the best possible scribing with respect to wafer breaking.

In order to permit the machine to automatically reset to the start position after completing the scribe cycle, a single revolution clutch capable of driving in two directions had to be designed. This was accomplished by modifying a standard spring type clutch.

No device changes affected this machine, however, it was found desirable to modify the machine to permit scribing on any of four indexing increments at will. This feature was not included in the original design and was not added until approximately one year after the machine was placed into shop trial.

IV Operational Problems

No major problems occurred on the machines during prove-in and shop trial but several minor ones were encountered and corrected. The vibration problem, caused partially by a chain and sprocket system, was partially corrected by replacing them with a timing belt and pulley and was completely eliminated by building a special vibration isolated stand for the machines.

The failure of the indexing system to return the cross slide stage to its original starting position was traced to the indexing clutch. As a result, the clutch was redesigned. The improved clutch combines two clutch principles into one versatile and extremely compact unit. This clutch makes use of a spring-type clutch for indexing during slice scribing - while a ball-type clutch is overrunning. When scribing has been completed, the cross stage slide must be returned to the start position. This is accomplished through the same clutch, however, in reverse drive the spring clutch is overrunning and the ball clutch provides continuous reversing action.

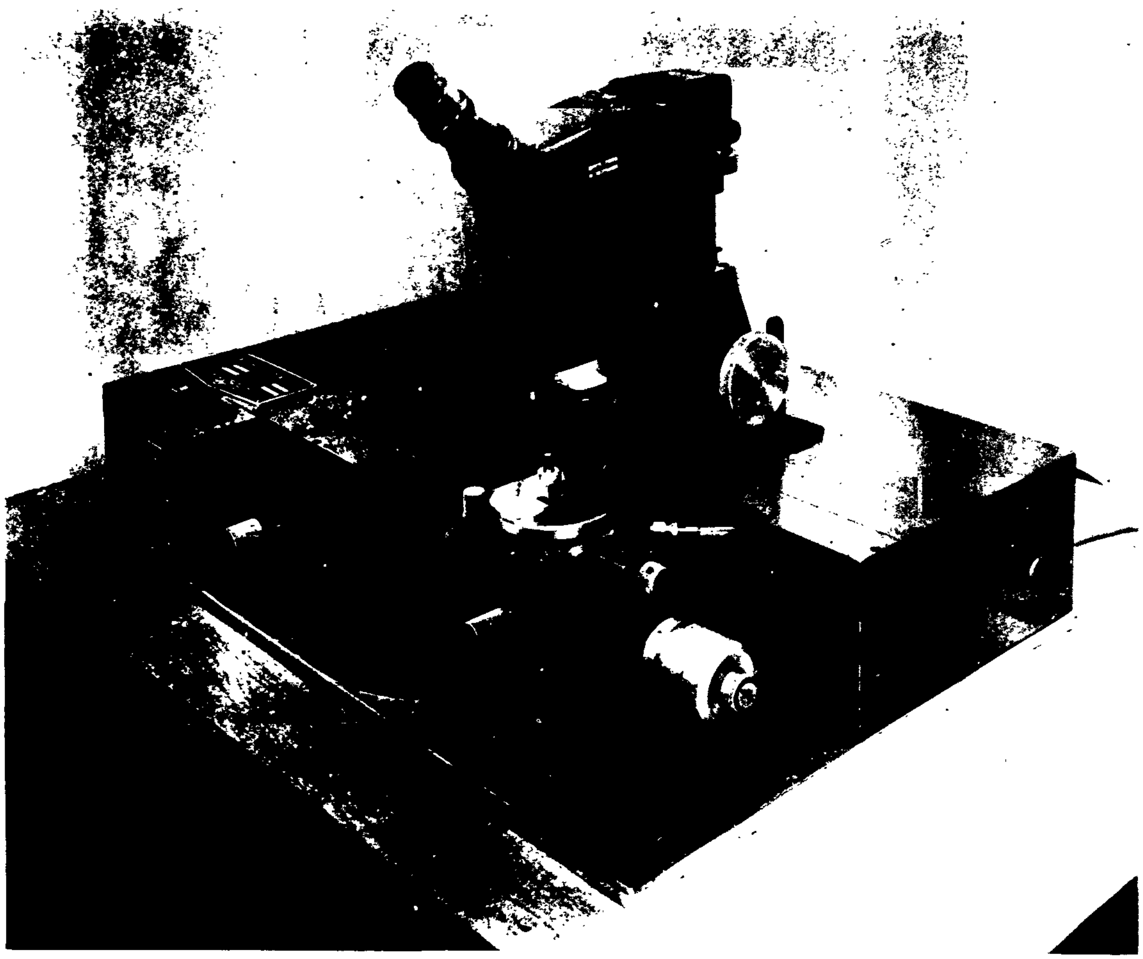
Drift in the scribing stage was eliminated by replacing a pressure brake on the scribing mechanism with an electric brake.

V Evaluation

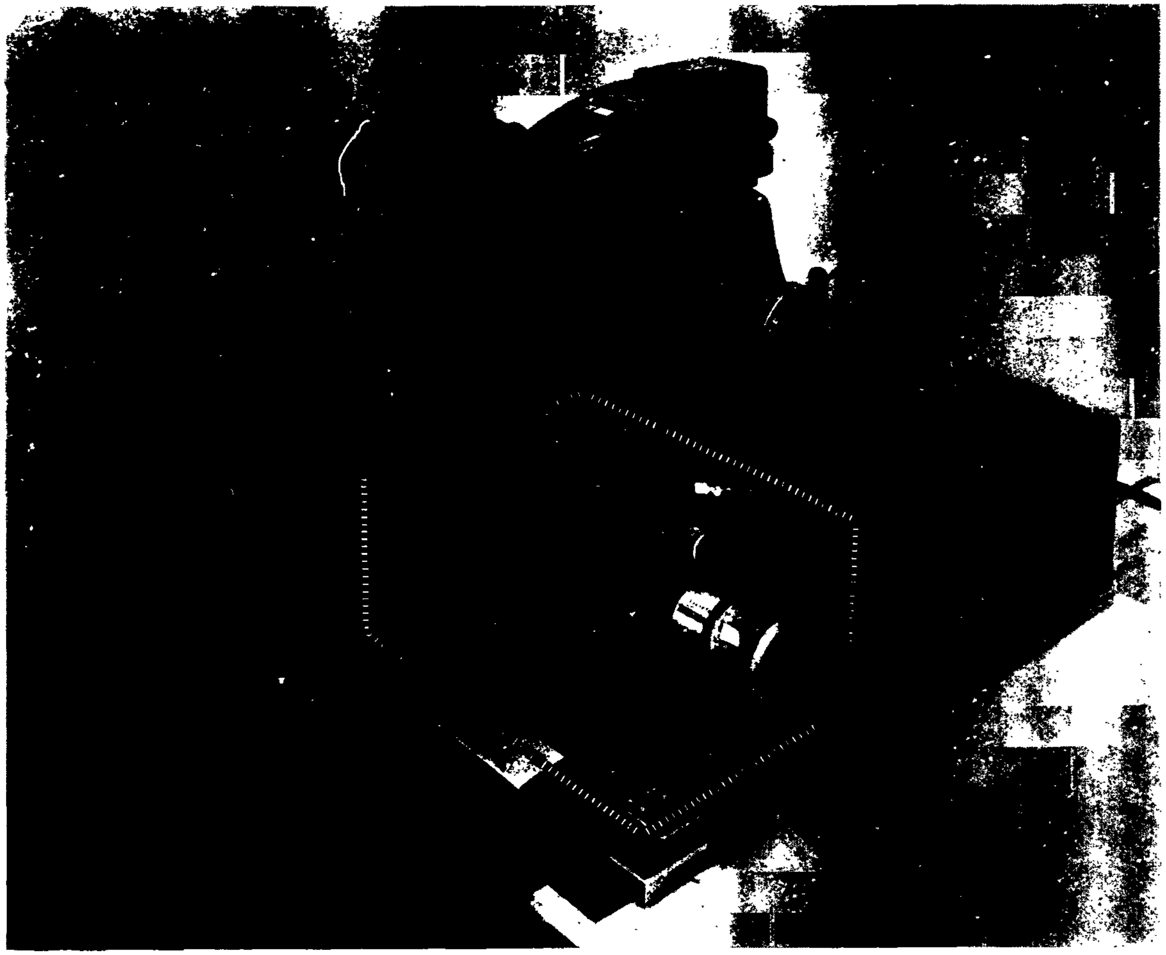
The Wafering Machines have been in operation for over two years and have provided reliable performance over this period. Accuracy and quality exceeding the original specification has been achieved with a minimum of operator effort and low machine maintenance.

VI Conclusion

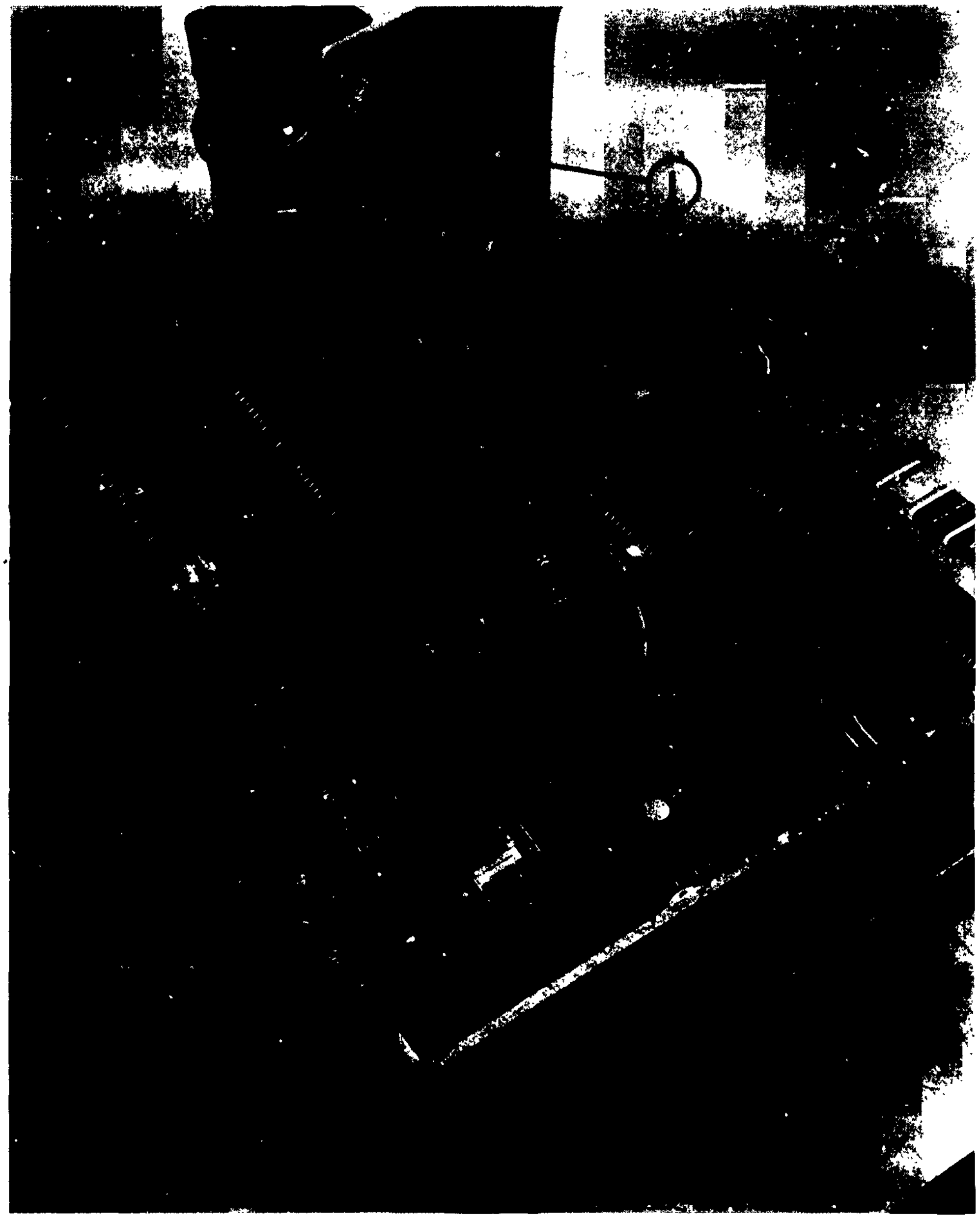
Success in attaining all original goals has been fully realized with the completion of this machine. The wafer processing and handling methods presently in use rely on the scribing accuracy and scribe quality of these machines.



WAFERING MACHINE NO. 1
FIGURE 3.4-1



WAFERING MACHINE NO. 2
FIGURE 3.4-2



OPERATING MECHANISMS OF WAFERING MACHINES
FIGURE 3.4-3

MANUAL SLICE SCRIBING TOOL
FIGURE 3.4-4

SECTION 3.5

WAFER LOADING (2N560-2N1051)

R. H. Morrow

WAFER LOADING (2N560-2N1051)

I General

Two 2N560-2N1051 Wafer Loading Machines were built to mechanize loading of unoriented .030-inch-square slicon wafers into metal trays prior to Wafer Screening in a rapid and easy fashion. The need for these machines was introduced by the discovery that silicon wafers could not be broken, screened, and loaded in the same manner as germanium wafers. The development of these machines was brought to a successful conclusion.

II Machine Description

The Wafer Loading Machines, as developed, load wafers from bulk into wafer trays with the active element up but in no specific orientation. The bulk wafers are placed into the saucer bottom of a vibrating, outside feed, rotary bowl. Single wafer feed is obtained by transferring the wafers to a vibrating linear track which rejects wafers having the active element down. At the end of the track, wafers are transferred to wafer trays by a reciprocating vacuum pickup timed to the indexing cycle. The wafer trays are fed from a magazine, indexed down a track, loaded, and fed into another magazine. A complete description of the wafer trays and magazines was presented in Section 2.

The Wafer Loading Machine consists of three main systems: the tray indexing system, the wafer pickup and transfer system, and the vibratory systems. The tray indexing system (Item 1, Figure 3.5-2) consists of a spring loaded tray magazine unload station, a cam operated system of indexing pawls and positive tray locating system, and a cam-operated tray magazine reloading station. This system is typical of tray indexing systems on five other machines and is discussed more thoroughly under the Wafer Screening Machine.

The wafer pickup and transfer system (Item 2, Figure 3.5-2) consists of a vacuum pickup needle which travels both vertically and laterally between the end of the linear track and the wafer trays. This system is cam operated from the main drive shaft and is timed to the tray indexing system.

The vibratory system (Figure 3.5-3) consists of a 3-inch outside feed, saucer bottom rotary bowl, which feeds bulk wafers onto a linear feed track, and a 6-inch linear feed track. The linear feed track is so designed as to eliminate wafer chips and pieces and oversize or upside down wafers. It feeds only those wafers having the active element up to the end of the track for pickup. The linear track is controlled by a variable frequency oscillator and power amplifier located in the cabinet. The variable frequency is needed to compensate for changes in the vibratory spring system caused by the end loading of the linear track.

The operator's duties consist of loading and unloading of magazines, loading of bulk wafers into the vibrating bowl, operation of all controls except on the electric eye, and monitoring the loading operation in order to obtain full wafer trays.

III Machine Development

The problems of maintaining clean wafers increased wafer thickness, and resistance to plane breaking of silicon prevented the use of the same machine for breaking, screening, and loading that is used for germanium wafers. The small chips and pieces produced when breaking silicon would jam the feed mechanisms and cause increased wear of parts. These problems made another solution for silicon material handling imperative.

Attempts to break and clean silicon while maintaining stripe orientation as done on the Wafer Breaking, Screening and Loading Machine, Contract No. DA-36-039-SC-72729, were made with little or no success and were abandoned.

The decision was made to break and clean silicon wafers by normal methods because these methods produce cleaner wafers. Stripe orientation is lost during cleaning and breaking; therefore, the bulk wafers were to be loaded into trays with the active elements up but without regard to stripe orientation.

Experiments were conducted to find the best method of handling these bulk wafers. Vibratory feeders, both rotary and linear, were tried with fair success in feeding. The rotary feeder posed little trouble with wafer feeding, requiring only that the bowl be free of burrs and cleaned properly. Linear feeding on the other hand posed many problems. Wafers would stick on a flat or flat grooved surface and were positioned on a flat with active element both up and down. Further experiments showed that the wafers satisfactorily moved down on a 45-degree inclined surface which was polished and then lightly grained at a 5-degree angle leading in the direction of desired wafer movement. Further tests were made to find a method of eliminating wafers riding with the active element down. A photoelectric sensing circuit was tried with some success, but sensitivity of the photocells available at that time was not high enough to provide consistent results.

The mechanical rejection system depicted in Figure 3.5-4 has wafers travel along a 45-degree angled track with only a small adjustable shelf at the bottom for the wafers to rest upon. This shelf is so adjusted that wafers having the active elements up can pass since the flat bottom rests on the 45-degree incline, while wafers having their active element down are unbalanced by the vibration and slip off the ledge back into the bowl.

Construction of the wafer track and vacuum pickup was started first to confirm their designs. The remainder of the machine was started as drawings became available.

IV Prove-In and Shop Trial

The wafer track was completed and cleaned. After mounting the track on a vibrator, tests were started. It was found that the wafers would not travel down the track. Examination showed that the track was rough. Diamond polishing increased wafer travel, but it was necessary to grain the track before good results were obtained. This graining consists of lightly marking the track with fine emery cloth starting at the input end of the track and going toward the discharge end. This graining is made on about a 5-degree angle leading toward the discharge end.

The vacuum pickup, which was based on the venturi principle to eliminate the need for a separate vacuum system, was finished and tested. First attempts to pickup wafers failed. It was found that the lack of a draw tube in the venturi throat provided pressure instead of vacuum. After inserting a draw tube, vacuum pickup was achieved. Further test, however, showed that this system was too slow to react at the desired machine speed; therefore, the venturi was replaced with a straight vacuum system.

The mechanical prove-in was completed with no difficulties other than timing and spring pressure adjustments. Operational prove-in, however, was a different story. Wafers being fed down the linear track would stop and pile up about 1-1/2 inches from the discharge end. An examination revealed neither burrs nor stickiness, but all attempts to feed wafers failed.

Tests with a vibration analyzer showed that a dead spot existed at the pile-up. Damping of the vibrations at this point resulted because the output end of the track rested on the jig plate. After placing a neoprene rubber pad under this end of the track, wafer feeding improved but was not satisfactory. Experimentation with a variable frequency oscillator and power amplifier showed that the spring system had changed enough that the frequency had to be increased from 60 cycles per second to 75 - 85 cycles per second to resonate the track. With this system installed, wafer feeding was good. This system is located under the work table inside the machine frame.

As prove-in progressed, it was found that better control of tray indexing was needed because the wafers were not feeding fast enough to fill the wafer trays. A pushbutton switch was inserted in the main index control line to permit the operator to control tray indexing. While the operator depresses the pushbutton, the machine will index continuously. Upon releasing the pushbutton, when no wafers are present for pickup, tray indexing stops and remains stopped until the operator depresses the button again. Using this control, an operator can load approximately 75 percent of the tray pockets with wafers.

Shop trial of the machine was started and an operator was trained. This training was accomplished over a 2-week period. 2N560 and 2N1051 wafers were loaded by the machine and then oriented and inspected on the Wafer Screening Machine. During shop trial it was found that chips and oversize wafers jammed the linear track; consequently, a system of sieves was used to screen out oversize wafers and remove small chips. These sieves reduced jamming to a minimum. Product changes introduced during shop trial altered the wafer configuration so that the mechanical rejection system would not work properly.

A new linear track was designed and built (Figure 3.5-5). It incorporated features to eliminate chips, pieces, oversize wafers and pile-ups. To reject inverted wafers from the new track, a photoelectric sensing circuit was incorporated. This circuit has a far more sensitive photoelectric cells than those available during development. The amplifier for this system is located under the work table inside the machine frame.

This rejecting system increases the versatility of the machine so that wafers other than mesa wafers can be loaded. Additional shop trial showed the new rejection system worked well, requiring adjustment only when changing codes.

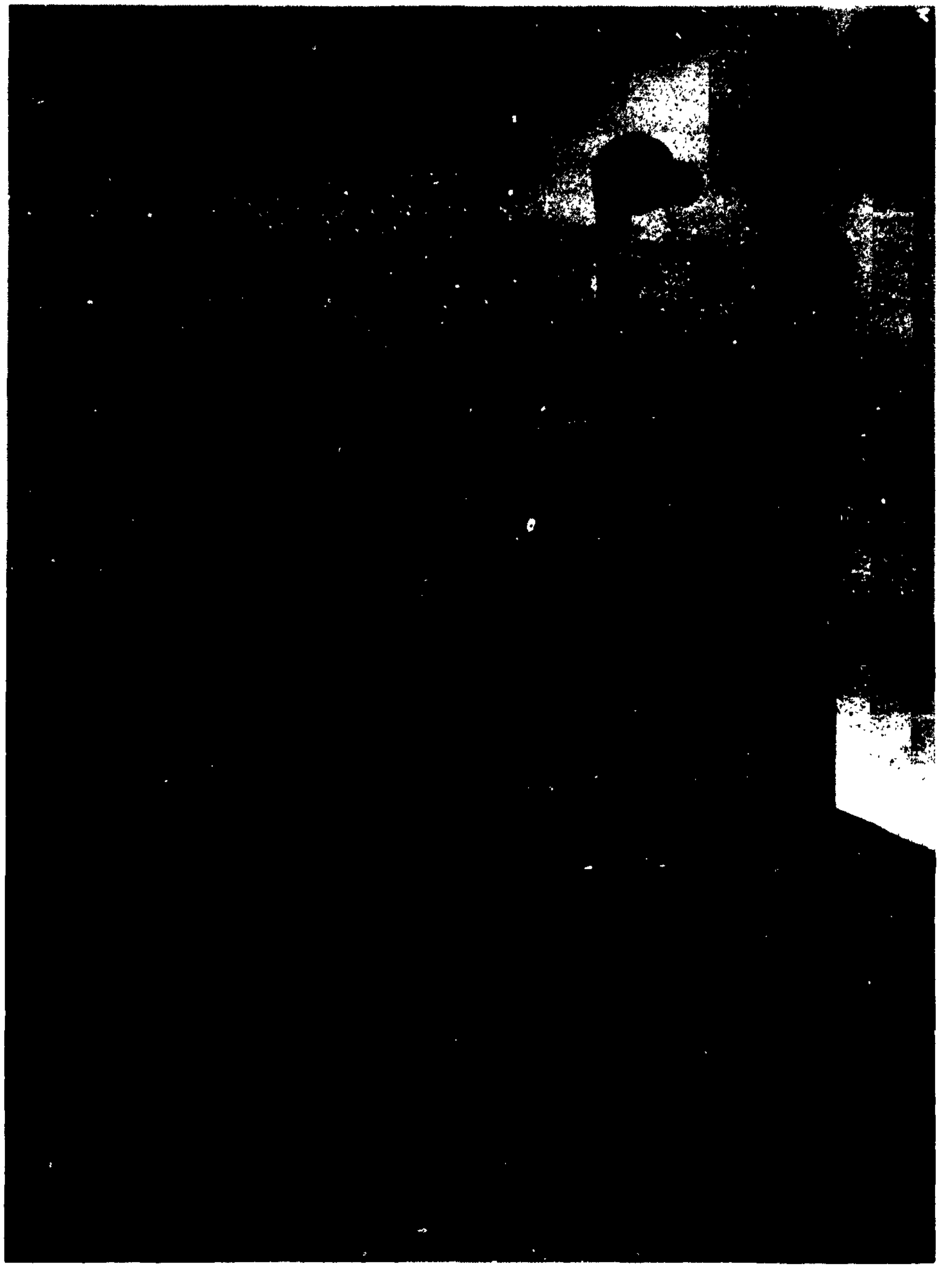
VI Evaluation

The use of the pushbutton control and the new linear track with its photoelectric sensing system enables the Wafer Loading Machines to load approximately 1200 wafers per hour with 95 percent of those loaded having their active element up. The remaining 5 percent lack sufficient front to back contrast to correctly actuate the sensing system.

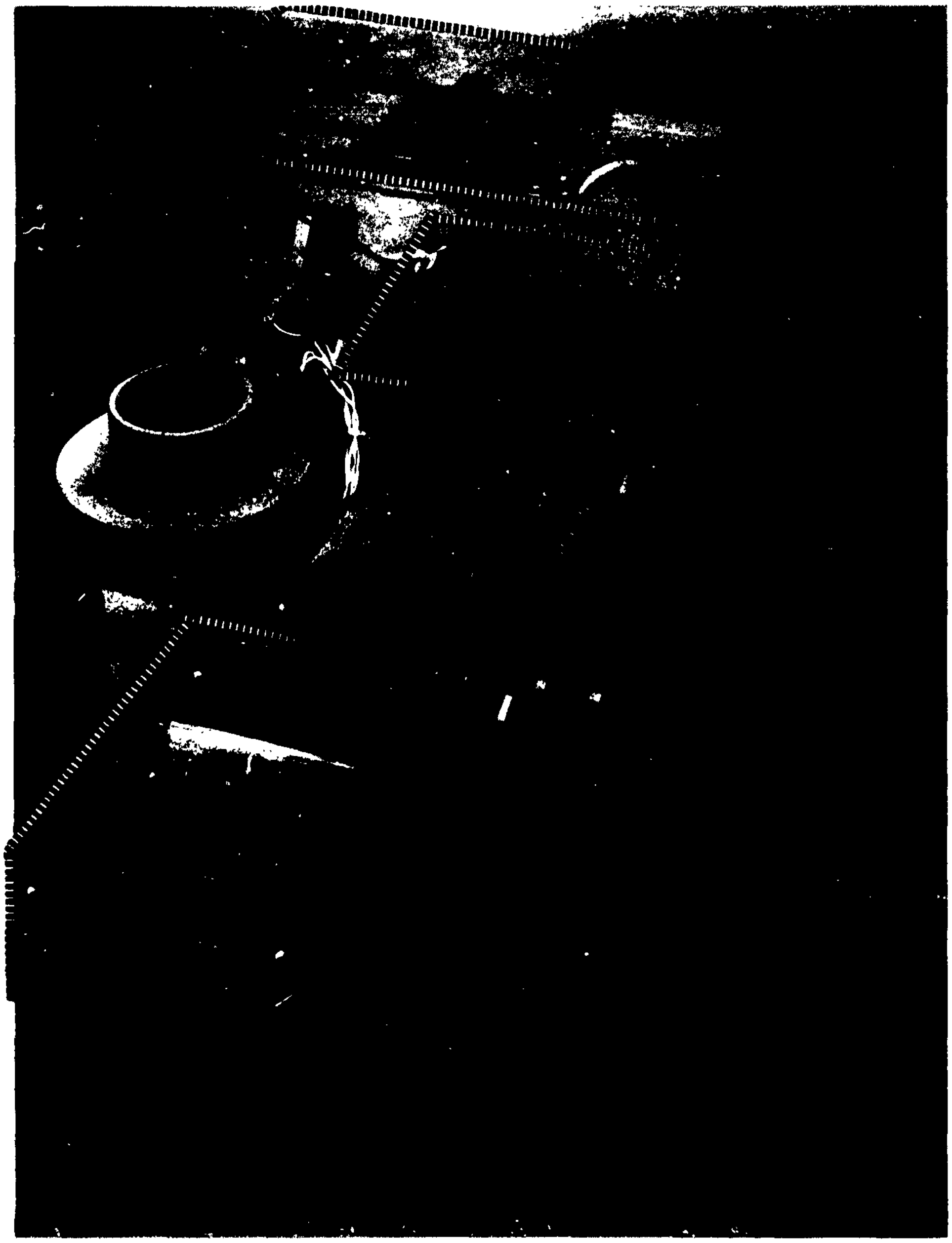
The new track and photoelectric sensing system have increased the versatility of the machine. Shop trial results show that little adjustment is required to change from one wafer code to another. Increased reliability of the photoelectric sensing system and wafer feeding system is needed to maintain an efficient Wafer Loading operation. A means must must be found to increase either the front to back contrast of the wafers or the sensitivity of the detecting system so that smaller differences are required for accurate sensing. Improved wafer feeding would not only lead to more completely filled trays but also relieve the operator of the monitoring responsibility.

VII Conclusion

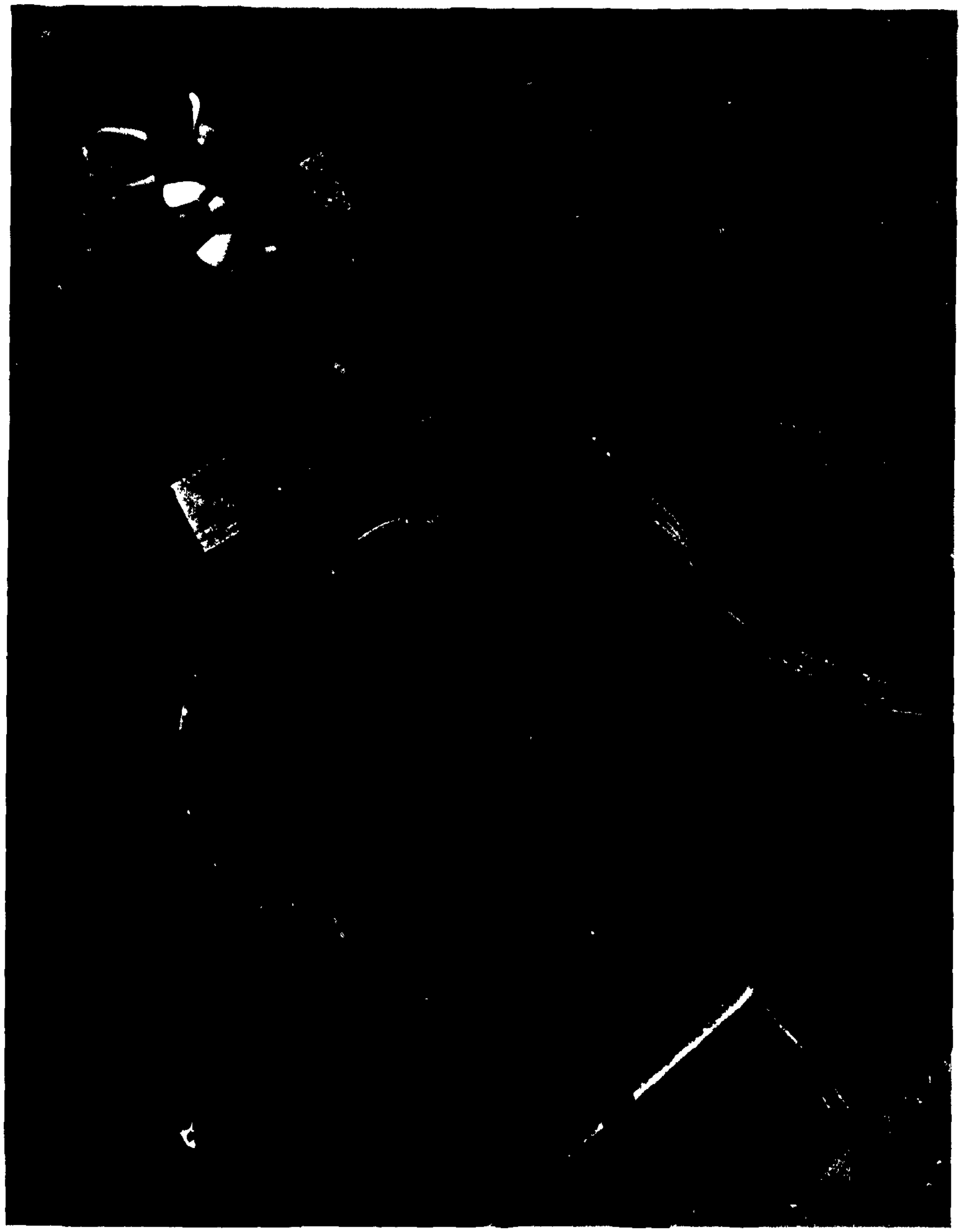
The Wafer Loading Machines have successfully met the design criteria, in that they will load .030-inch-square silicon wafers, both mesa and planar type, into wafer trays at approximately 1200 wafers per hour. A recent reduction in wafer size from a .030-inch to a .020-inch square limits the usefulness of the machines. Further study of wafer handling techniques will be required to determine whether the machines can be modified to feed and load .020-inch wafers satisfactorily. These studies will be conducted during Phase 2 of the Contract.



WAFER LOADING MACHINE (2N560-2N1051)
FIGURE 3.5-1



**WAFER TRANSFER AND TRAY INDEXING SYSTEMS
OF WAFER LOADING MACHINE
FIGURE 3.5-2**



VIBRATORY FEEDERS OF WAFER LOADING MACHINE
FIGURE 3.5-3

Wafer Rejection System

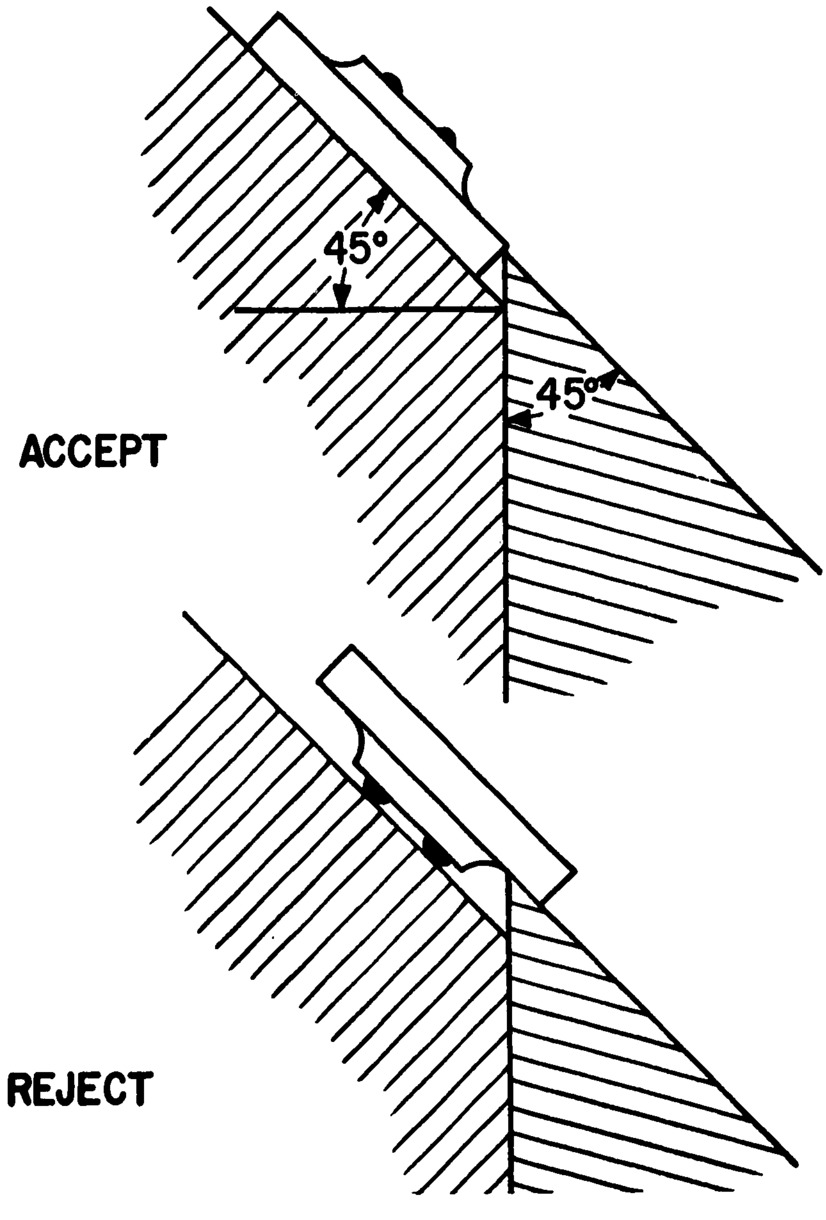


FIGURE 3.5-4

NEW LINEAR TRACK FOR WAFER LOADING MACHINE
FIGURE 3.5-5

SECTION 3.6

WAFER SCREENING (2N560-2N1051)

R. H. Morrow

WAFER SCREENING (2N560-2N1051)

I General

The Wafer Screening Machine (2N560-2N1051) was built to mechanize the screening operation of .030-inch-square silicon wafers, to improve operator output and efficiency, and to prepare the wafers for mechanized Wafer to Header Bonding. The need for this machine evolved from the type of wafer handling system selected for silicon wafers. It was designed to accept loaded wafer trays from the Wafer Loading Machine, to screen and orient the wafers and to load accepted oriented wafers back into wafer trays for the Wafer to Header Bonding Machine. Development of the machine was brought to a successful conclusion.

II Machine Description

The Wafer Screening Machine consists of five major assemblies: (1) the optical comparator; (2) the rear tray indexing system; (3) the front tray indexing system; (4) the wafer transfer system, and (5) the wafer orienting system. This machine is capable of handling 1,800 wafers per hour.

The optical comparator (Figure 3.6-1) is a Nikon Model 3 modified to incorporate a new lighting system and a 200-power magnification system, and to replace the adjustable cross-slide stage with a work table containing the indexing and wafer transfer system. The lighting system consists of two zirconium arc lamps and one tungsten lamp mounted on the comparator and arranged to provide maximum light on the wafer being viewed.

The rear indexing system (Item 1, Figure 3.6-2) consists of a spring loaded push out system which unloads wafer trays onto the tray transfer track, a system of index pawls and positive tray locator controlled by the operation cycle, and a cam operated tray pushout system which reloads trays into another magazine. The index pawl and location system is so designed that, on the push stroke, the locating pin is disengaged and the pawls engage the teeth in the trays advancing the trays one tooth or .0625 inches. On the return stroke, the locating pin is engaged holding the trays in position and the pawls ride back over the next tooth and drop in behind it ready for the next stroke. The front tray indexing system (Item 2, Figure 3.6-2) is the same as the rear system except that indexing occurs only when a wafer is accepted. During the rejection cycle, the tray is not indexed to prevent having empty pockets in the trays.

The wafer transfer system (Item 3, Figure 3.6-2) consists of a double transfer needle, a 4-position rotary table, and a wafer rejection area. The transfer needles operate simultaneously: when the back needle is picking up a wafer from the rear track, the front needle is picking up a wafer from the 4-position table, and when the back needle is depositing a wafer in the 4-position table, the front needle is depositing the wafer in the front tray. The 4-position table rotates 90 degrees during each index: At Position 1, wafers are picked up from the rear track; at Position 2, wafers are viewed on the screen; at Position 3, accepted wafers are placed in the front tray, and at Position 4, rejected wafers are blown out of the wafer pockets. The orientation system consists of the 4-way control stick; the motor, clutch and switch assembly (Figure 3.6-3); and the rotating mechanism on the front needle.

The operators duties consist of placing and removing both full and empty wafer tray magazines, operation of all comparator switches, and operating the orientation and rejection controls after focusing, viewing and screening of each wafer.

III Machine Development

Prior to mechanization of this operation, wafers were screened manually using either a 100-power metallurgical microscope with vertical illumination (Figure 3.6-4) or a standard 90-power binocular microscope with side lighting (Figure 3.6-5). The maximum screening rate using these manual set-ups was 750 wafers per hour. Development of this machine closely followed the original Wafer Screening Machine design, later superseded by the Wafer Breaking, Screening and Loading Machine design, under Contract No. DA-36-039-SC-72729. This design included the same type optical system, work table and wafer handling system.

Major differences were the addition of a tray magazine system and an electro-mechanical wafer orientation system. The wafer tray magazine system was adopted to standardize the wafer handling system on all applicable machines under this Contract.

Since the Wafer Loading Machine places wafers into trays with their active element up but in no set orientation, a system had to be devised that would allow the operator of the Wafer Screening Machine to place these wafers back into wafer trays after visual inspection and orientation. Wafer handling had to be done in such a way that a minimum of operator skill was required.

The orientation system was designed such that it had a floating zero position and did not require mechanical resetting after each cycle. The system, will rotate either 0, 90, 180, or 270 degrees in accordance with the position selected, through a 4-position switch and a relay-memory system. It is designed so that the operator need not know what position is being selected; the only requirement being that she position the

4-way switch in accordance with a designated stripe position. The system then positions accepted wafers correctly for the wafer bonders. Rejected wafers are disposed of by means of a separate reject button which prevents the wafer from being picked up by the front needle. Figure 3.6-6 shows the switch positions versus stripe position and the resulting angular rotation of the wafer.

IV Construction and Prove-In

The machine construction was completed on schedule with only minor changes necessary. A control box was mounted on the rear of the comparator to house the relay system for the orientation system as well as the motor and solenoid controls. A spring loaded detent system was added to the front needle assembly to provide positive positioning of the needle in 90 degree increments for accurate orientation.

Mechanical prove-in proceeded with only minor changes necessary in timing and spring pressures. During operational prove-in it was found that two areas needed changing. The original lighting system was inadequate for proper screening of the wafer under 200 power magnification and the wafer reject system proved incapable of consistently putting the rejected wafers into the scrap receptacle.

The lighting system was changed by adding two zirconium arc lamps, one on each side of the objective lens system, to add side lighting to the vertical lighting already on the comparator. After improving the lighting system, all screening defects were readily discernable on the 6-inch-square projected image. Small defects not recognizable using a microscope could be picked out on the large image presented on the comparator.

The wafer rejection system, which in its original form consisted of a vacuum tube over the wafer pocket, proved to be incapable of removing the wafers from the pocket and carrying them to the scrap receptacle. This was remedied by drilling a small hole through the bottom of each pocket, placing a small air jet under the rotary table at the reject position to blow the wafers out, and connecting a copper tube directly to the scrap receptacle after the vacuum system was removed. Any wafer left in the pocket is blown out at the reject station through the tube and into the scrap receptacle. After these changes, prove-in was resumed. During the remainder of prove-in and shop trial, only minor adjustments were required.

Some sticking of the wafers, both in the tray and rotary table pockets, was noted and was found to be caused by a static charge on the wafers. Exposure of the loaded wafer trays to an ultraviolet lamp for 10 to 15 minutes before processing alleviated this problem.

V Shop Trial

Shop trial of the Wafer Screening Machine paralleled shop trial of the Wafer Loading Machine. Material which was loaded on the Wafer Loading Machine was processed over the Wafer Screening Machine. In addition, other trays were hand loaded to test the screening system on codes other than those used on the Wafer Loading Machine.

During a one-week period in which accurate records were kept on all phases of the machine operations, the following percentages were compiled:

Wafer transfer from back tray to rotary table	98%
Wafer transfer from rotary table to front tray	98%
Correct orientation of wafer	99%

During the entire shop trial the machine averaged 95 to 97 percent accuracy in transfer and orientation.

VI Evaluation

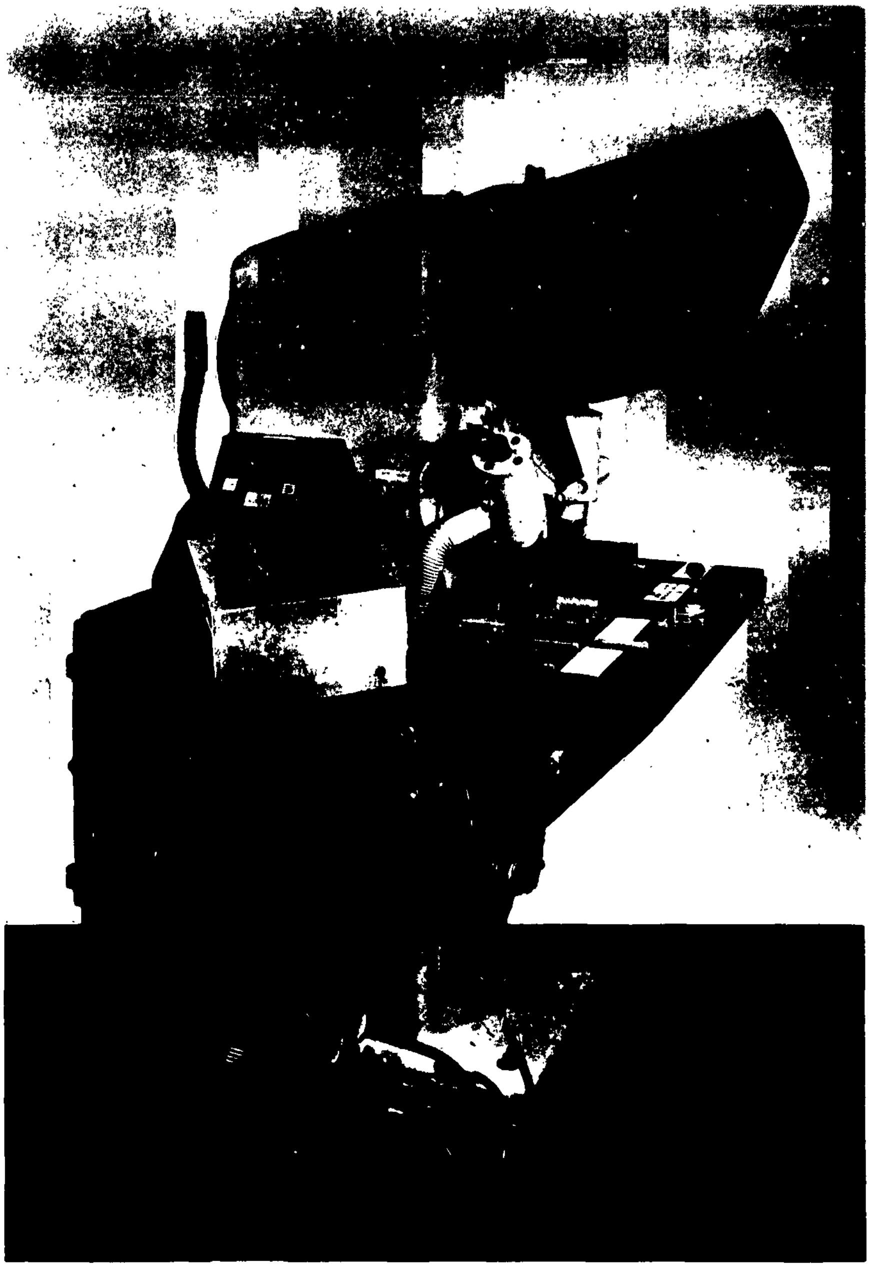
The Wafer Screening Machine performed the screening and orienting of .030-inch wafers satisfactorily and within design specifications. The use of the Wafer Screening Machine substantially reduced wafer damage from manual screening, loading, and orienting thus increasing production yields.

The electro-mechanical orientation system performs in a satisfactory manner but is quite bulky and noisy, since it requires numerous relays for proper operation. The bulk of the relays and system can be greatly reduced through new techniques developed since the construction of the machine. The use of these techniques would improve reliability, reduce the size and noise of the present system, and greatly simplify the electrical system.

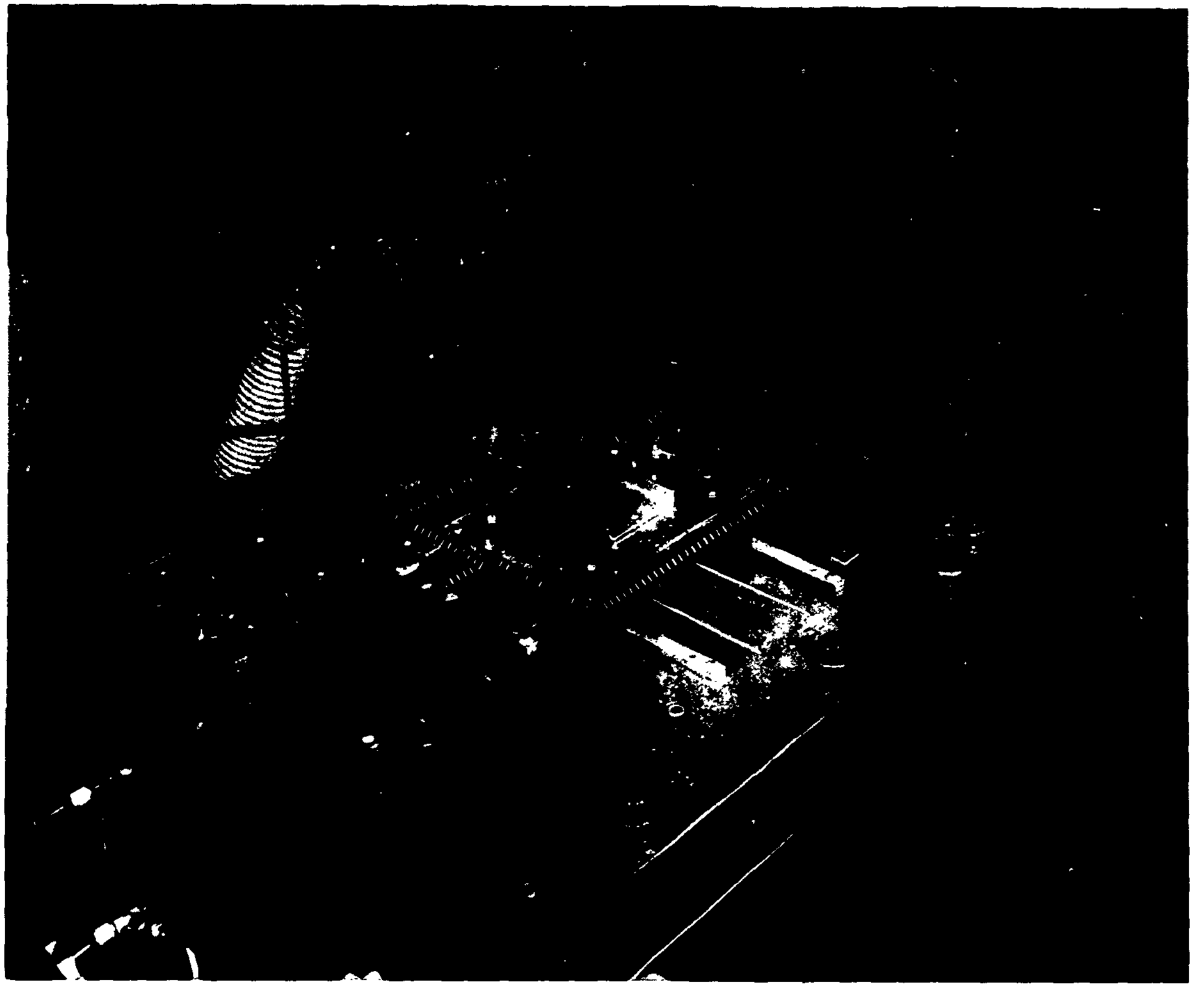
The large viewing area and improved lighting result in greater operator efficiency. Because of the improved working conditions, the operator is less likely to make mistakes either in screening or in loading the wafers into the trays.

VII Conclusion

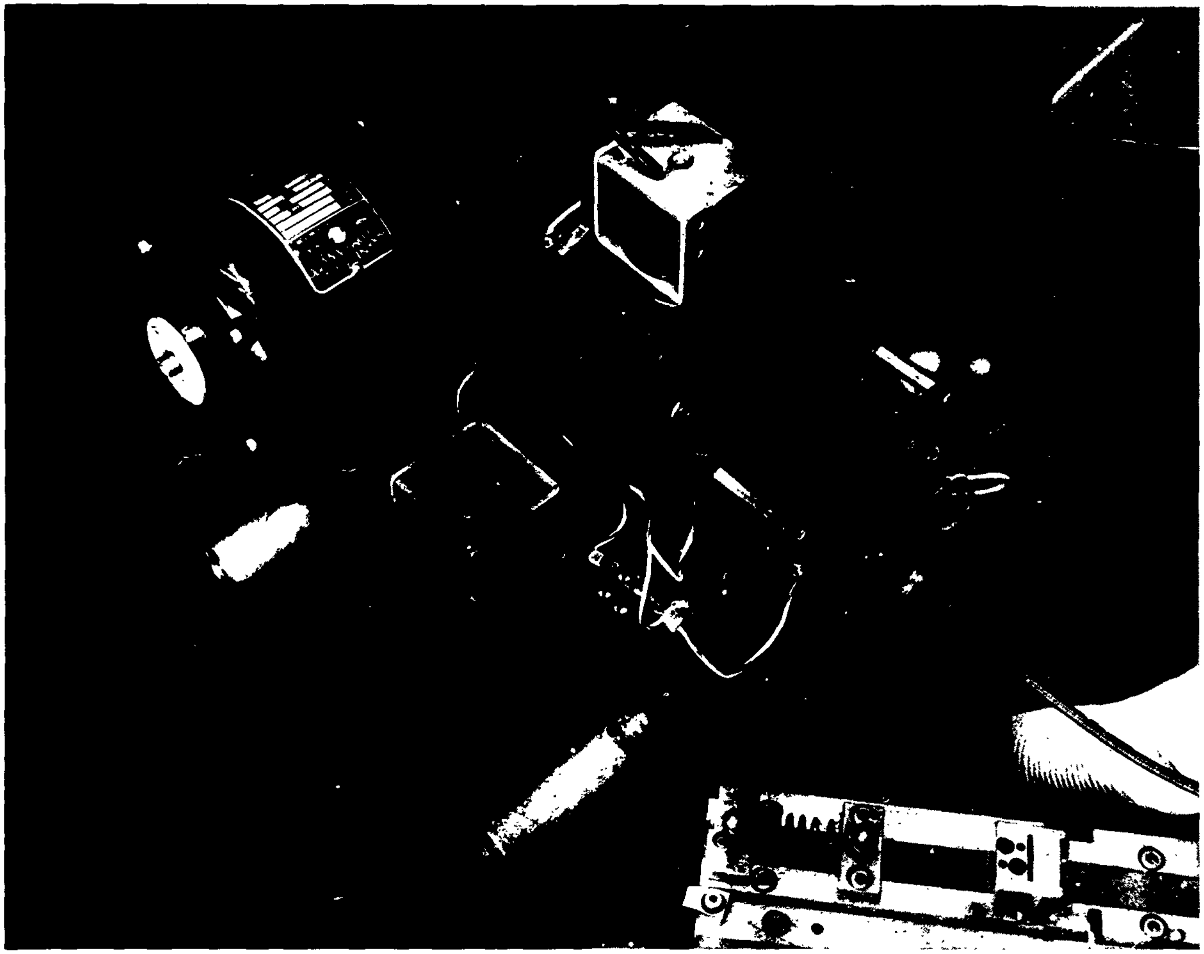
The Wafer Screening Machine has successfully met the design criteria in that it will screen and orient .030-inch-square silicon wafers quicker, easier, and with greatly improved reliability. A recent reduction in wafer size from a .030-inch to a .020-inch square limits the usefulness of the machine. Further studies of wafer handling techniques will be required to determine the changes necessary to handle these wafers in a satisfactory manner. These studies are to be conducted during Phase 2 of the Contract.



WAFER SCREENING MACHINE (2N560-2N1051)
FIGURE 3.6-1



WORK TABLE LAYOUT OF 2N560-2N1051 WAFER SCREENING MACHINE
FIGURE 3.6-2



DRIVE AND SWITCH MECHANISMS FOR ORIENTATION SYSTEM
OF 2N560-2N1051 WAFER SCREENING MACHINE
FIGURE 3.6-3

MANUAL WAFER SCREENING - VERTICAL ILLUMINATION
FIGURE 3.6-4

MANUAL WAFER SCREENING - SIDE ILLUMINATION
FIGURE 3.6-5

WAFER POSITION VERSUS ROTATION

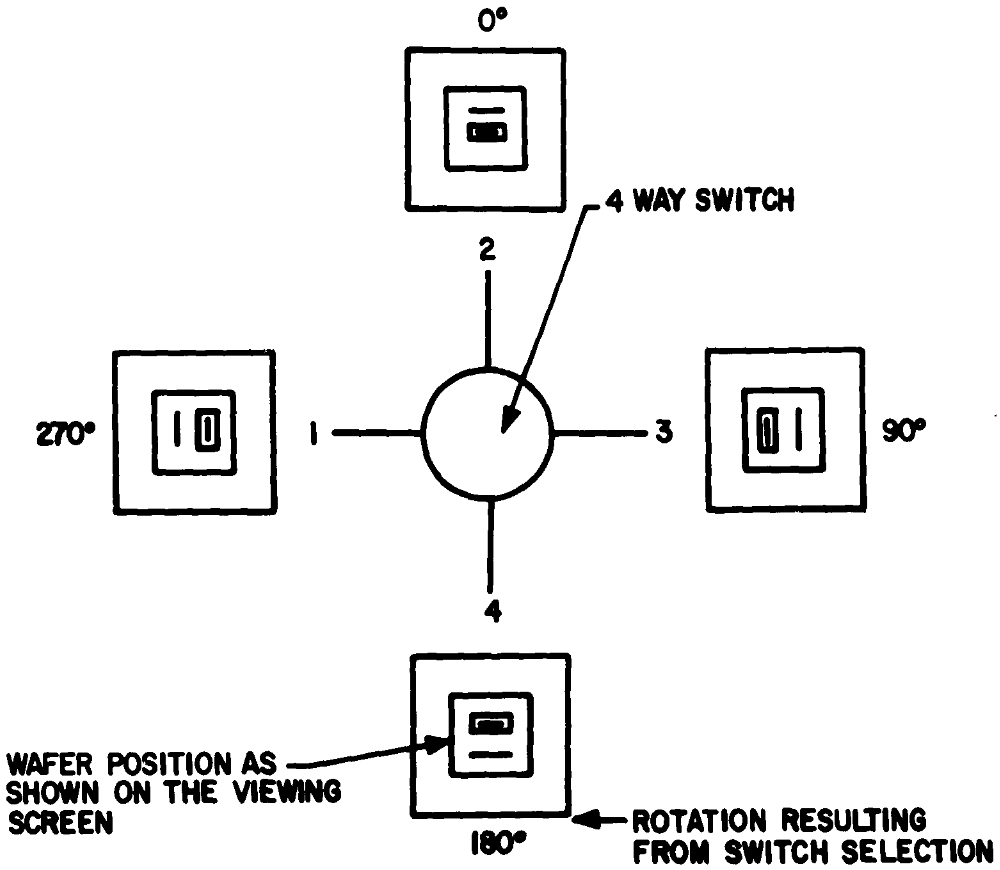


FIGURE 3.6-6

SECTION 3.7

WAFER SCREENING

J. F. Anderson

P. A. Lajoïe

C. H. Weller

WAFER SCREENING

I General

This Wafer Screening development evolved from Wafer Loading and two earlier Wafer Screening developments. It incorporates two wafer handling concepts not included on earlier Wafer Screening Machines: feeding single wafers from a pile and turning wafers stripe-side up. These concepts avert problems and increase efficiency by eliminating separate loading and screening operations as provided for 2N560 and 2N1051 wafers.

The work table of this Wafer Screening Machine is mounted on a comparator base. It feeds wafers from a vibrating bowl, through a stripe sensing station, and then is transferred to a viewing station which projects a 6-inch-square image on a screen by magnifying the wafer 300 times. Inverted wafers are turned stripe-side up after sensing and accepted wafers are oriented for proper stripe orientation during transfer from the viewing station to the standard wafer trays. The machine is designed to process germanium or silicon wafers .020 inch square. The wafers must, however, have sufficient contrast in stripe-to-back reflectivity for photo-optical sensing.

Problems common to mechanized wafer handling and to photo-optical sensing limit the use of the machine. Phase 2 effort will be directed toward refining the machine so that it will ~~be more~~ reliable.

II Description

This Wafer Screening Machine consists of a floor model comparator - Model #3 Shadowgraph - with the adjustable viewing station replaced by a work table containing wafer and tray handling mechanisms (Figures 3.7-1 and 3.7-2). The comparator is equipped with a 300 power lens and a Fresnel viewing screen.

The work table retains the vertical adjustment of the comparator viewing station to facilitate focusing the image on the screen. All mechanical components are included on the work table. They include a small vibrating bowl; two 4-position rotary tables, one for optical sensing and one for inspecting the wafer; a tray indexing mechanism; a magazine for empty trays and another for full trays.

Four vacuum needles transfer wafers from one station to another: One needle transfers wafers from the bowl feeder to the rotary sensing table. Two vacuum needles in the flipping mechanism (Figure 3.7-3) are required to invert and transfer wafers to the inspection table; however, only one of these needles is used when the stripe-side is up. The fourth needle is part of the orienting and tray loading mechanism (Figure 3.7-3).

All motors, drives, and clutches excepting the transmitter drive for the orienting mechanism are housed in the cabinet below the work table. The electrical control cabinet is mounted against the back of the comparator pedestal with the transmitter drive located in the bottom of this cabinet.

Services required for the Wafer Screening Machine are vacuum, nitrogen, and 115 volt power. Estimated weight of the machine is 700 pounds. A 6-foot by 8-foot floor space will provide enough area for seating the operator and servicing electrical components in the control cabinet.

Wafers and wafer trays flow through the machine as diagrammed in Figure 3.7-4. Empty wafer trays are automatically fed from a magazine on the left, mechanically indexed across the back of the work table every time a wafer is loaded, and returned to another magazine on the right.

Wafers in bulk are placed in the vibrating bowl. They are separated and initially oriented as they move out of the bowl, across a short section of straight track, to a pickup station. A vacuum needle then transfers wafers to the front rotary table every time the machine cycles. A wafer on the table then passes through the machine as follows: During the next cycle, the table rotates the wafer under the photoelectric sensing station. A memory circuit stores the side orientation information obtained at this station until the wafer reaches the flipping station after the next cycle.

At the flipping station one of two things happen: (1) A wafer with the stripe-side up is transferred directly from a nest on the front table to another nest on the rear table by a rearward movement of the flipping mechanism, or (2) an inverted wafer is picked up by the same needle, but instead of moving to the rear, the two needle holders of the flipping mechanism rotate 90 degrees in opposite directions until the needles are aligned on the same axis with the wafer between. Switching the vacuum from the pickup needle to the rear needle effect a wafer transfer. After the needle holders return down to the rotary tables, the wafer is deposited stripe-side up in a nest of the rear table.

On the next machine cycle, the rear table carries the wafer under the comparator viewing station. If visual defects are observed, the operator depresses the reject button (Figure 3.7-2) with her left hand. This activates a memory circuit so that the tray loading station is bypassed. Upon reaching the reject station, a vacuum is turned on which draws the wafer into a reject receptacle.

The toggle switch to the right of the reject button in Figure

3.7-2 also permits the operator to setup the memory circuit to orient the wafer. This switch can be placed in four positions - 0, 90, 180, or 270 - according to the number of degrees the wafer must be turned to orient the stripes for the Wafer Bonding operation. After the next machine cycle, accepted wafers are transferred into wafer trays by the orienting and tray loading mechanism. During transit, the orienting mechanism of the tray loading station rotates the wafer according to the information supplied by the operator after screening.

In addition to inspecting the wafers and cycling the machine, the operator supplies wafers and wafer trays to the machine and restores wafer feed if restrictions occur in the vibrating bowl. Periodic cleaning of the bowl will minimize such restrictions. Periodic cleaning of the wafer nests and needles is also required to minimize wafer damage and handling problems. The only machine adjustment required of the operator is the height adjustment of the work table in order to obtain a clear image on the comparator screen. All other adjustments are preset.

To start the machine, the operator depresses the Master switch located along the right hand edge of the work table, turns on the comparator light and blower, and depresses a momentary contact switch to strike the zirconium arc lamp. Cycling is accomplished by depressing the Reject button or by moving the Accept toggle switch to any of its four positions. The machine is designed to process 1800 wafers per hour maximum; the actual output will, however, vary according to the efficiency and thoroughness of the operator.

III Development

Originally, this Wafer Screening Machine was intended to screen 2N1195 germanium wafers which are dimensionally the same as 2N559 and

2N1094 wafers. A Wafer Breaking, Screening and Loading operation was already developed for the 2N559 and 2N1094 wafers under Contract No. DA-36-039-SC-72729. An updated model of the Wafer Breaking, Screening and Loading Machine was started for 2N1195 Wafer Screening. Addition of magazine loading and unloading stations were the only major changes made to the prototype design.

This development was needed not only to increase the output of the screening operation but also to permit rapid and accurate orientation of screened wafers prior to wafer bonding. The manual handling technique and the microscope screening operations illustrated in the previous section were not suited for manual stripe orientation. Even without orienting the stripes, the average output for these operations was only 750 wafers per hour per operator.

During the construction phase of the machine, a prove-in evaluation of the 2N559-2N1094 Wafer Breaking, Screening, and Loading Machine indicated that it was a delicate operation and that high precision was required at the breaking stations. Therefore, construction was halted on this machine until the operation was modified. Development of the 2N560-2N1051 Wafer Loading and Wafer Screening Machines (Sections 3.5 and 3.6) had by this time progressed far enough to influence the redesign. As a result, a single machine capable of processing any .020-inch-square wafer was desired.

In order to develop an improved Wafer Screening operation, photoelectric cells and systems were re-evaluated. Photoelectric sensing systems were considered during initial Wafer Screening developments, but were not then considered practical. Preliminary trials now indicated that with the improved photocells available sufficient contrast in reflectivity existed between the stripe-side and the back of 2N1195 wafers to detect inverted wafers. So, a suitable means of turning over inverted wafers was sought.

This need led to development of a flipping mechanism. It eliminated the possibility of wafer damage from repeated passes through a vibrating bowl as on the Wafer Loading Machines. After these developments proved to be feasible, the partially constructed machine was redesigned to include a wafer feeding system and two orienting systems - one for orienting wafers stripe-side up, the other for orienting stripes prior to wafer loading. The wafer breaking station of the former design was eliminated. Both the flipping mechanism and the photoelectric sensing system were later refined on the 2N1072 Wafer Screening and Electrical Probe Testing Machine, Section 3.15.

The 2N560-2N1051 Wafer Screening Machine has a suitable stripe orienting system; an improved version was, however, developed for this machine. The original system was developed around an electromechanical concept for control and a mechanical concept for action based on the following requirements: (1) a simple 4-position toggle switch to indicate any one of the four possible stripe positions, (2) system isolation to prevent reselection during a machine cycle, (3) elimination of a zero reset on the orienting mechanism, and (4) orientation in accurate 90-degree increments.

In an effort to reduce the physical size of the system used on the 2N560-2N1051 Wafer Screening Machine and to increase system reliability, the approach used on this machine was divided into two parts - the orientation mechanism and the drive mechanism. This was done with a set of synchros which allowed placement of the drive mechanism in the control cabinet. In effect, the flexible shaft which was used to connect the drive to the wafer transfer arm on the 2N560-2N1051 Wafer Screening

Machine was replaced with an electrical equivalent. This Wafer Screening Machine was then outfitted with a receiver synchro on the transfer arm and a transmitter synchro on the orienting drive mechanism. The quarter revolution clutch was reduced in size by employing a new design requiring only one solenoid instead of four.

IV Operation

The completed machine was set up for prove-in and adjustments were made to align various motions involved. Difficulty was encountered setting up and maintaining certain motions due to overcrowded conditions. Precision of various motions was improved, but it was not readily possible to eliminate the overcrowding. During initial prove-in, the power of the original comparator lens was increased from 100 to 300 power. With the new lens, the .020-inch-square wafer was magnified to a 6-inch square on the comparator screen. By substituting a Fresnel screen for the regular ground glass screen, the intensity of the image was increased.

Several operating problems were encountered with the new wafer handling systems. The major one, photoelectric sensing of inverted wafers, has not been resolved satisfactorily. Since evaluating the sensing system for the redesigned machine, the difference in reflectivity of the stripe-side and the back of 2N1195 wafers decreased by a change in the backing of the wafer. This results in some wafers not being processed to the inspection station with the stripe-side up.

A contact problem affected initial reliability of the stripe orienting system. Excessive spring pressure on the rotary switch removed plastic between the contacts and deposited it on the contacts. Erratic operation resulted until the spring pressure was decreased.

Feeding wafers from the vibrating bowl was also erratic initially.

The conventional rheostat furnished with the bowl could not be adjusted to overcome the problem. To correct this condition, an oscillator and amplifier were temporarily connected to the vibratory bowl. A smooth, steady flow of wafers was provided by increasing the vibrating frequency from 60 to 78 cycles per second.

V Evaluation

Prove-in modifications have made all components except the photoelectric sensing system operational. It has not been possible to evaluate the modified Wafer Screening operation completely due to the sensing problem. Therefore, the greatest need at this time is wafers with greater contrast in stripe-side to back reflectivity and/or a more perceptive sensing system to accomodate the change in device design.

Limited operation of the Wafer Screening Machine indicates that other components function as designed. The stripe orienting system has been improved over its prototype on the 2N560-2N1051 Wafer Screening Machine. Larger cams and redesigned linkages would improve the smoothness of operation, and crowded conditions make lubrication difficult in certain areas.

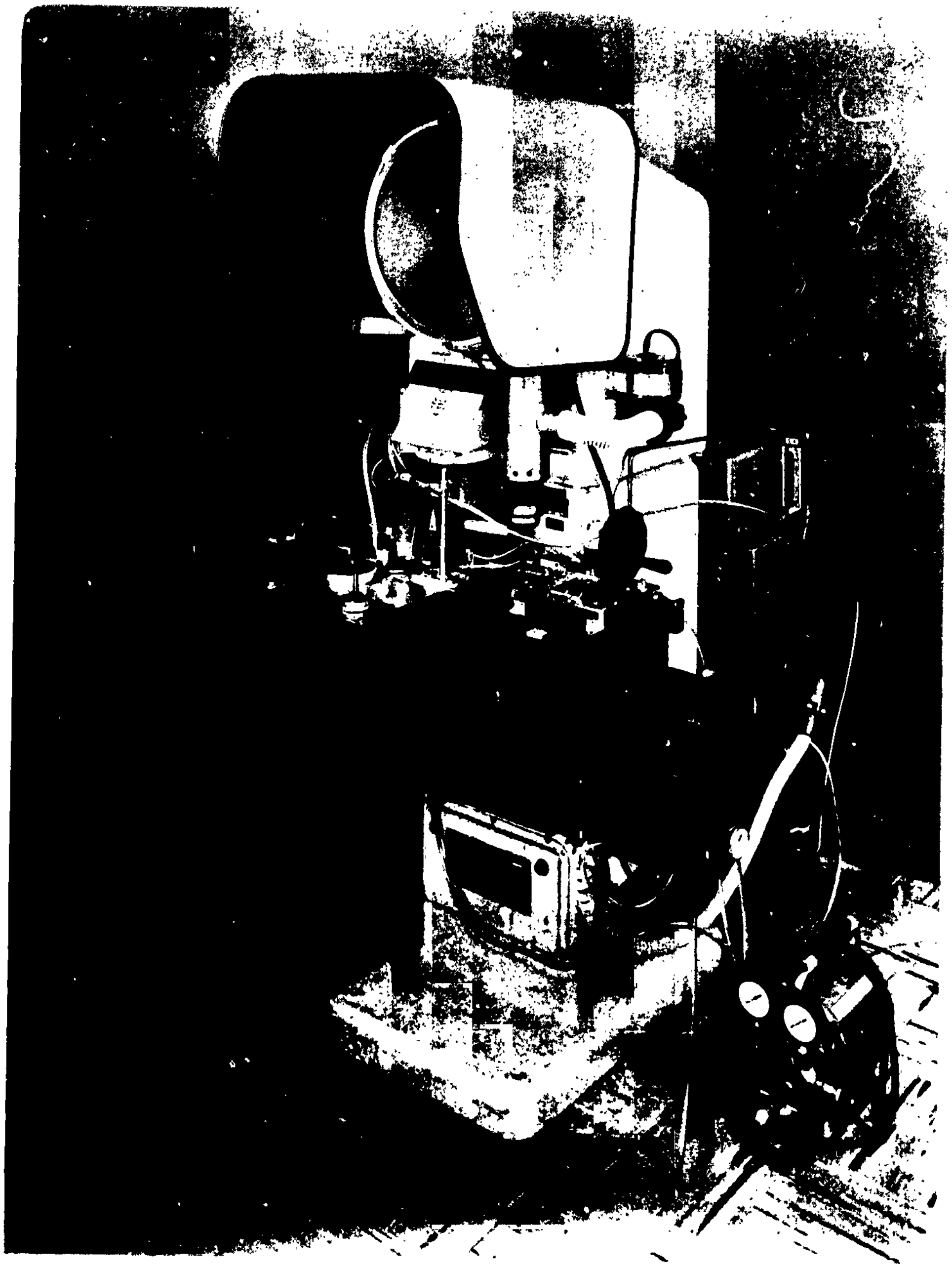
The machine will improve working conditions for the operator not only by eliminating wafer handling but also by eliminating microscope work. The large clear image projected on the screen should result in more thorough and reliable wafer screening. Operating requirements are so simple that an operator can learn them readily.

VI Conclusion

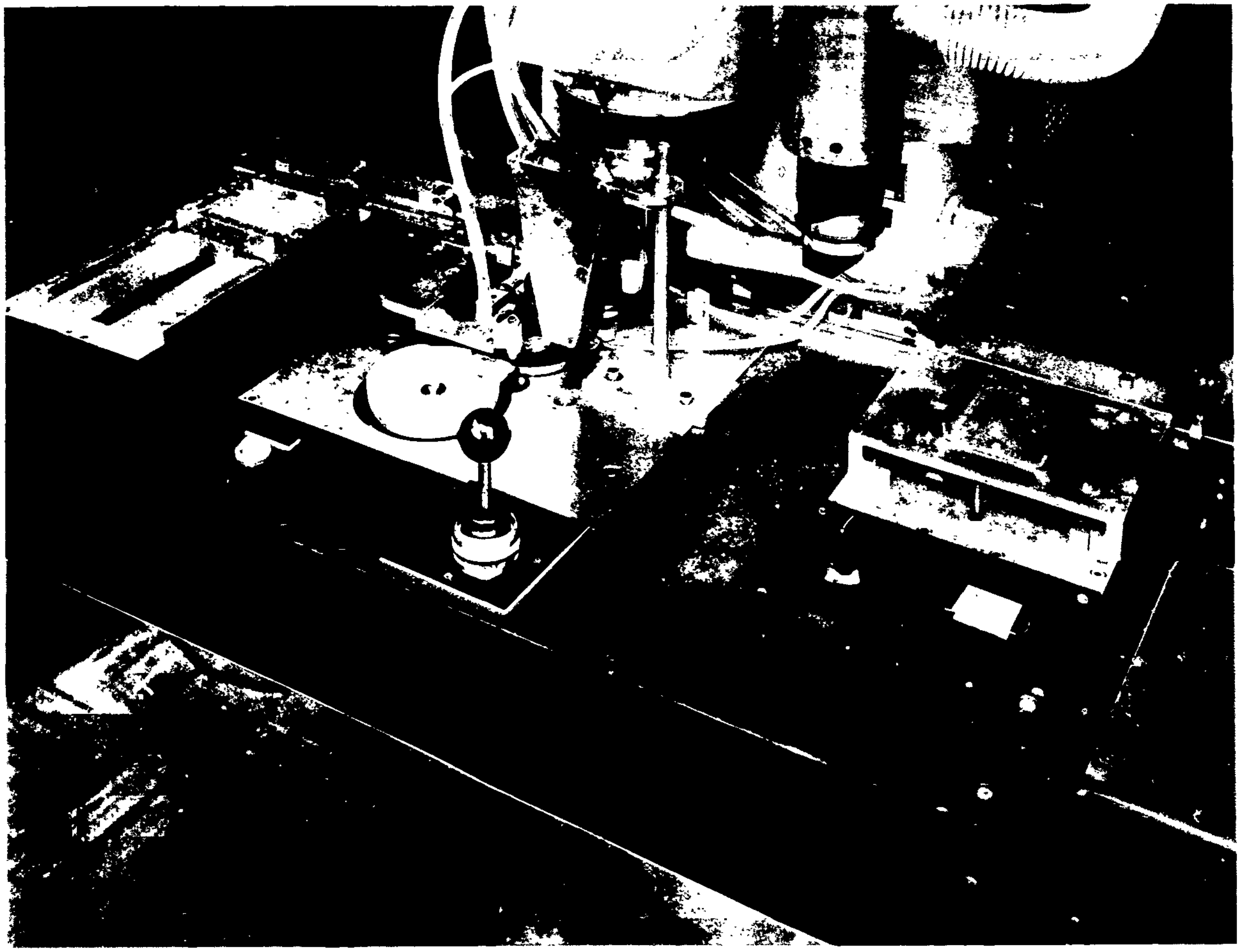
The concepts developed for this Wafer Screening Machine will provide a more versatile operation once the sensing problem is overcome.

It will then process any .020-inch-square wafer having sufficient contrast in reflectivity between the stripe-side and the back. The flipping mechanism will forestall wafer damage through recirculating inverted wafers in a vibrating bowl.

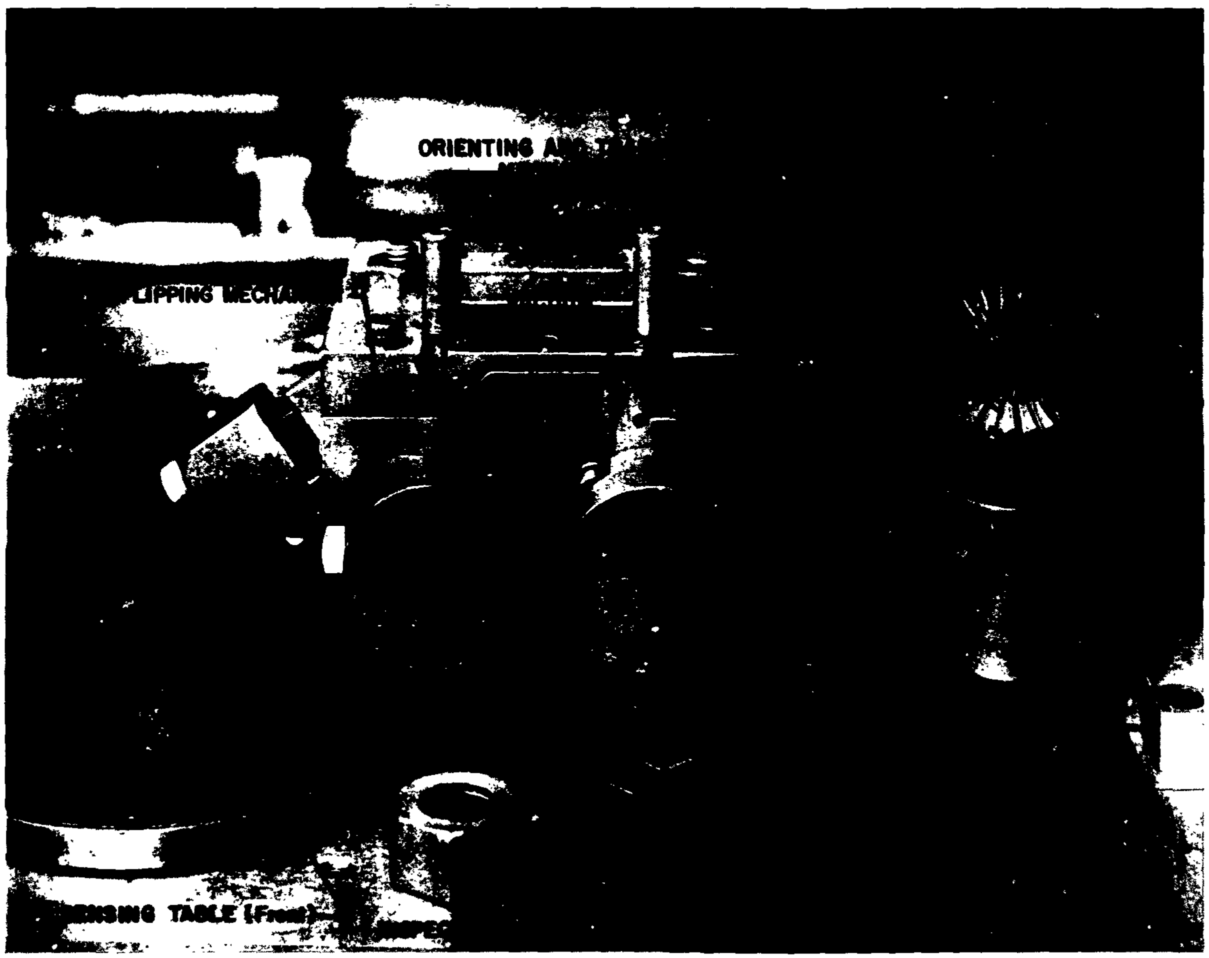
Through redesign of the machine, delicate operations and adjustments were eliminated, and the anticipated output was increased from approximately 700 to 1800 wafers per hour. If this output is realized, the mechanized operation will more than double the manual output without requiring a more skilled operator. Other benefits that will accrue from mechanized Wafer Screening are properly oriented wafers and improved working conditions.



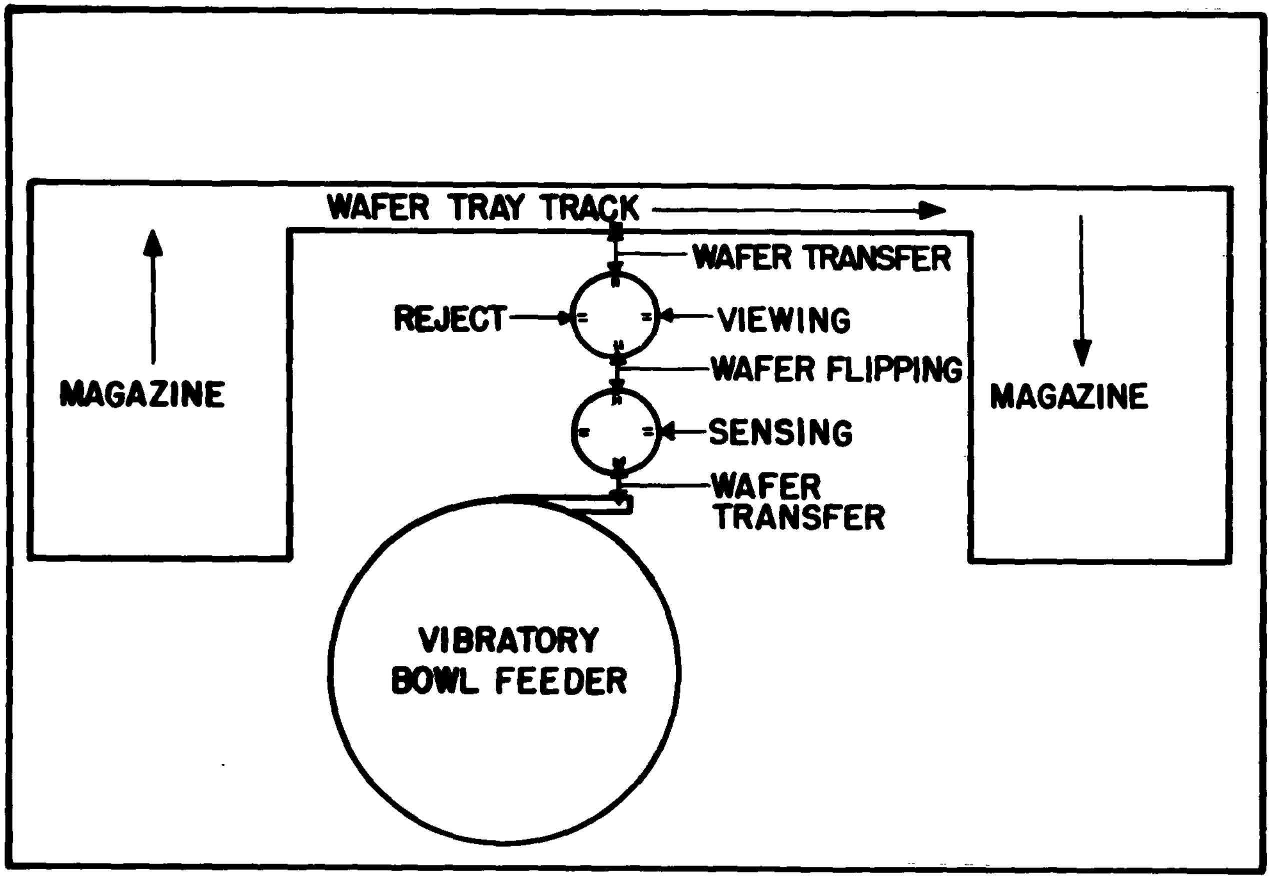
WAFER SCREENING MACHINE
FIGURE 3.7-1



WORK TABLE OF WAFER SCREENING MACHINE
.GURE 3.7-2



FLIPPING AND ORIENTING MECHANISMS OF THE
WAFER SCREENING MACHINE
FIGURE 3.7-3



WAFER SCREENING FLOW DIAGRAM

FIGURE 3.7-4

SECTION 3.8

WAFER TO HEADER BONDING

H. J. Huber

WAFER TO HEADER BONDING

I General

The Wafer to Header Bonding program was initiated to mechanize gold-silicon and gold-germanium eutectic bonding between oriented wafers and gold plated TO-5 headers for the 2N560 and 2N1051 silicon and the 2N1195 germanium transistors. The key objectives of this program were to develop a high output process and to improve the mechanical and electrical yields.

Under this program, two Wafer to Header Bonding Machines were constructed. Although both machines were constructed to the same basic machine concept, there are some differences in the mechanical construction and the electrical controls. As a result of a modification to the Contract, the machines were later modified to also wafer bond the 2N559 and 2N1094 germanium transistors, which use the smaller TO-18 header, in addition to the original transistor codes.

The Wafer to Header Bonding Machines utilize a combination of heat, pressure and high frequency agitation to form a gold-silicon or a gold-germanium eutectic bond. The basic machine is built around a highly accurate rotary index table with supplementary supply stations providing wafers and headers. Magazines containing loaded trays of oriented wafers and oriented headers are supplied to the machine from previous operations.

The purpose of the Wafer to Header Bonding operation is to obtain a strong mechanical bond between a wafer and a header without causing physical or electrical damage to the transistor wafer. Using the original manual wafer bonding method, an operator could produce only 50 to 60 germanium or silicon bonds per hour.

With the Wafer to Header Bonding Machine, a production rate of 900 units per hour was attained. The machine utilizes a resistance heating of the header, which is the passage of electrical current through the metallic header platform, and an ultrasonic scrubbing of the wafer to produce a sound eutectic bond. As over-heating of the wafer during bonding can degrade the electrical characteristics of the device, a major problem of high production wafer bonding was the accurate control of the header temperature for bonding. A satisfactory and controllable heating cycle was provided by controlling the resistance heating with an infrared controller (Section 7.3). The ultrasonic scrubbing, which caused a more intimate contact between the wafer and header surfaces, initiated the eutectic formation at a lower bonding temperature and contributed to the formation of a complete, low resistance wafer to header bond. In addition, mechanization of the wafer bonding process has resulted in a more accurate and repeatable placement of the wafer on the header.

Controlled experiments to compare the mechanized and the manual silicon and germanium wafer bonding processes showed that the mechanized wafer bonding process produced transistor devices with better collector voltage breakdown, collector leakage current and saturation voltage characteristics. On the silicon devices, which are wafer bonded at a higher temperature than the germanium devices, some degradation of the glass-to-metal header seal was noticed on units processed by the Wafer to Header Bonding Machine. This condition, resulting from a high heating rate, was corrected by the introduction of header preheating prior to the bonding station which permitted a more gradual heating rate without decreasing the machine production rate.

In summary, the Wafer to Header Bonding Machine - which provides a combination of lower bonding temperature, shorter time at temperature, accurate and repeatable wafer positioning, and complete low resistance wafer bonds - has demonstrated a reliable, high production capability for the manufacture of transistor devices having improved electrical characteristics.

As part of the future refinements of the Wafer to Header Bonding Machine, further studies will be conducted on the thermodynamic properties of the headers and on improved techniques for temperature measurement and control.

II Description of the Machine

In order to meet the wafer to header bonding requirements of this Contract, two Wafer to Header Bonding Machines were constructed. Both machines were designed about the same basic bonding process and mechanical principles; however, the electrical control systems vary slightly. The first machine (Figure 3.8-1) was originally designed to process 2N560-2N1051 subassemblies and the second machine (Figure 3.8-2) was designed to process 2N1195 and 2N560-2N1051 subassemblies. These two machines will be referred to in this report as Machines A and B, respectively.

As originally constructed, both machines wafer bonded only transistor codes which were assembled on the TO-5 header. As a requirement of subsequent contract modifications, both machines were modified to provide manufacturing capability for the 2N559 and 2N1094 transistors, which require the bonding of a germanium wafer to a TO-18 header, in addition to the 2N560, 2N1051 and 2N1195 transistor capability.

For this report, the basic machine description and cycle will be presented for Machine A with the variations of Machine B indicated where applicable. In general, oriented headers and wafers are mechanically loaded into the machines with the wafer placed on the header. By the application of heat, pressure and mechanical agitation, a gold-silicon or gold-germanium eutectic wafer bond is formed. The wafer bonded header assemblies are then mechanically unloaded from the machine.

The Wafer to Header Bonding Machine is an intermittent rotary machine having eight bonding head assemblies on the rotary table and three common stations for header loading, wafer loading and wafer bonded header unloading. Referring to the Plan Diagram of the Wafer to Header Bonding Machine (Figure 3.8-3) the sequence of operation for the counter-clockwise rotation of the machine is as follows:

Station #1 - Header Loading - Oriented headers are transferred from header trays and loaded into the bonding nests of the bonding head assemblies.

Station #2 - Wafer Loading - Oriented wafers are transferred from the wafer tray by the vacuum pickup needle of the bonding head assembly and the headers are clamped by the heating electrodes.

Station #3 - Header Preheat - The wafers are placed and held on the headers and header preheating is started by the passage of electric current through the header platform.

Station #4 - Wafer Bonding - The wafer to header gold-silicon or gold-germanium eutectic bond is formed as ultrasonic energy is applied to the wafer through the pickup needle after the header has been heated to and controlled at the bonding temperature. An infrared controller, which detects the infrared emission from the header, varies the electric current passing through the header platform to maintain the header at the bonding temperature.

Stations #5, #6 and #7 - Spare

Station #8 - Wafer Bonded Header Unloading - The wafer bonded headers are transferred from the bonding nests and reloaded into header trays.

The Wafer to Header Bonding Machine was designed and constructed about a highly accurate 8-position index table. An indexing accuracy of ±0.0002 inch at an 18-inch diameter was selected to meet the precise wafer placement requirement which was initially imposed by the mechanized Wire Bonding operation. The index table, belt driven by a variable speed motor pulley drive, operates on a fixed indexing to dwell time ratio. Power take-offs from the table drive provide the actuation for the auxiliary equipment at wafer loading and header loading and unloading. The balance of the machine cycle is sequenced during the table indexing by a system of adjustable cams and switches which are mounted in the control tower located in the center of the rotary table and by a stationary barrel cam which controls the motions of the bonding head assemblies.

Machine B differs from Machine A in that the index table, having a direct motor clutch-brake drive, operates on a constant indexing cycle with a variable dwell cycle. In addition, Machine B has a variable speed cam programmer which controls the complete machine cycle, including the table indexing, and drives all auxiliary equipment.

The eight bonding head assemblies, which are mounted on the index table, are complete individual bonding tools consisting of a wafer pickup needle, ultrasonic transducer and header heating or bonding electrodes. Each bonding head assembly is independently programmed as the index table rotates; mechanical motions are cam operated, and adjustable cams and switches control the header heating and ultrasonic application.

At the Header Loading Station, a transfer arm removes oriented headers from header trays and loads them into the ceramic nests of the bonding head assemblies. (For more versatile use of the machine, header loading may also be done manually.) During the indexing to the Wafer Loading Station, the headers are clamped in position by the bonding electrodes in preparation for wafer placement and header heating.

During the dwell at the Wafer Loading Station, oriented wafers are transferred from wafer trays to the bonding head assembly by the vacuum pickup action of the wafer needle. During the indexing to the Header Preheat Station, the wafer needle is lowered until the wafer is placed on the header. The wafer is held in position on the header by mechanical pressure of the wafer needle after the vacuum is removed.

Header heating is initiated at the Header Preheat Station by the passage of a low voltage, high amperage electric current through the header platform between the two bonding electrodes holding the header and is continued during the indexing to the Wafer Bonding Station. Individual step-down transformers, which are part of each bonding head assembly, supply the low voltage, high amperage current from a common power source.

At the Wafer Bonding Station, header heating is continued with a higher voltage current. Header temperature is controlled to a preset bonding temperature by a non-contacting infrared controller which detects the infrared emission from the header and varies the electric current passing to the header platform to maintain the bonding temperature. At the end of the bonding cycle, an ultrasonic pulse, which is applied to the wafer by the wafer needle for about a 1/2-second duration, provides the mechanical agitation for initiating and/or completing a 100 percent eutectic bond between the wafer and the header. The ultrasonic energy is supplied from a common 10-watt ultrasonic generator to the individual transducer-probe assembly which is part of each bonding head assembly. The wafer needle is part of this transducer-probe assembly being rigidly mounted in the end of the probe. For uniform ultrasonic energy to the wafer at each bonding head assembly, the individual transducer-probe assemblies were matched with the ultrasonic generator for balanced impedance.

After the Wafer Bonding Station, the bonding head assembly is indexed past the three spare stations. During the index between the first and second spare station, the wafer needle is raised. The header is then unclamped as the bonding electrodes are cammed apart during the index into the Wafer Bonded Header Unloading Station. At this Unload Station, the headers are removed from the nest of the bonding head assembly by a transfer arm and reloaded, with the header orientation retained, into the header trays, thus completing the machine operation.

The top of the machine is completely protected by a transparent cover which protects the transistor components from external contamination during the wafer bonding process. Access openings are provided in the cover so that the operator can supply headers and wafers to and can remove completed wafer bonded units from the machine.

III Machine Development

One of the most critical operations in the assembly of transistors is the bonding of the wafer to the transistor header. For both silicon and germanium devices, the manual wafer bonding operations, which were used to form the gold-silicon or gold-germanium eutectic bond between the wafer and header, were relatively slow and not necessarily repeatable.

In this manual operation, the wafer was manually placed and held on the header, which had been previously loaded and clamped on a heater strip, by a vacuum pickup needle or by tweezers and an auxiliary wafer hold-down. The heating cycle, which was established experimentally, was initiated by the passage of electric current through the heater strip. The header was heated by conduction from the heater strip until the header, at the wafer location, reached the bonding temperature for the formation of the eutectic bond. For the silicon devices, the operator mechanically scrubbed the wafer on the header to initiate the formation of the eutectic bond and to attain a complete bond. The heating cycle was terminated either by a preset timer or by the operator upon completion of the wafer bond. The wafer bonded header was then manually unloaded. The production rate for the manual wafer bonding tools was 50 to 60 units per hour.

Variations in temperature from header to header were experienced with these bonding tools due to inconsistent heating conditions, such as non-uniform thermal contact between the headers and the heater strip. As a result, although the wafers were bonded to the headers, a controlled and repeatable bonding operation was not attained.

At the start of the program for mechanizing the Wafer to Header Bonding operation, the machine development was supplemented by studies of various wafer bonding cycles in order to overcome the low production and the non-repetitive limitations of the manual bonding processes.

For this Contract, the initial effort was concentrated on mechanizing the wafer bonding of the 2N560 and 2N1051 silicon transistors as the formation of a gold-silicon eutectic bond presented more problems than the corresponding germanium bond. In parallel to the development effort of the Western Electric Company, a feasibility study was performed by a subcontractor, Designers for Industry, Inc., to establish an engineering approach for a wafer to header bonding machine for the 2N560 and 2N1051 silicon transistors. This study basically proposed an in-line machine, radio frequency induction heating of the header with automatic temperature indication but with manual temperature control, automatic wafer transfer and orientation, and a rotary mechanical wafer scrubber.

As part of the development effort by the Western Electric Company, the feasibility studies and machines for wafer bonding the 2N537 and 2N559 germanium transistors, which resulted from PEM Contract DA-36-039-SC-72729, were reviewed for possible adaptation of techniques and mechanisms. The results of this review and of other feasibility studies conducted by the Western Electric Company introduced the following items which were incorporated into the initial design of the Wafer Bonding Machine:

1. Rotary index table.
2. Resistance heating of the header, i. e., heating the heade. ' .he passage of electrical current through the metallic heaaei platform.
3. Infrared heating of the header.
4. Infrared temperature sensing for controlling the header temperature.
5. Ultrasonic vibration of wafer or header to provide the scrubbing action.

The selection of an accurate rotary type index table for use in the Wafer to Header Bonding Machine was made in order to meet the requirement of a precise wafer placement on the header. This requirement was initially imposed by the mechanized Wire Bonding operation which specified the location of the wafer stripes relative to the internal lead posts of the header within an extremely small tolerance. As a result, the specification for an 8-position index table included an indexing accuracy of

±0.0002 inch at an 18 inch diameter.

At the start of the machine design, two methods for heating the header remained under consideration with both heating methods using the infrared temperature sensing method for controlling the header temperature. These alternate methods for heating the header were (1) infrared heating and (2) resistance heating.

During the concurrent development of header heating and header temperature control, the studies demonstrated that the header temperature could be controlled for wafer bonding by sensing the infrared emission from the header platform and then using this signal to control the electrical power input of the header heating source. The development of this infrared temperature controller is presented in Section 7.3 of this report.

The application of infrared heating to the top of the header platform was precluded by the use of the infrared temperature controller. As the infrared temperature controller sensed the infrared emission from this surface for controlling the header temperature, the presence of the infrared heating source for heating the top surface would interfere with the operation of the temperature controller. This interference would result from both the reflected infrared radiation from the header and the stray direct radiation from the heating source.

As a result, the infrared heating source was placed beneath the header and focused at the underside of the header platform. The advantages of this method of infrared heating were that the header was heated without being physically contacted by the heating source and that the thermal stress in the glass-to-metal seal was minimized as the header glass was independently but simultaneously heated along with the header platform. However, two disadvantages of this infrared heating method made it impractical for use in the Wafer to Header Bonding Machines. One disadvantage was the relatively short life of the available heating sources. The second disadvantage was the presence of stray radiation which caused erratic temperature control by introducing errors into the infrared sensing.

With the elimination of infrared heating, the Wafer to Header Bonding Machine was designed for a resistance heating of the headers by the passage of a low voltage high amperage electric current through the header platform. Provision was made for varying this electric current by means of the infrared temperature controller so that the header heating could be controlled within an acceptable temperature range. The machine design also incorporated the material handling equipment - magnetic header trays and magazines and wafer trays and magazines - which was developed as an overall mechanization project for the Contract and is presented in Section 2 of this report. Vacuum pickup and transfer systems were adapted for loading and unloading the wafer and headers at the machine. To provide the mechanical scrubbing of the wafer for the eutectic bond formation, an ultrasonic transducer-probe assembly was designed for applying ultrasonic energy to the side of the wafer pickup needle.

After the completion of the initial machine concept, a prototype bonding head assembly (Figure 3.8-4) was constructed in order to completely evaluate the design concepts and to continue the development studies on the wafer bonding cycle.

The initial development studies with the prototype bonding head assembly definitely established the feasibility of modifying the existing manual wafer bonding process to overcome the low production and non-repeatable limitations of this process. The proposed process changes for mechanizing this operation consisted of the more rapid resistance heating of the header, a lower and more controllable header bonding temperature, and an ultrasonic scrubbing of the wafer.

During the development of the resistance heating of the header, the original method clamped the header with a pair of "Elkonite" electrodes at diametric points on the top of the header platforms and passed a low voltage, high amperage electric current across the header between the electrodes. Satisfactory header clamping and heating were obtained but modifications to this method resulted from the introduction of different sized headers and from continued investigations on electrode materials. In the final arrangement, the headers are diametrically clamped on the outside body diameter of the header platform by a pair of "Gibsaloy" electrodes. The "Gibsaloy" material, a silver-nickel alloy, provided an optimum combination of low contact resistance at the header and acceptable electrode life under the conditions imposed by the low voltage, high amperage current.

With the resistance heating, headers were heated to a platform temperature of 400°C to 450°C in as little as 2 seconds with no observable degradation of the header glass or the glass-to-metal seal. However, as a heating cycle of this short duration is not required for meeting the production requirements of this machine because of preheat provisions and as variable glass and glass-to-metal seal conditions can be expected in header manufacturing, a header heating cycle of 6 to 8 seconds was established for the machine for reduced thermal stressing of the header.

An infrared temperature controller was developed which was capable of controlling the resistance heating of the header within a 10°C range at the header bonding temperature. This controller operates on the principle of sensing the infrared emission from the header platform with a detector cell, amplifying the detector signal and controlling the resistance heating power input by the difference between the detector signal and a preset reference. As this method of temperature control is dependent on the emissivity of the gold plated header platform, the controller reference must be reset to account for any variations in the emissivity of the gold plate between header lots in order to control at the same header temperature. As previously noted, the development of the infrared temperature controller is discussed in Section 7.3 of this report.

The last major area of development on this project was the application of ultrasonic energy for mechanically scrubbing the wafer relative to the header platform. As insufficient technical information was available concerning either the equipment or the techniques for this particular application of ultrasonic energy, numerous experiments were conducted to establish the state of the art. During these experiments, it was determined that the original design concept of placing the ultrasonic probe against the side of the needle, which held the wafer against the header, was not a suitable arrangement for the transmission of ultrasonic energy. Modification of this concept resulted in a bonding tool having the wafer needle rigidly mounted in the end of the probe of the ultrasonic output transducer-probe assembly. Analytical and experimental development of the probe configuration was required for amplification of the ultrasonic energy and for location of the wafer needle at an anti-node point. With this modified bonding tool, a controllable and repeatable application of ultrasonic energy to the wafer was attained. The wafer bonding experiments also demonstrated that the intimate wafer to header contact, provided by the ultrasonic scrubbing action during the latter part of the heating cycle, resulted in the formation of complete eutectic wafer bonds at a lower header temperature than that required by the manual Wafer Bonding operation.

In order to evaluate the mechanized ultrasonic wafer bonding, two controlled experiments were conducted; one with the 2N560 silicon transistor and one with the 2N1195 germanium transistor. These experiments compared the mechanized ultrasonic and the manual bonding operations in the areas of wafer placement, header heating, temperature control, mechanical yield and electrical yield.

For the 2N560 silicon transistor experiment, the following wafer bonding cycles were used:

1. Mechanized Ultrasonic Bonding

   A 6-second preheating of the header to 300°C was followed by a 3-1/2-second infrared temperature controlled heating to and at 400°C. Ultrasonic energy was applied to the wafer for 1 second after 2 seconds of controlled header heating. A bonding force of 60 grams held the wafer on the header.

2. Manual Bonding

   The header was gradually heated to 425°C in approximately 45 to 60 seconds by conduction from a heater strip. The wafer was manually scrubbed at the end of the heating cycle until a eutectic bond was completed. A bonding force of 65 grams held the wafer on the header.

Fifty transistor devices were processed by each bonding method. The mechanical and electrical yields of both groups of devices were essentially the same. On the basis of these experimental results, it was concluded that the mechanized ultrasonic wafer bonding method could produce wafer bonds which were comparable to those of the manual wafer bonding in approximately one-fifth of the cycle time and at a 25°C or 6 percent lower bonding temperature.

For the 2N1195 germanium transistor experiment, the following wafer bonding cycles were used:

1. Mechanized Ultrasonic Bonding

   The header was heated to temperature in approximately 4 seconds at which time the ultrasonic energy was applied to the wafer for 1/2 second. The header temperature was below that required for a eutectic bond formation under the static conditions of manual wafer bonding but a thermal lag, due to the rapid heating rate, probably introduces some error in the header temperature of 330°C which was measured by a thermocouple. A maximum bonding force of 15 grams was used to hold the wafer on the header.

2. Manual Bonding

   The header was heated to approximately 375°C in about 20 seconds at which time the gold-germanium eutectic wafer bond formed automatically under the static condition of a 15 gram maximum bonding force which was used to hold the wafer on the header.

One hundred devices were processed by each bonding method for this experiment. The devices processed by the mechanized ultrasonic bonding showed substantially higher electrical yields than those of the manually bonded control group. Definite improvements were noted in specific electrical characteristics of the ultrasonically bonded devices, such as higher collector breakdown voltages, lower collector leakage currents and lower saturation voltages. Improvement of these transistor parameters is indicative of reduced base stripe alloying due to lower wafer temperatures at bonding and of a lower resistance wafer bond due to an effective and intimate contact between the wafer and the header platform.

In summary, the machine development program has resulted in a high volume production Wafer to Header Bonding Machine. The machine is capable of a highly reproducible operation and produces transistor devices having improved mechanical and electrical characteristics.

IV Operational Problems

Most of the process problems in the prove-in phase of the Wafer to Header Bonding Machines were associated with the first machine. One of the initial prove-in problems was the controlling of header heating. This problem resulted from an imcompatible arrangement of the machine and the infrared temperature controller which senses and controls the header temperature. The interim solution to this problem was the use of straight variac bonding during the machine prove-in and the initial shop trials. By means of a variac on the input side of the step-down transformers, which supply the low voltage, high amperage header heating current, the input voltage can be manually adjusted to produce different header heating cycles; that is, a different heating rate and equilibrium header temperature combination for each variac setting. With straight variac bonding, the resistance heating of the header is not specifically controlled as the header temperature is dependent on the preset heating cycle. Under these conditions, the eutectic wafer bond is formed during the temperature rise part of the heating cycle. Although the bond formation is completed and the header heating is terminated before the equilibrium header temperature is reached, this method of heating, which is not specifically controlled, subjects the header to higher temperatures than those required by the bonding cycle with the infrared temperature controller. After refinement of the infrared temperature controller and the machine arrangement, the controller was installed on the Wafer to

Header Bonding Machine and used to control the header temperatures during the final shop trials and the production operation.

Another major problem encountered during prove-in was the non-availability of tip welded headers. The initial mechanized header handling system had been designed for the use of tip welded leads and would not perform satisfactorily without them. This difficulty lead to the temporary removal of the header supply system and the introduction of manual header loading. This action was taken so that shop trials could be completed. In the development of Machine B, a side-entry bonding nest was developed in order to enable the machine to handle non-tip welded headers. This design modification has proven to be satisfactory.

It is anticipated that this system will be incorporated in Machine A as part of the Phase 2 machine refinement.

During the initial shop trials, very few problems were encountered in operator training. Some operator inconvenience did result with the changeover to manual header loading during the shop trial as the machine had not been primarily designed for manual loading. However, even with this operator inconvenience, no difficulty was experienced with manual header loading in attaining and maintaining a machine production rate of 900 units per hour.

Another significant phase of the machine prove-in was the mechanical alignment of the bonding head assemblies. This alignment was very critical as a satisfactory wafer bonded header was the direct result of precise locating and positioning of the component parts. The specific criteria, which had to be satisfied, are discussed below:

1. At the wafer loading station, precise alignment of the wafer pickup needle and the multipocketed wafer trays was required so that the wafer would be picked up

symmetrically by the wafer needle.

2. The header nest location had to be referenced to the wafer needle to obtain the proper wafer placement on the header.

3. The heating electrodes had to be adjusted so that the clamping action on the header did not disturb the position of the header in the nest.

4. Parallelism of the header nest and the wafer needle end surface must be maintained so that the wafer is placed flat on the header. The wafer-header flatness is a requirement for making a complete eutectic bond without damaging the wafer by chipping or by smearing the evaporated stripes.

Special machine setup gauges and procedures were developed to fulfill the preceding alignment criteria. Although the alignment procedure was complex and required numerous remeasurements and readjustments, machine realignment was not generally necessary for at least five hundred thousand machine cycles.

A header positioning problem developed as the result of wearing and burning in the original header nest material. To withstand the operational temperatures of approximately 300°C, the header nest material was changed to a molded ceramic. Header positioning was satisfactorily retained as these nests could be fabricated with a 0.002-inch tolerance on both the locating slot and counterbore.

During shop trial, approximately 10 percent of the wafer bonded units were rejected for mechanical defects. These defects consisted of broken or chipped wafers and smeared wafer stripes. The causes for these defects were the alignment problems associated with the bonding head assemblies and the square pocketed tips of the wafer needles. The square pocketed tips, provided to hold the wafers captive, required accuracy requirements at wafer loading which exceeded the criteria previously established for the alignment of the bonding head assemblies. This problem was overcome by the development of a flat-tipped needle which provided satisfactory handling of the wafers. As a result of the flat-tipped needle and of the accurate alignment of the bonding head assemblies, the rejection rate for mechanically damaged wafers was reduced to approximately 1 percent.

Variations in the gold plate on the headers and variations in the alloying on the back (collector) side of the wafers contributed to some erractic wafer bonding during the initial production trials. The effect of these variations could not be fully evaluated until the mechanical alignment problem of the bonding head assemblies was resolved. After the establishment of the mechanical alignment criteria, the effects of the variations in the gold plate and in the alloyed wafer material were identified. It was then possible, by optimizing both the header heat control and the ultrasonic application, to minimize the effects of the plating and wafer variations and substantially reduce the erratic performance of the mechanized wafer bonding process. As effective mechanization is dependent on the uniformity of component parts, further improvements for a repeatable bonding process were accomplished by operational changes in the header manufacturing for more uniform headers.

Based on the machine modifications, the mechanical alignment procedures and the operational techniques which were developed during the prove-in, shop trial and production trial of the first machine, prove-in of the second Wafer to Header Bonding Machine was accomplished with only minor difficulties.

V Conclusion

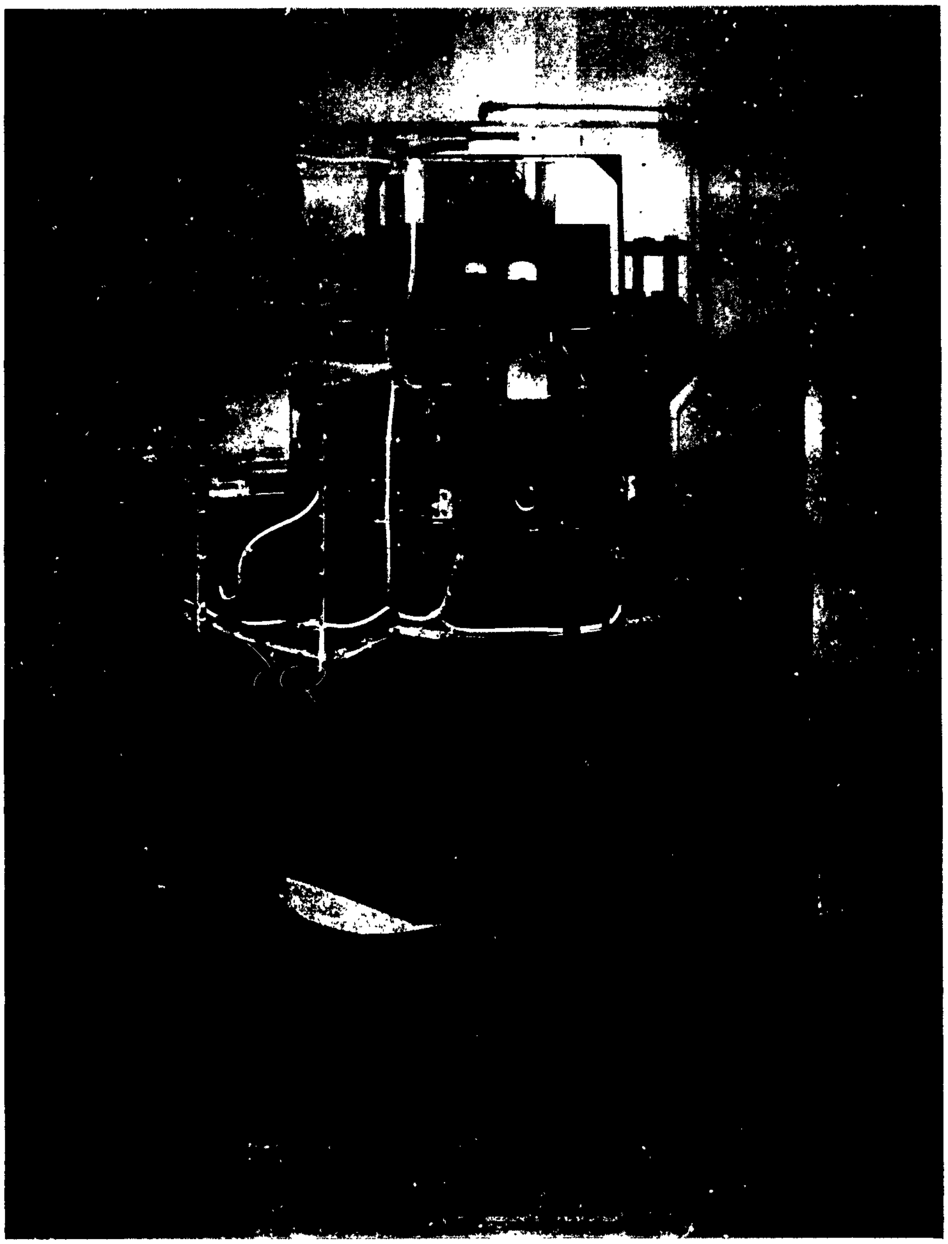
The production performance of the Wafer to Header Bonding Machines has demonstrated the development of a high volume, repeatable wafer bonding process and operation. The production of the various transistor codes, which can be processed on this machine, has averaged a mechanical yield of 95 percent with a sizeable amount of the defective product resulting from the non-uniformity of the component parts. The loss of this latter production potential has been more than offset by the increased production rates and by the improved electrical yields of the completed devices.

The construction of the Wafer to Header Bonding Machines to close tolerances about highly accurate index tables has resulted in machines of excellent stability even after the somewhat complex alignment and set-up procedures. Furthermore, the electro-mechanical systems of the machines have required a minimum amount of maintenance. The machine stability and the electro-mechanical reliability have been demonstrated by extended periods of continuous production, including some 3-shift operation.

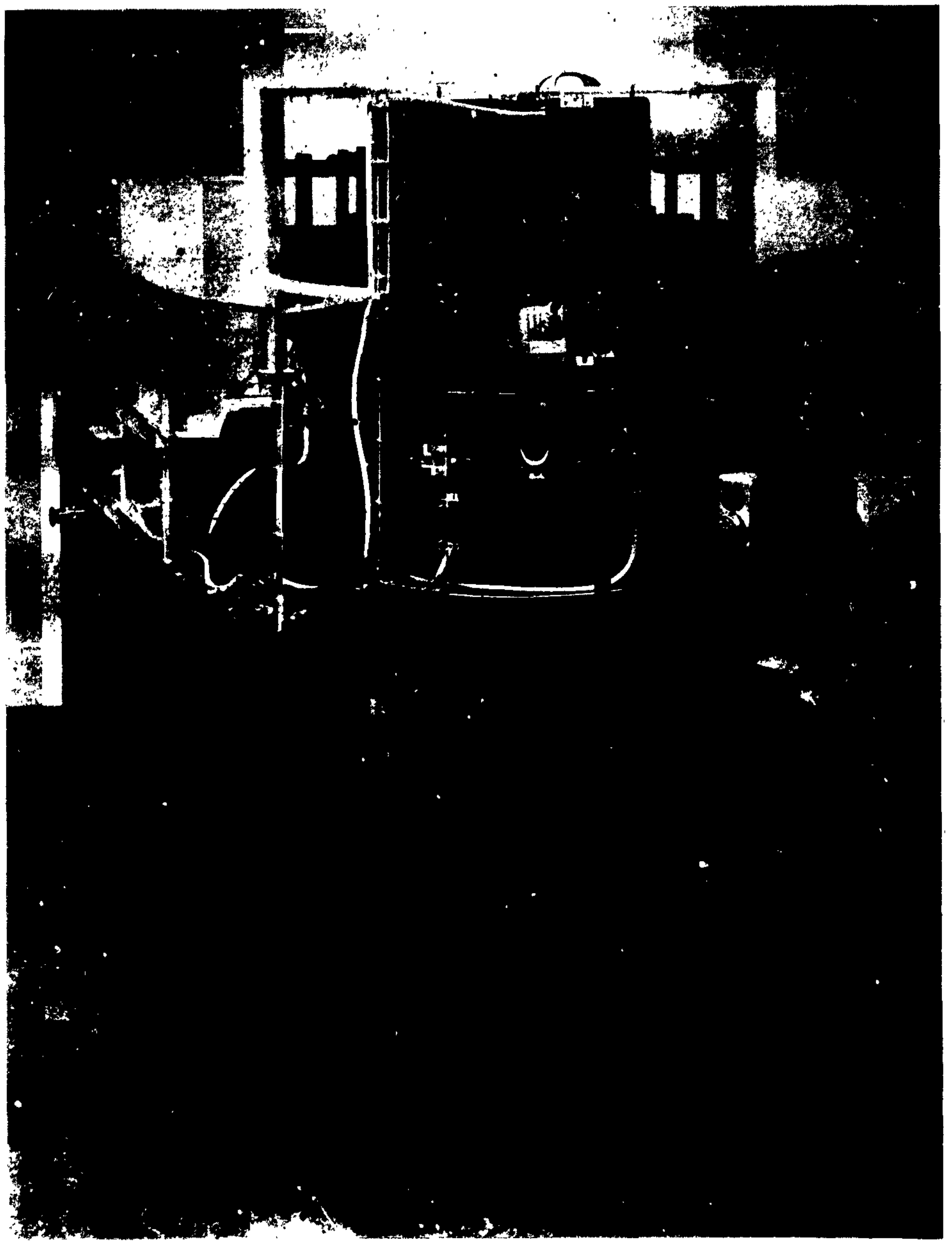
The mechanization developments on the wafer bonding process have provided the techniques for a high volume, repeatable production operation. These techniques, consisting of the rapid resistance heating of the header, the infrared control of header temperature and the ultrasonic scrubbing of the wafer, provide the methods for the formation of complete eutectic wafer bonds at lower temperatures. The completeness of the bonds and the lower bonding temperatures have contributed to definite improvements in the following electrical characteristics of the transistors: collector breakdown voltages, collector leakage currents and saturation voltages.

Refinement of the Wafer to Header Bonding Machines will be continued during the Phase 2 portion of the Contract. One area of refinement will be to facilitate the machine alignment and setup procedures. Further developments will be directed toward continued improvements of the wafer bonding process with studies covering the thermodynamic properties of the header, header heating and preheating, infrared temperature control and automatic ultrasonic application by header temperature.

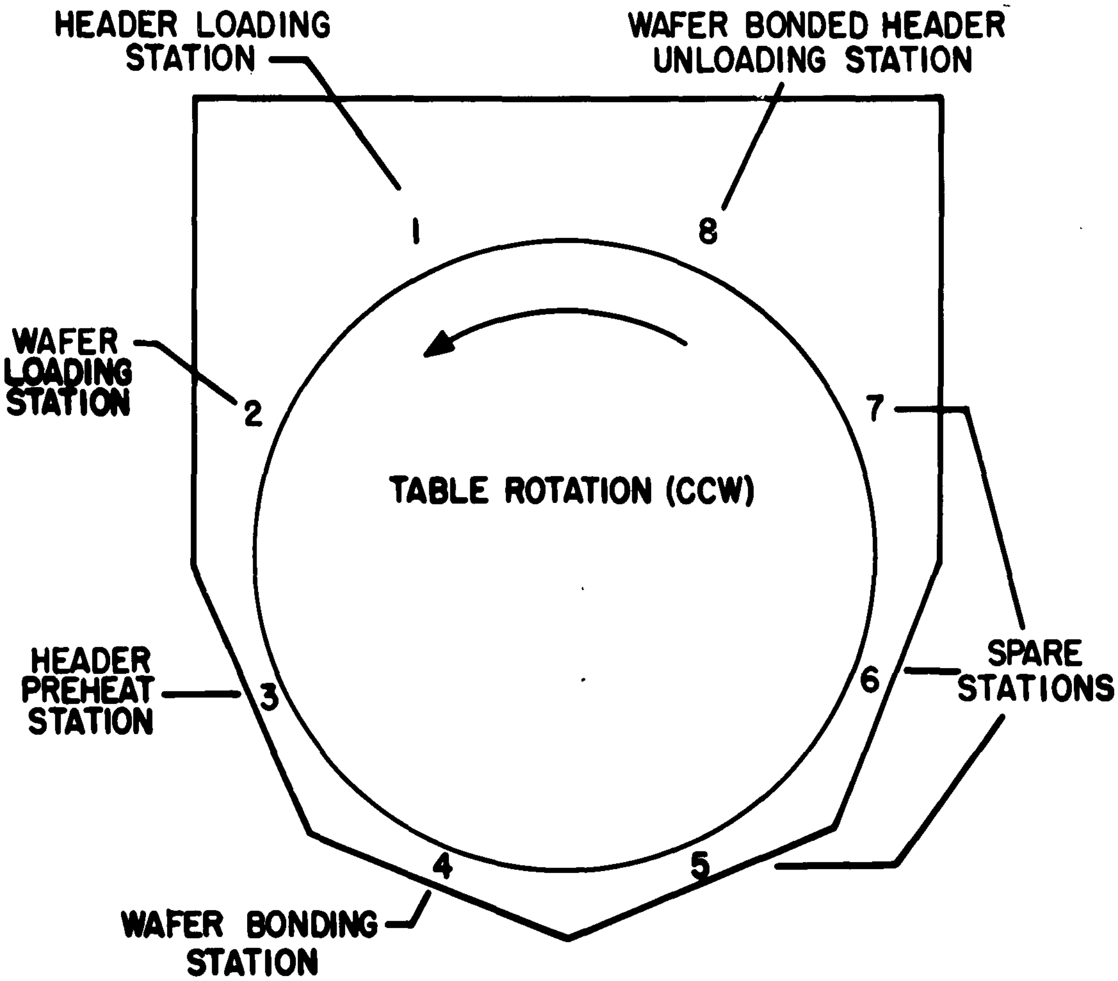
In conclusion, the development of this mechanized Wafer to Header Bonding operation has advanced the state of the art for the manufacture of transistors and other semiconductor devices.



WAFER TO HEADER BONDING MACHINE A
FIGURE 3.8-1



WAFER TO HEADER BONDING MACHINE B
FIGURE 3.8-2



PLAN DIAGRAM OF THE
WAFER TO HEADER BONDING MACHINE

FIGURE 3.8-3

PROTOTYPE BONDING HEAD ASSEMBLY SET UP FOR
DEVELOPMENT STUDIES
FIGURE 3.8-4

SECTION 3.9

WIRE BONDING

M. K. Avedissian

WIRE BONDING

I General

The purpose of this Wire Bonding Machine is to attach .0005 or .001-inch-diameter gold wire to the stripes and internal leads of the devices. Twenty magnetic trays loaded in a magazine are supplied to the machine. The wafer bonded units held in the magnetic trays are automatically transferred through the machine and bonded. The bonds produced must be capable of withstanding 20,000 g's acceleration.

II Objectives

Prior to this development the Wire Bonding operation was manual, slow, and involved:

The operator placed the wafer bonded header in the wire bonding tool. Next, she placed two blocks in the tool which carried the gold wire segments to be used for bonding to the emitter and base stripes. These blocks were prepared in a previous operation. Originally, the segments of fine diameter gold wire were inserted in pieces of nickel tubing, leaving a length of the wire extend beyond the tubing. The nickel tubing was crimped to hold the wire, and the assembly of wire and tube were installed in the handling blocks. After placing the two blocks in the wire bonding tool, the operator had to operate six micro-manipulator screws in order to make a bond to the one stripe. After completion of this bond she had to operate a lever to perform the bond to the appropriate internal lead or post. After making the bond to the post the operator again had to manipulate a micro-manipulator screw to break the gold wire loose from the post. This completed wire bonding one-half of the device. Figure 3.9-1 shows a typical manual wire bonding tool and 10 of 11 micro-manipulators used in the manual Wire Bonding operation.

The average hourly output of the previously described manual operation is approximately 60 units per operator. However, one extra operator is required for every two wire bonding operators to load the wire handling blocks. Therefore, the average hourly output per operator is approximately 40 units. The operation requires an appreciable amount of skill and judgment by the operator.

The following objectives were established for development of the Wire Bonding Machine:

1. Eliminate the use of wire handling blocks.
2. Use continuous gold wire feeding system.
3. Increase rate of production.

The anticipated increase in production requirements made the development of a machine to fulfill the above objectives necessary.

The basic principle of the mechanized as well as manual operation is thermocompression bonding. This principle was developed and patented by the Bell Telephone Laboratories. Presently this principle appears to be the most reliable way of wire bonding if proper operating conditions exist, such as proper temperature, pressure, and above all cleanliness of the surfaces to be bonded.

III Description of the Machine

This machine employs the Stitch Wire Bonding method developed by the Western Electric Research Center in Princeton, New Jersey. The bonding tip used for the Stitch Wire Bonding operation performs two functions: one function is to guide the gold wire to the point to be bonded, the other function is to perform the bond.

The Wire Bonding Machine (Figure 3.9-2) has three operating sections: material inlet section (1), bonding section (2), and material outlet section (3). The magnetic trays which contain the wafer bonded headers are loaded in the material inlet section with their magazine. Here the magnetic trays are automatically discharged, one at a time, from the magazine into the track of the machine. The trays are indexed through the machine. In the bonding section the headers are automatically transferred into the bonding nest. After completion of the bonding operation they are pushed back into the magnetic trays. In the material outlet section the trays with the wire bonded units are discharged into another magazine.

In the bonding section (Figure 3.9-3) an X-Y-Z micro-manipulator (1, 2) permits the alignment of the tip (3) containing the gold wire with the parts to be wire bonded. Viewing is done with a microscope (4). The bonding arm (5) carries the bonding tip, the spool holder (6) and spool with the gold wire. The cutting device (7), located under the bonding arm, cuts the wire after completion of the bond. The bonding nest (8) rotates 180 degrees to permit bonding of both sides of the device.

The function of the operator is to view the work through the microscope and to position the bonding tip containing the gold wire with the X-Y micro-manipulator in proper relation to the point to be bonded. The Z-lever (2) is lowered to perform the bond to the one stripe. Then the Z-lever is moved up and the tip is positioned above the appropriate post. The bond to the post is made by lowering the Z-lever. After the Z-lever is moved up again, the cutting device is actuated to cut the wire and form the tail which is required for the next bond. After rotating the next 180 degrees the next bond is made to the other stripe, then to the other post and the wire is cut as already described.

IV Machine Development

The original intention was to mechanize the simultaneous positioning of two bonding tips containing the gold wire to bond, first, to the posts of the headers and then to the stripes of the wafer. Development work was initiated in two directions: first, to design an open loop system with a high degree of accuracy which repeats its motions within extremely small tolerances and, second, to develop methods to manufacture piece parts with tolerances compatible with such an open loop positioning system.

A cam operated positioning system was developed capable of repeating its motions with great accuracy. The headers were viewed through a comparator and positioned to a mask contained on the view plate. Simultaneous bonds of both stripes and both posts of the unit were made successfully.

The manufacture of piece parts with the required tight tolerances proved to be uneconomical. Although it was possible to produce these piece parts, the high accuracy required made them too expensive. Therefore, it was decided to abandon this method of operation.

As previously mentioned, positioning of the bonding tip containing the gold wire is now controlled by the operator. This permits the use of piece parts with relatively wide tolerances without sacrifice of speed of operation.

In the beginning the bonding tip was prepared out of stainless steel tubing with .063 inch outside diameter, .004 inch inside diameter and approximately 1/2 inch long. One end of this tubing was swagged down to .0015 inch inside diameter. Tungsten wire was welded to this end and serves as a bonding anvil. The preparation of tips by swagging was difficult to control; the tubing had the tendency to crack during the swagging operation and the finish inside the tubing was not good. When these tips become clogged, cleaning of the fine inside diameter was rarely successful.

These difficulties were eliminated by the development of the split bonding tip. This tip is made out of two halves which form a tip with .063 inch shank diameter. These halves are brazed to small plates which are aligned to each other with dowel pins. One half of the tip has a groove which guides the gold wire. The lower end of this half is provided with the bonding anvil made out of .002-inch-diameter tungsten wire and attached there by a welding operation. The other half of the tip serves merely as a cover for the groove (Figure 3.9-4).

The manufacture of this tip is precisely controlled and the finish of the groove is good. When clogged, it is a simple matter to open and clean the tip without removing it from the machine.

Cutting the .0005-inch-diameter gold wire and forming a tail of proper length (.001 inch minimum and .002 inch maximum) for the succeeding bonding operation also presented a problem. The first attempt to solve the problem was made by using blades only .002 inch thick. The performance of these blades was fair; however, more reliable operation was obtained by using blades .032 inch thick. The lower blade was ground 70 degrees to the cutting plane; the upper blade was ground 20 degrees to the cutting plane. Due to the speed of the cutting operation, the 20-degree slope of the upper blade pushed the gold wire up into the bonding tip instead of forming a tail. To eliminate this condition it was necessary to break the cutting edge of the 20-degree slope (Figure 3.9-5).

The mechanisms for discharging the magenetic trays from the magazine into the track, indexing of the trays along the track and discharging the trays with completed units from the track into the receiving magazine are powered by three electric motors. Although the armatures of these motors were balanced and the motors were mounted on resilient supports, vibrations generated by motors, gears and shafts were detrimental for the Wire Bonding operation. This problem was solved by modification of the control circuit, to stop the motors when they are not used. Furthermore, the members carrying the electric relays and pneumatic valves were mounted on shock absorbers in order to isolate all sources of shocks from the bonding section of the machine.

Another problem was the handling of the .0005-inch-diameter gold wire. In order to simplify the wire supply system it was decided to use precision made spools with conical shaft-ends running in spring loaded jewel bearings. This approach permits operation without motors, drives, and all associated problems of motorized wire feeding systems.

V Operational Problems

For reliable thermocompression wire bonding care must be exercised to assure cleanliness of the surfaces to be bonded. The bonding method used in this machine permits a high rate of production if the operation is not interrupted. With good bondability of the units, these interruptions can be reduced to a minimum. If bondability to stripes or posts is poor, interruptions must be expected, causing a drop in the rate and quality. Poor bondability is frequently caused by contamination of the surfaces to be bonded. For reliable operation these surfaces should be as perfectly clean as possible.

As previously mentioned, the machine employes magnetic trays for header handling. These trays utilize the leads of the devices for holding; therefore, they are designed to be used with headers having straight, parallel leads, welded at the tips. Such headers were not always available. The operation with conventional headers without welded tips is satisfactory. However, headers with straight, parallel and tip welded leads must be used for optimum performance. The variation of lead lengths should not be more than 1/8 inch.

The operation of the machine is entirely different from the manual wire bonding operation; therefore, training of the operators is most important. Usually operators quickly adapt to this more convenient operation.

For efficient operation of the machine the training of maintenance and set-up personnel is of great importance. As previously mentioned, in order to obtain good production rates and also good quality of the product, interruptions of the production must be kept to a minimum. Minor adjustments, requiring a few minutes, must be made as soon as they are required.

VI Machine Performance

The design rate of the machine is approximately 240 units per hour. It is believed, this production rate can be attained if proper operating conditions are provided.

Following are some of the factors causing difficulties:

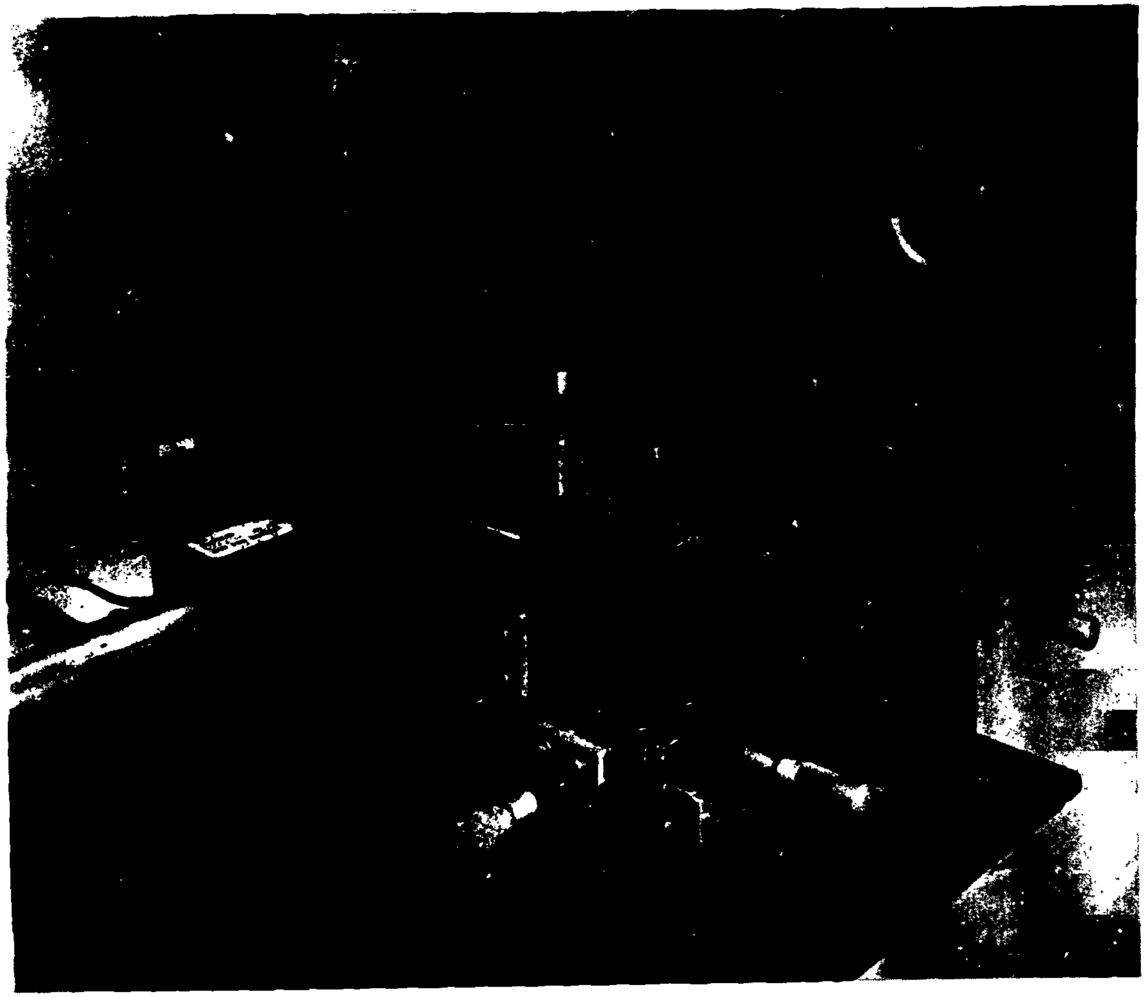
1. The leads of the headers are bent or have excessive variation of length (more than 1/8 inch).
2. The internal leads (posts) of the headers have surfaces not suited for thermocompression wire bonding.
3. Cleanliness of stripes and gold wire are not adequate.
4. Floor on which the machine is mounted transmits vibrations.

(Because of the low frequency of the beat, shock mounts are ineffective).

5. Shortage of properly trained set-up and maintenance personnel.

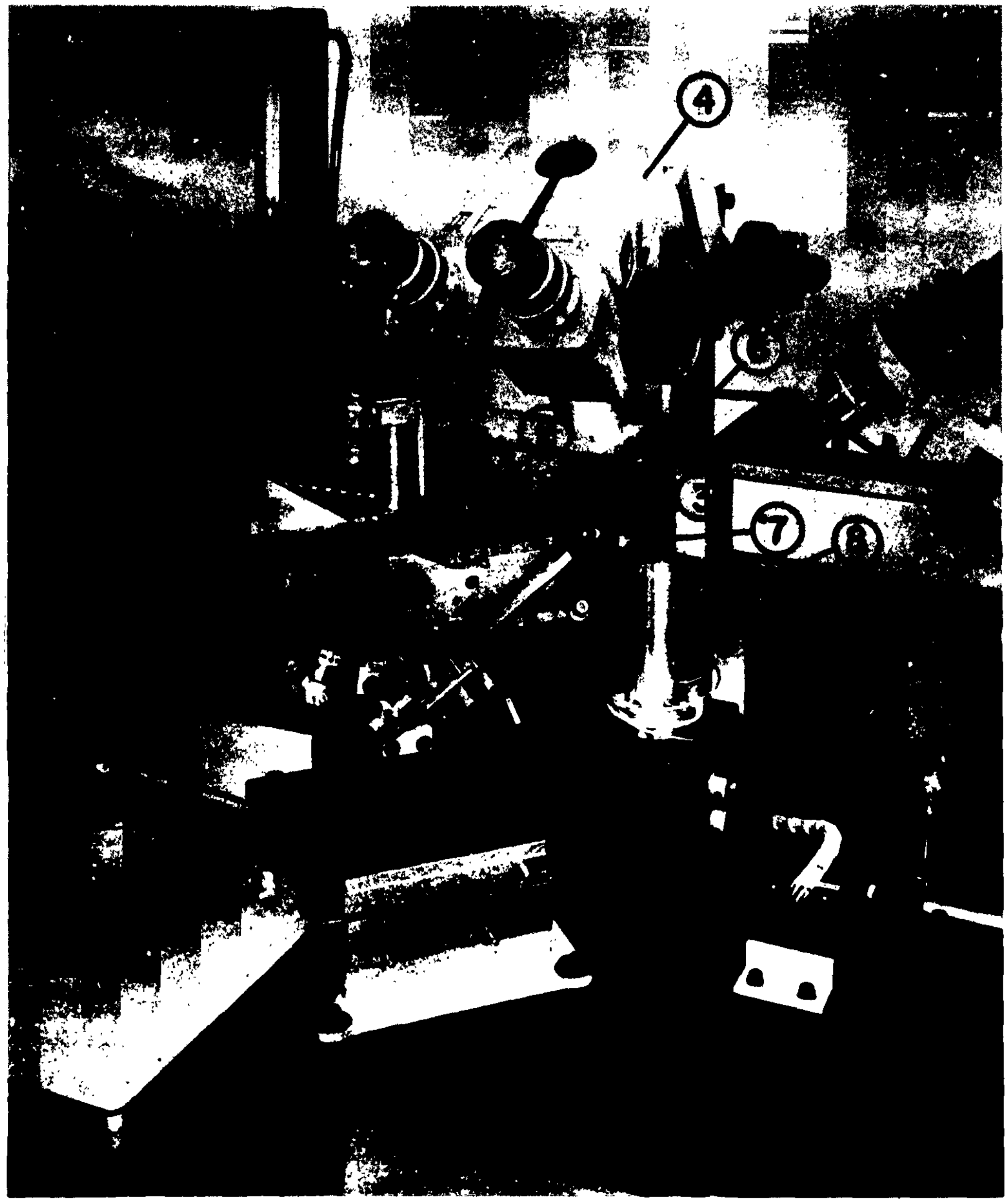
VII Conclusion

At this writing operation of the machine appears to be reliable and to require little maintenance. Although the parts to be bonded are small and the accuracy required is high, especially in the bonding section, only infrequent adjustments are necessary. However, in order to have a good production rate and good quality of product, adjustments should be made as soon as possible. Thorough training is required for best performance. In order to reduce interruptions of operation, along with proper adjustment of the machine, cleanliness of the parts to be bonded must be regarded as the most important factor.



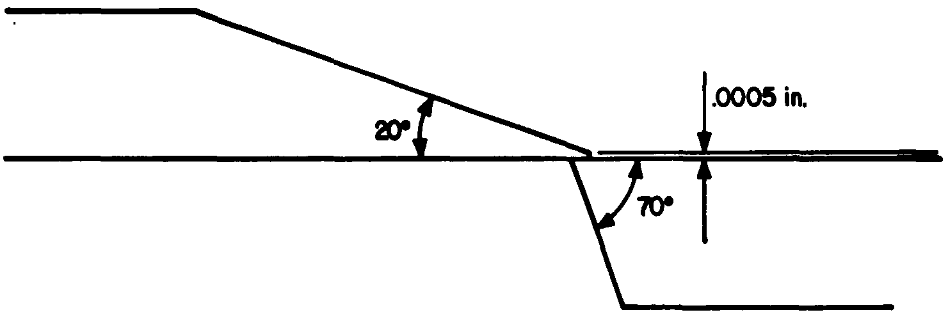
MANUAL WIRE BONDING TOOL
FIGURE 3.9-1

WIRE BONDING MACHINE
FIGURE 3.9-2



BONDING STATION OF WIRE BONDING MACHINE
FIGURE 3.9-3

SPLIT BONDING TIP USED ON THE WIRE BONDING MACHINE
FIGURE 3.9-4



WIRE CUTTING DEVICE ON WIRE BONDING MACHINE

FIGURE 3.9 - 5

SECTION 3.10

CAN GETTER ASSEMBLY

R. W. Ingham

CAN GETTER ASSEMBLY

I General

Fabrication of a moisture seeking TO-5 nontubulated can is accomplished on an in-line multi-station Can Getter Assembly Machine. This machine has been constructed on two separate machine frames. The first or Can Loading Section receives precleaned, nontubulated TO-5 type cans and feeds, orients, and loads these cans into pallets. The pallets serve as holding devices during furnace treatment and storage while the cans are awaiting further processing. The operator manually loads the pallets into a rack from which they are mechanically removed as required by the machine. As the pallets are indexed along a track, cans are placed into the holes or nests in the pallet. These cans are then filled with measured amounts of finely ground pure nickel. After this has been accomplished, the pallets are placed in magazines for transportation to the controlled atmosphere sintering furnace. The furnace is not considered to be a part of the Can Getter Assembly Machine and, for this reason, will not be covered in this report.

Loaded pallets are fed into the sintering furnace by an auxiliary component - the Powder Leveler. This component removes one pallet at a time from the magazines and places each on an electric bin vibrator. The vibrator levels the powder by means of a low amplitude vertical movement. Then the pallets are moved from the vibrator and placed on the moving hearth of the sintering furnace. While this component is a vital part of the operation, it will not be described in this report since it was provided under Contract No. DA-36-039-SC-72729 as part of the TO-18 Can Getter Assembling Machine.

The second or Getter Loading Section receives the pallets after they have been removed from the sintering furnace. After the pallet and its contents are removed from the magazine, the machine moves them into the shake-out station which removes any loose particles from the cans before the powdered getter - barium hydroxide - is added at the next station. Successive indexes move the pallet into location over the heating station where the barium hydroxide is melted into the porous nickel sponge. Finally, the pallet is moved into the unload station where it is reloaded into a magazine.

The concept, design and requirements of this machine were based on work done on a similar machine built for the TO-18 cans on Contract No. DA-36-039-SC-72729. Experiences gained during the prove-in period of the TO-18 machine made modifications mandatory so that portions of this machine are quite different from the machine built for TO-18 cans.

Since the actual machine, as covered by Contract No. DA-36-039-SC-81294, is really two separate machines; the description, development, operation and conclusion for each portion will be handled separately. The group will then be tied in by an overall evaluation or summary relating original intent and the degree to which the machine satisfies this intent.

CAN LOADING SECTION

II Description

The Can Loading Section (Figure 3.10-1) is an in-line type machine approximately 8 feet in length by 2-1/2 feet wide. The frame of the machine is a welded box type construction and has a table height of 3 feet. A 3/4-inch aluminum jig plate serves as a mounting plate for the stations that feed and orient cans, convey these cans to the loading station, stack and feed pallets, measure and deposit nickel powder into the cans, and restack or load the pallets (holding 66 cans each) into magazines. The machine is suitably interlocked so that stations will not operate unless a pallet is in place.

Feeding and orientation of the precleaned cans is handled by a Model EB-01-C Syntron Electric Parts Feeder fitted with a 14-inch stainless steel cascade-type bowl (Item 1, Figure 3.10-1). This bowl which serves to orient and feed cans also becomes a reservoir with capacity for about 2 hours of running time. The bowl has a single discharge opening to which is mounted a 6-track stainless steel chute. The chute maintains orientation and conveys the cans via gravity to the can insertion station (Item 2, Figure 3.10-1). Empty pallets are loaded into a magazine which also serves as the support for the stainless steel chute. This magazine (Figure 3.10-2) holds approximately 30 pallets which is equivalent to about 20 minutes of operation.

The can insertion station performs several functions all of which are initiated by the lowering of the inserting frame. Lowering of the inserting frame opens the escapement, prevents feeding of more than one row of cans at a time, and moves all cans except the row to be loaded back about 1/32 inch to prevent overlapping of can flanges. The inserting or guide pins have been drilled so that dry, filtered air can be blown through them to overcome static and/or magnetic charges that might cause the cans to cling to the guide pins while they are being withdrawn.

Indexing of the pallets, one row at a time, is done by a special air powered rectangular indexing device. A pin located on the indexing mechanism engages a hole in the pallet and moves a row of holes into position directly below the can loading station. The pallets continue to index one row of holes at a time until they reach a predetermined position under the powder load station (Item 3, Figure 3.10-1). With the pallet in position a measuring plate is indexed and a load of nickel powder is allowed to fall via gravity into the cans. The entire pallet of 66 cans is loaded at one time.

From the powder load station the pallets are moved to the pallet loading station (Item 4, Figure 3.10-1) where they are stacked in the magazine. Loading is from the bottom using a hydraulically controlled air motor located directly below the table. This station is electrically interlocked so that it must be in the low or ready position before the pallet feeder may move an empty pallet into position to activate the indexing and can loading station.

This section of the machine operates from a 440-volt, 3-phase, 60-cycle power supply. The control circuits are operated from a 120-volt, 60-cycle single phase source furnished by a 2-KVA transformer. Air requirements are approximately 4 cubic feet per hour at a line pressure of 85 pounds per square inch gauge.

III Development

The original feasibility studies were conducted under Contract No. DA-36-039-SC-72729 on TO-18 size packages. The only development actually attributable to this contract was determining the amount of nickel powder necessary to provide ample storage room for the getter material.

Before actual design was started, mock-ups of the various stations were built to determine the practicality of using the motions and devices developed for the TO-18 type package. The can loading station required only dimensional changes in order to be adopted for the TO-5 package. To provide for flexibility of production schedules, it was decided to keep the external dimensions of the pallets used for the TO-5 cans the same as those used on the TO-18 Machine. This allows for better use of the handling magazines and furnaces. Cut over time from one code to another could be eliminated. Wherever possible, designs used on the TO-18 Can Getter Assembly Machine, made under Contract No. DA-36-039-SC-72729, were used. The only changes being those required by differences in the sizes of the piece parts.

IV Operating Problems

When the machine was put into operation by the engineers, the pallet indexing mechanism caused the cans to bounce out of the holes in the pallets. Flow controls on the air valves were used to smooth out the mo ..ol. but, while improvement was noted, reliability was below that which would be acceptable for operation. The pallets were counterbored about .020 inch deep. This reduced the bouncing or lifting of the cans.

The pallet indexing mechanism, as originally designed, was spring driven with a positive return. This method was used to prevent serious damage to parts and the machine. The spring, which was under an average force of about 60 pounds, required resetting at regular intervals to overcome normal "set". To overcome these periodic resettings, the moving force was changed from a cam to two one-inch double acting air cylinders with flow controls on both the inlet and exhaust, and the spring was removed. This modification to the original design made it easier to correct malfunctions due to out-of-limits or damaged piece parts.

V Conclusion

The Can Loading Section of the Can Getter Assembly Machine has demonstrated that it is capable of performing the operations for which it was designed. The machine can operate continuously and furnish cans containing accurately measured amounts of nickel powder at the rate of 5000 cans per hour. The quality of the cans fabricated on the machine and their uniformity is an improvement over those produced by the manual methods.

GETTER LOADING SECTION

VI Description

The Getter Loading Section of the machine is of the in-line type. Pallets are moved from station to station by means of an air operated pawl-type index and guided by the track visible on Figure 3.10-3. The machine is approximately 8 feet long by 2-1/2 feet wide. The frame which is of welded box-type construction has a floor to work table height of 3 feet.

The table top supports a 3/4-aluminum jig plate. The top side of the plate serves as the mounting medium for the various stations while the hydraulically controlled air motors are located on the under-side. Each motion is air powered, electrically controlled and suitably interlocked so that each operation must have been completed or have progressed to a predetermined state of completion before another or related motion is initiated. At the present time, pallets are manually loaded into magazines after emerging from the sintering furnace. The magazine is then placed on the pallet loading station located at the left end of the machine in Figure 3.10-3. The Getter Loading Section mechanically unloads pallets from the magazine one-at-a-time and places them on the track that guides the pallet into position for successive operations. At the shake-out station, which is the first work station, the pallet and sintered cans are clamped to a section of track by an air operated plate. This station rotates 180 degrees and then vibrates to remove loose particles from the cans. It then returns to the feed track and the pallet indexes to the getter loading station which is identical to the nickel powder loading station. It measures the powdered getter - barium hydroxide - and adds equal amounts to each can in a pallet when a pallet is positioned under the hopper.

The third and last work station of this section, the heating station, melts the powdered barium hydroxide so it attaches firmly to the nickel sponge formed in the can during sintering. The pallet remains relatively cool and can be handled safely with bare hands after the heating cycle is completed. Sixty-six cylindrical projections forming the top of the heat sink of this station move up into contact with the bottom of the cans to heat and fuse the getter to the nickel sponge. After completing the heating cycle, the station moves down, clear of the pallet, and the pallets are moved into the unload magazine after the next index. Filled magazines can be stored or transported to the activating furnace to be prepared for closure welding.

VII Development

The development of the Getter Loading portion of the machine follows the development of its TO-18 counterpart, developed under Contract No. DA-36-039-SC-72729. The design differs from that used for the TO-18 type can only in those dimensions necessary to accommodate the TO-5 can. The unloading station on this machine is identical to the one provided for the TO-18 package and required no new work. The shake-out station also was designed and built identical to the one used for the small cans. The only part changed was the clamping plate used to hold the cans during the actual period of vibration or shake-out. Rotary air motors were purchased to provide the "flip-over" or 180 degree rotation because of their apparent simplicity and safety. Due to the off-center nature of the load, adequate control of the motors could not be obtained by regulating the exhaust. The station was redesigned to use linear air motors with hydraulic speed controls. The linear motion was converted to rotary motion through a rack and pinion arrangement. The entire station was covered with suitable guards to insure operator safety.

The heating station followed the design calculations made for the TO-18 machine built on Contract No. DA-36-039-SC-72729. A Fenwall Proportioning Indicating Controller and thermistor probe were chosen to provide the heat control. Actual heating is obtained from four cartridge heaters. Four heaters were chosen to more effectively distribute the heat throughout the heat sink. To provide a means of checking heater burn-out, a checking circuit was designed to permit reading the current drain of each heater while in use.

The machine is operated through and by an electrical control circuit that permits both manual and automatic operation. During manual operation, all safeties and interlocks remain in effect so that no damage to the piece parts or machine will be caused by attempting to operate stations out of sequence.

VIII Operation

After the machine was installed on the production floor, the machine was started up following the procedures outlined. When the units were checked for moisture getter ability, they were found to fall below manual production. Checking revealed that in the construction of the powder loader the thickness of the plate was reduced without considering the effect on the volume of the getter powder. The station was removed and the diameter of the holes enlarged to increase the volume of powder dispensed to bring the finished can within specification.

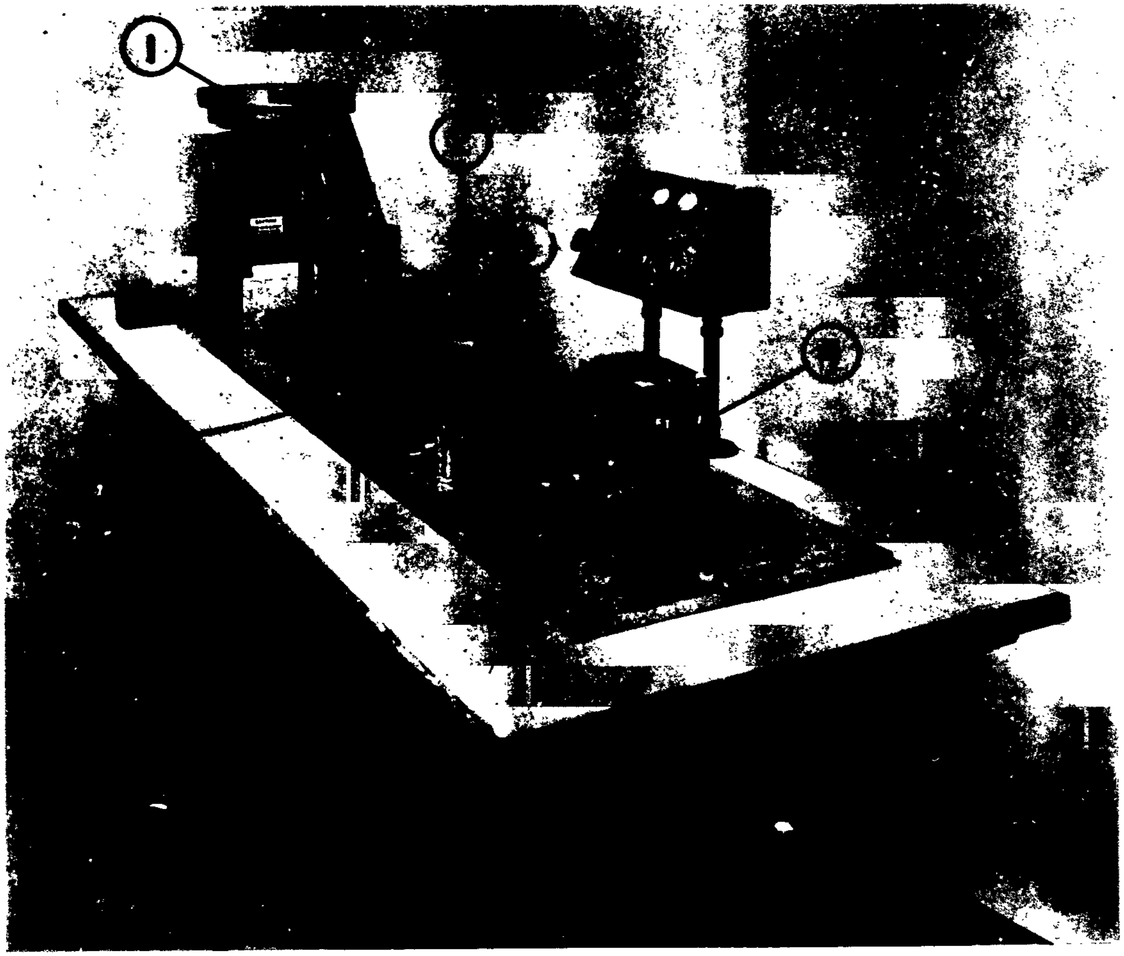
IX Conclusion

The Getter Loading Section of the Can Getter Assembly Machine has demonstrated that it can provide cans for TO-5 type transistors that meet specifications with less waste of material and operator effort.

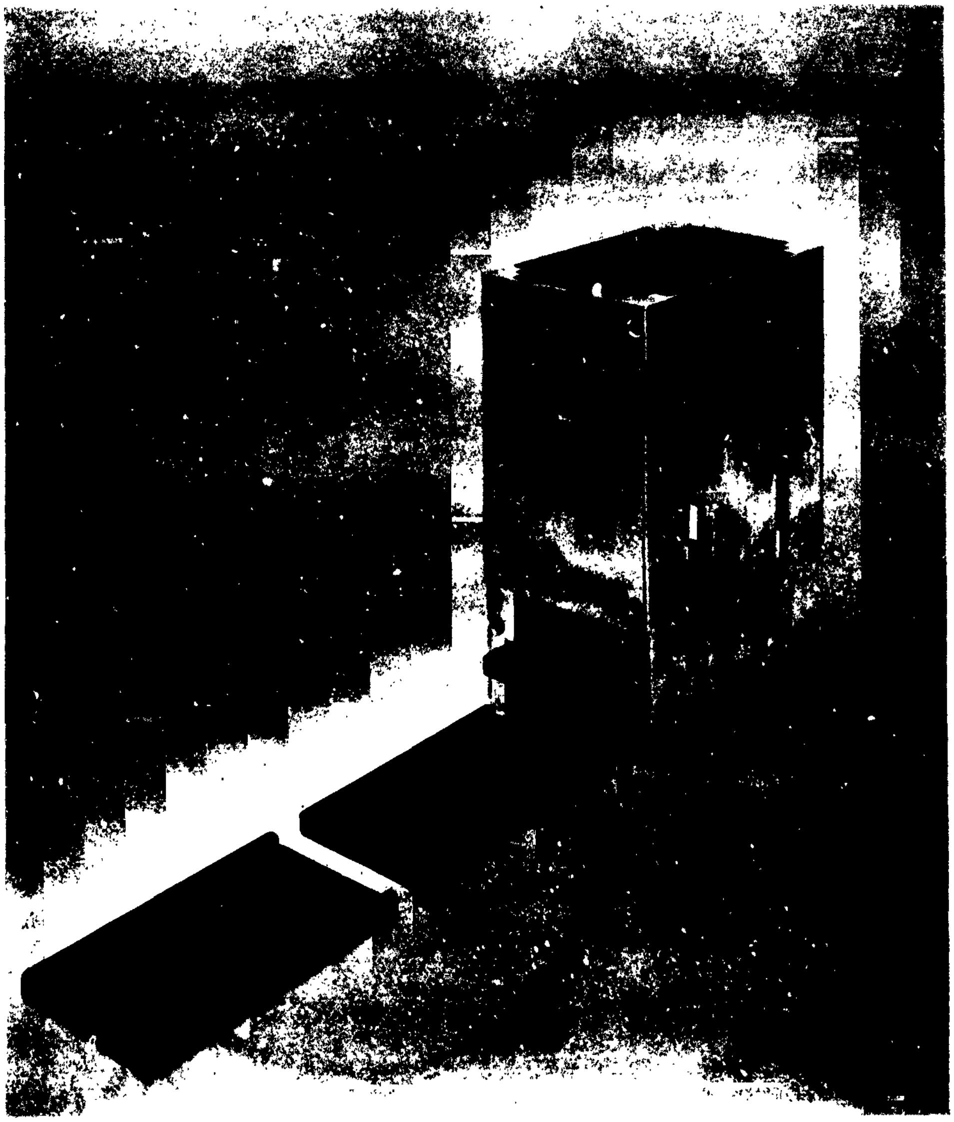
The machine is set to handle one pallet of 66 cans every 48 seconds; this time can be reduced to 40 seconds if a higher production is required.

X Summary

The Can Getter Assembly Machine, as designed, built, and later modified, has demonstrated that it is capable of producing high quality nontubulated closure cans for TO-5 semiconductor devices. The machine was built specifically for the high reliability type device requirements of Nike Zeus program. The installation, of which the Can Getter Assembly Machine is a part, is depicted in the flow diagram (Figure 3.10-4) and allows for the production of a large number of devices with minimum floor space.



CAN LOADING SECTION OF CAN GETTER ASSEMBLY MACHINE
FIGURE 3.10-1



TO-5 PALLETS AND MAGAZINE FOR CAN GETTER ASSEMBLY MACHINE
FIGURE 3.10-2

GETTER LOADING SECTION OF CAN GETTER ASSEMBLY MACHINE
FIGURE 3.10-3

PALLET FLOW DURING CAN GETTER ASSEMBLING

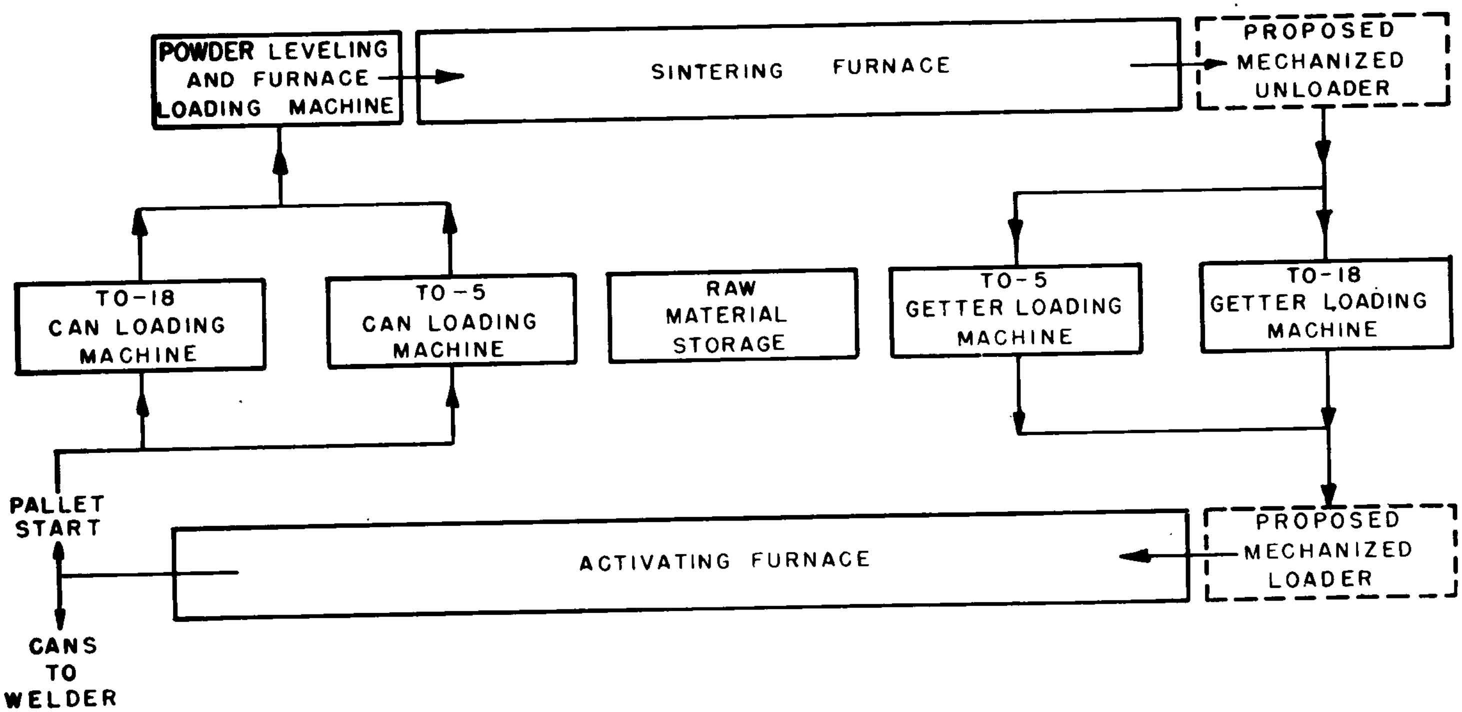


FIGURE 3.10-4

SECTION 3.II

CAN TO HEADER CLOSURE WELD

R. W. Ingham

CAN TO HEADER CLOSURE WELD

I General

The Can to Header Closure Weld Machine will semiautomatically mate a can to a wired header and hermetically seal the parts with a resistance weld. This machine was built to mechanize manual welding operations of TO-5 devices, to increase production rates, to improve welding yields and reliability, and to conserve helium gas. This machine is of the rotary index type and is used in conjunction with controlled atmosphere, low humidity, bake ovens. The ovens, while physically attached to the machine, are not a part of it, nor will they be covered in this report. The index turret and the machine work area have been totally enclosed and sealed from room ambient to maintain a controlled atmosphere during the encapsulation and welding of the device. This machine can provide a suitable atmosphere for, and weld, any TO-18 package with only minor modifications to the welding electrodes.

A need for this machine was emphasized by the anticipated high volume Nike Zeus production requirements and the need to conserve helium gas. This machine is the second machine of its kind to be built; the first machine was built under Contract No. DA-36-039-SC-72729 for the 2N559.

II Machine Description

The basic concept of this machine is to provide a number of small dry-box enclosures within a larger dry-box that has been designed to isolate the work area from the room ambient. The large outer enclosure houses the necessary mechanized equipment and work area for handling the cans and headers while the small inner enclosures, of which there are 16, constitute the welding fixtures. These welding fixtures are of a 2-piece construction, an upper section and a lower section, to facilitate loading the piece parts into the nest in the welding fixture. After the piece parts have been loaded into their respective nests, the welding fixture is mechanically closed; however, the piece parts remain separated until after the fixture has been flushed with clean, dry gases. During welding the inner enclosure is flushed with nitrogen gas to prevent discoloration of the can. After welding, a nitrogen flush removes the gaseous by-products resulting from the welding operation and exhausts them to the atmosphere.

It was deemed essential that the work area be sealed from all foreign ambients if product reliability was to be maintained. To obtain the desired sealing, the index unit was ordered with an oversized center post and an outside surface ground and polished to a 6 micro-inch rms finish. A welded stainless steel controlled atmosphere enclosure was mounted on the machine base to totally enclose the work area. Two sets of arm holes fitted with commercial rubber sleeves and surgical gloves provide the operators with access to the work area. Parts are moved to and from the work area through two double-door air locks. One of these airlocks connects the machine to the baking ovens and the other allows parts to be moved to or from the work area and to or from the room while the machine is operating.

Constant monitoring of the moisture content of the work area is available. The Electrolytic Water Analyzer constantly samples the atmosphere in the work area and indicates moisture content on an easily read scale and records the information on a 24-hour chart. Provisions have been made for checking the moisture of the individual gases fed to the machine, the work area, or oven storage area. The sample selection is controlled by electric valves which are in turn operated by a selector switch located on the sloping panel of the control console. A recirculating gas dryer is used to supply the low moisture ambient used in the ovens and work area. While the dryer is essential to the economical operation of the machine, the dryer is not considered to be a part of the Can to Header Closure Weld Machine. The control console houses all machine controls, flow controls, valves, relays, power transformers and timer. Figure 3.11-4 is a view of the rear of the console with the access door opened. A storage area for electrodes and related parts is located in the lower section of the console and is accessible only from the front.

Figure 3.11-1 pictures the machine as covered by this report and shows the general arrangement of the 16-station Swanson Erie Turret Index Unit (1); the stainless steel controlled atmosphere enclosure (2); and the 20 KVA Taylor Winfield Resistance Welder (3). A panoramic view (Figure 3.11-5) of the welder, console, baking ovens, and recirculating dryer shows the arrangement of the complete installation.

Figure 3.11-2 is a view of the welding fixtures and gas distribution system as seen by the operator. (Item numbers are for the purpose of identification only.) Sixteen 2-piece welding fixtures (1) are located on the face of the index turret. The upper half of each fixture is mounted on two round shafts that insure positive alignment of upper and lower halves of the welding fixture. A fiber nest (2) surrounds the lower electrode (3) and locates the header until the upper electrode (4) lowers the can into place over the header.

Each welding fixture is connected to a valve body (5) which houses three "on-off" type valves. The valves are operated by cam plates (6) that are attached to the fixed center post of the index machine. These valves control the flow of gases to the flushing chamber. An electrode resetting device (7) checks and resets the height of the upper electrode after each welding cycle to insure the proper location of the can during the flushing period prior to welding. Figure 3.11-3 illustrates the flow pattern of the gases during the flushing cycle.

The sequence of operations is shown on Figure 3.11-6. The numbers indicate the index positions; the unload position has arbitrarily been chosen as number 1.

The duties of the operator consist of: starting the machine by pressing the start button, loading the cans and headers into the welding nest, and unloading the finished devices and placing them into racks. Raw material and finished product is supplied to and received from the operators through the air locks by material handlers. The duties of the operators also include replacing the welding electrodes when so instructed.

III Development

The development work associated with this machine was done prior to building the original Welding Machine under Contract No. DA-36-039-SC-72729, and, consequently, will not be discussed in this report. Except for minor dimensional changes required due to the larger size of the 2N560, 2N1051, and 2N1195 device, this machine is an exact duplicate of the 2N559-2N1094 machine.

IV Operational Problems

Experience gained from the 2N559-2N1094 Closure Welding Machine built under Contract No. DA-036-039-SC-72729 has aided greatly in correcting and/or avoiding the minor problems usually associated with the prove-in and shop trial runs of a machine. The major problem presently plaguing this machine is in providing a satisfactory welding schedule for the 2N560 device. The original welding schedule, while providing satisfactory electrode life has not proven completely satisfactory from a welding standpoint. Consequently, it was found necessary to change certain key welding parameters. The resulting welding schedule has produced satisfactory welding results; however, electrode life has dropped from approximately 300 welded devices per pair of welding electrodes to 150 welded devices per pair of electrodes. In addition to the loss in electrode life, difficulty is being encountered with the welded devices adhering to the welding electrodes. In some cases it has become necessary to remove the electrodes in order to remove the welded devices. This problem has resulted in downtime and, consequently, a loss in production. A study is presently being conducted in an effort to provide a more satisfactory welding schedule. Meanwhile, operation of this machine will continue.

V Performance

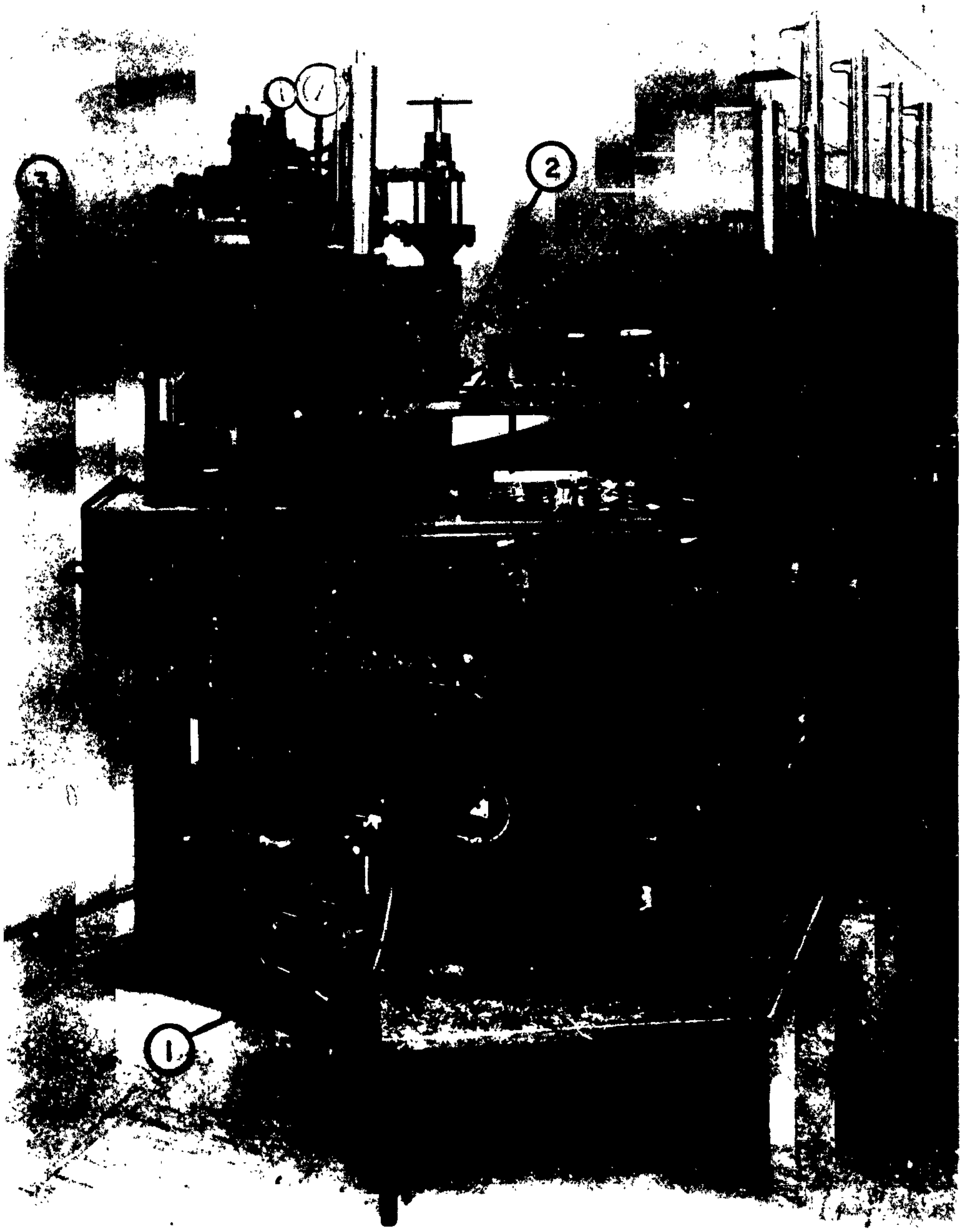
The Can to Header Closure Welding Machine was one of the last machines built and installed under this phase of the PEM Contract. Shop trial runs have started and about 25,000 units have been welded. The cycle time is variable between 3.33 seconds and 15 seconds depending on device requirements; however, the machine is usually operated on a 4-second cycle that yields a gross output of 900 units per hour.

Material handling in this machine is identical to that in a similar machine built under PEM Contract No. DA-36-039-SC-72729. The same handling problems exist and cause an estimated production loss of 90 units per hour. Peak operating rates of over 800 devices per hour have been maintained for periods of several hours without operator fatigue; however, the average production rate over extended periods is considerably lower. The principle reason for the difference between the operating speed and actual net product welded is attributed to difficulties connected with removal and replacement of electrodes. Arcing between the electrode and the electrode holder during the high current welding period has been identified as the factor responsible for the problems connected with removal and replacement of the lower electrodes. A modification to the electrode holder is expected to overcome this condition by providing positive clamping. Other than replacement of electrodes, the only maintenance required was adjustment to the electric clutch to overcome initial wear.

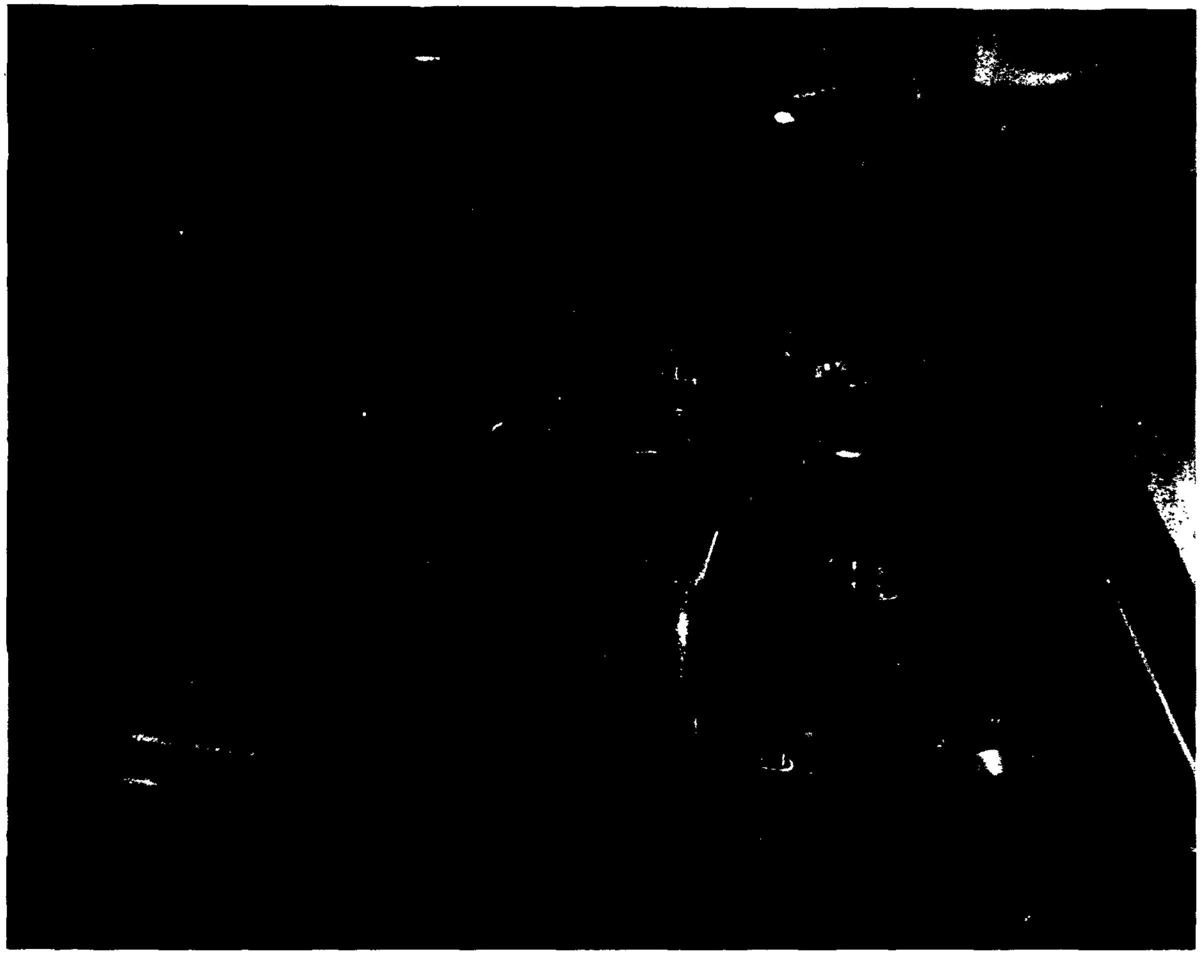
VI Conclusion

The Can to Header Closure Weld Machine has demonstrated that it can produce units capable of meeting all device specifications. Nitrogen gas consumption has been reduced to approximately one-fourth and helium gas consumption has been reduced to approximately one-sixth the manual line requirements. Also, a safe and reliable method for handling pure oxygen has been provided.

In addition to an expected improvement in electrode life resulting from an improved welding schedule, it is believed at this time that electrode life, and consequently, estimated hourly output can be further improved by modifying the existing electrode design. This modification is scheduled for the Phase 2 portion of the PEM Contract.



CAN TO HEADER CLOSURE WELD MACHINE
FIGURE 3.11-1



WELDING FIXTURES AND GAS DISTRIBUTION OF
CAN TO HEADER CLOSURE WELD MACHINE
FIGURE 3.11-2

FLOW PATTERN OF GASES IN FIXTURES OF CAN TO HEADER CLOSURE WELD MACHINE PRIOR TO WELDING

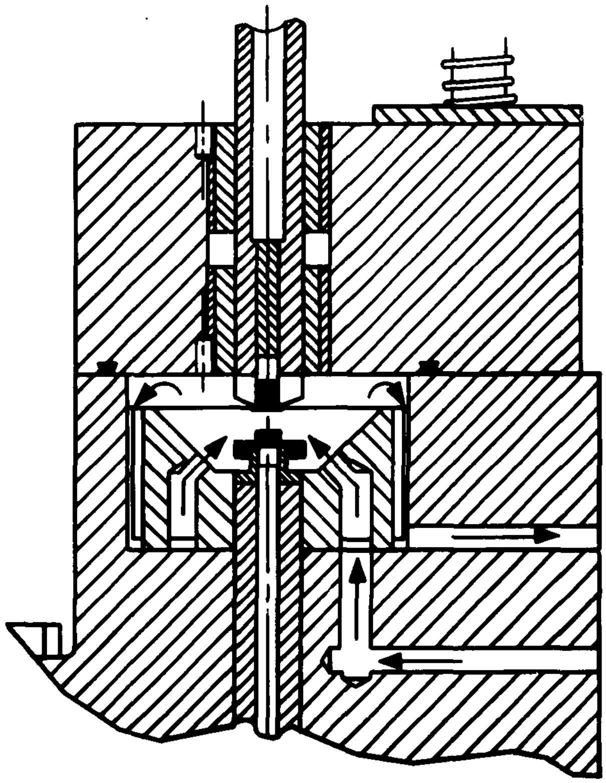
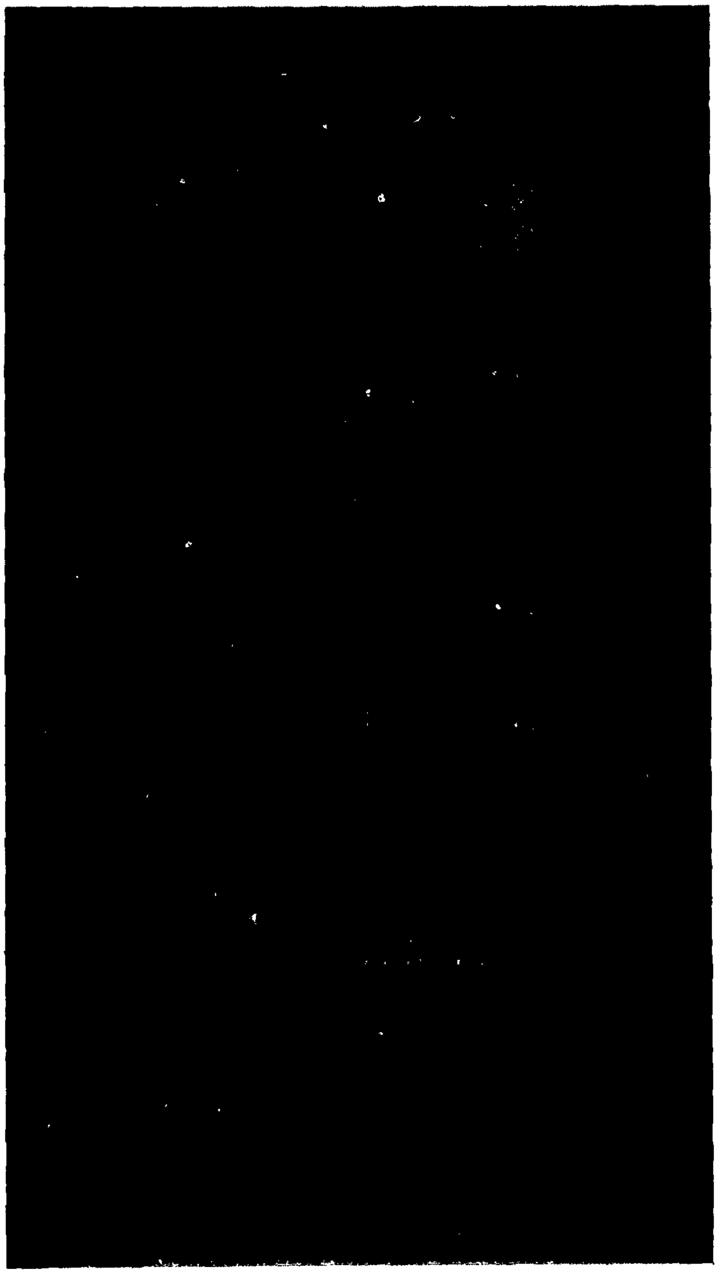
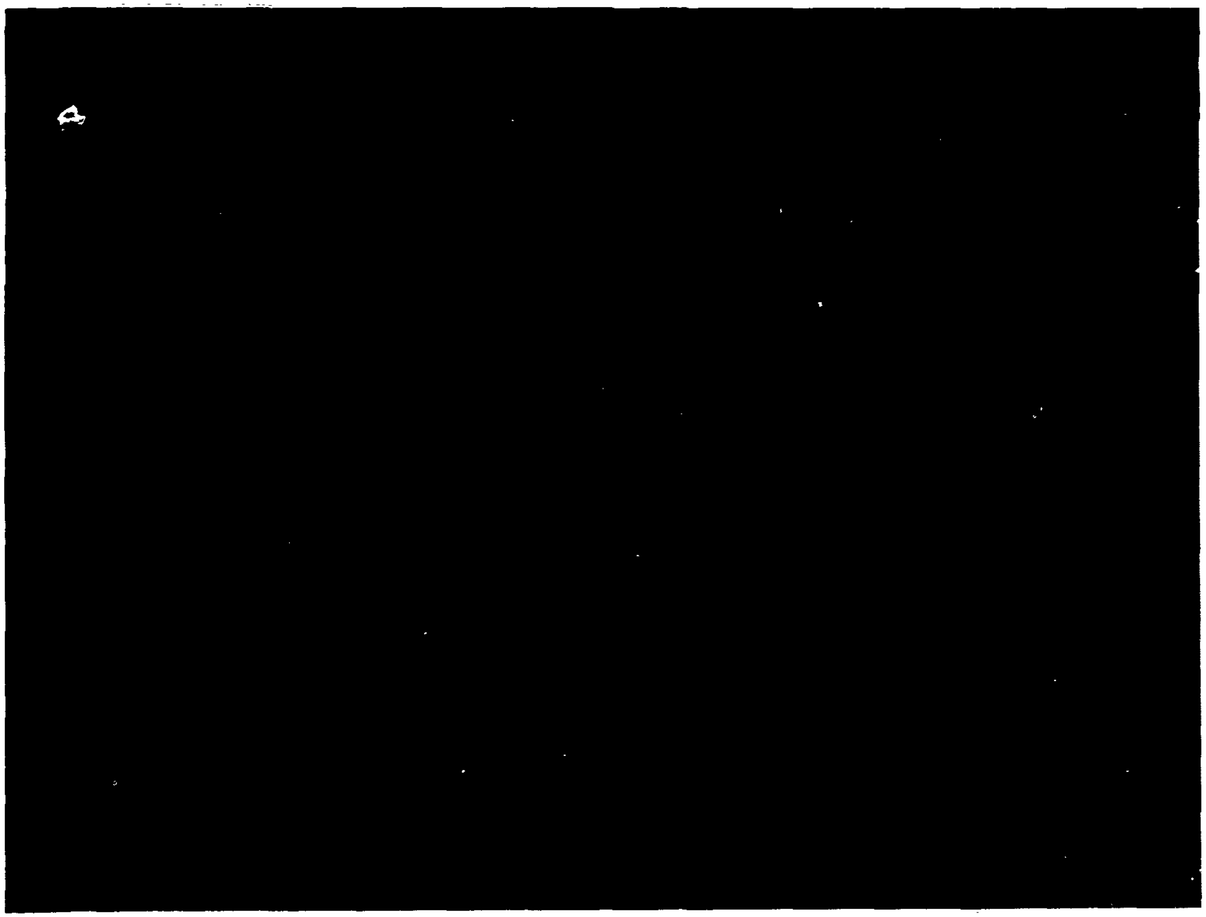


FIGURE 3.11-3

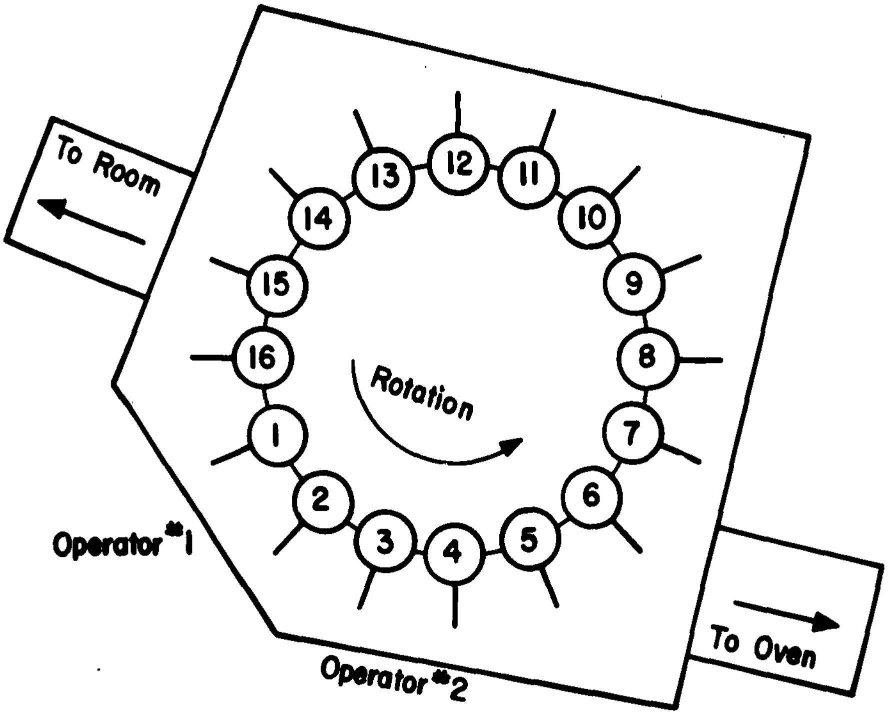


CONTROL CONSOLE OF CAN TO HEADER CLOSURE WELD MACHINE
FIGURE 3.11-4



CONTROLLED ATMOSPHERE BAKE OVENS ATTACHED TO
CAN TO HEADER CLOSURE WELD MACHINE
FIGURE 3.11-5

SEQUENCE OF OPERATIONS ON CAN TO HEADER CLOSURE WELD MACHINE



1. UNLOAD FINISHED UNIT
2. LOAD GETTERED CAN IN UPPER ELECTRODE

3&4. LOAD HEADER IN LOWER ELECTRODE

5,6&7 CLOSE WELDING FIXTURE HOLD ELECTRODES OPEN

8,9&10 FLUSH WITH DRY N_2 GAS

11 FLUSH WITH ENCAPSULATION AMBIENT

12 CLOSE ELECTRODE (CAN IS NOW LOCATED ON HEADER) AND WELD.

13. FLUSH WITH N_2 TO REMOVE WELDING RESIDUE

14,15&16 OPEN WELDING FIXTURE.

FIGURE 3.11-6

SECTION 3.12

PAINTING AND COATING

C. A. Lowell

PAINTING AND COATING

I General

Painting completed transistors provides a protective background for identification and improved appearance. Application of fungus-proof varnish, after transistor identification, supplies the final protective coating. Damage by exposure to ambient conditions is prevented by the additional sealing coat. Coating also affords permanence to the printed code markings by minimizing the risk of chipping or erosion.

A versatile and economical approach to transistor finishing has been provided by expanding a single machine concept for TO-5 transistors to include TO-18 transistor codes of Contract No. DA-36-039-SC-72729. The Painting and Coating Machine synchronizes a mechanical transistor handling system with a programmed pneumatic paint-spray set-up. Manual transistor masking as well as nest loading and unloading have been eliminated. Fluid material waste, associated with semi-automatic painting and coating, is also reduced by the "stop and go" concept of the transistor conveyor. These process improvements help to fulfill the initial goals of this mechanized operation which were fully automatic transistor painting and coating capability, multi-code transistor capacity, and high level continuous output. The purpose of this report is to show how these goals were accomplished.

II Description

Spraying paint or varnish on the cans of completed TO-5 and TO-18 transistors is the primary function of the Painting and Coating Machine. This is accomplished by carrying transistors through a spray booth one at a time. The fully automatic operation includes loading a 24-nest turret, indexing in front of a focused spray gun, and unloading after spraying. The nests not only carry transistors, but provide protective masks so that a predetermined portion of the transistor may be coated.

The secondary function of the machine is transistor supply and handling. The universal handling system is used to provide a continuous supply of transistors to and from the spray zone of the Painting and Coating Machine. Each holder is a magnetic tray that carries 30 transistors. This tray slips into a magazine that holds 20 such trays. Full trays of transistors feed from the supply magazine to the paint nest loading station where trays are emptied and then indexed along a track to the reload position. At the end of the indexing cycle the refilled trays enter the storage magazine.

The physical construction of the automatic Painting and Coating Machine is shown in Figure 3.12-1. The machine body is a 4-foot by 4-foot square cabinet with stainless steel sides, doors, and table top. The mechanical drive is totally enclosed and mounts on a shelf inside the cabinet. Two doors provide access to the enclosed mechanisms. The magnetic tray handling system occupies one third of the table top. The paint booth and hood partially enclose the index table to which the paint nests are mounted. This takes up half the table top area and leaves room for the transistor transfer arms that load and unload the paint nests and the magnetic trays. A transistor lead collector and guide is located over the loading position of the turret, close to the nest load transfer arm. One "Start and Stop" switch is mounted beside the paint booth and a duplicate is mounted on the opposite side of the machine between the magazine receptacles. An air transformer and paint heater are attached to the sides of the paint booth. The paint and varnish guns mount on posts inside the booth and are easily adjusted to direct the spray toward the transistor painting and coating station. Quick disconnecting air and fluid hoses run from the spray guns to the 2-quart pressure paint tank and the paint heater. All the switches, electric motor, paint heater, solenoid air valves, electrical conduit and fittings are explosion proof. Seal-off condulet is arranged to confine an explosion within the originating device. The paint booth has replaceable filters and a forced air exhaust system. A variable speed drive motor powers the Painting and Coating Machine. Hourly output rates can be changed from 0 to 1,800. The usual operating speed is 1,200 to 1,500 per hour.

Compressed air is used for programming the indexing, spraying, magazine loading and magazine unloading stations. Automatic air controls are also used to detect empty and full magazines and to provide fail-safe operation. The extensive use of the pneumatic controls was planned to reduce the risk of electrical arcing and consequent explosion hazard.

The operator of the Painting and Coating Machine has several duties in addition to putting the magazines in place and changing them after painting 600 transistors:

1. Spray gun set-up and cleaning is necessary once a day.
2. Minor adjustments of spray gun as well as air and fluid control valves may be required occasionally to assure uniform finishing.
3. Paint and varnish must be mixed and tested for proper viscosity.
4. The paint supply tank requires filling at least once every shift.

5. Periodic inspection of finished transistors must be performed to assure adequate and uniform coating.

6. In addition the operator must maintain overall surveillance of the machine for mechanical defects or malfunctions.

Periodic maintenance of the machine includes cleaning the permanent nest masks and lubricating the functional machine components. Sticking air valves and excessive wear will hamper the machine's performance if the pneumatic line oil system is neglected.

III Transistor Handling and Painting

For mechanized painting and coating, transistors and magnetic trays move in the following manner. A full magazine is placed in one side of the machine and an empty one in the opposite side, as shown in Figure 3.12-1. One magnetic tray moves from the full magazine into a track every 30 indexes of the index table. An index pawl engages one of the tray notches and pushes the tray 3/8 inch along the track. A transfer arm, which is synchronized with the indexing of both the tray and the turret, removes a transistor from the tray and places it through the lead guide into the painting nest. This action is shown in Figure 3.12-3. Vacuum is used for the pickup force. As the transistors are removed, the tray indexes down the track to the unload point. The unloader, seen in Figure 3.12-4, picks up a painted or varnished transistor by its leads and places it in the waiting magnetic tray. When the tray is filled with finished transistors, it is pushed into the empty magazine for storage, and a new supply tray moves from the load magazine into the track position. This sequence is repeated 20 times per magazine.

The nest turret indexing and transistor spraying is synchronized with the mechanical cycling of the tray indexing system. The following sequence occurs after the transistor is placed in the paint nest by the loading arm. Each nest travels in a large circle as the turret indexes and carries transistors into the paint booth. The turret pauses briefly after each index to allow time for the loading, painting, and unloading operations. The pause may be varied by changing the machine speed. During the turret stop, the nest at the spraying station contacts a friction drive belt. This spins the nest for the interval of paint or varnish spray. The automatic spray guns (Figures 3.12-5 and 3.12-6) are synchronized with the turret index so that they spray during the pause and shut off during the index. Shields cover the turret and nests, leaving exposed only the portion of the transistor that is being sprayed. As the turret continues its circuit, the painted transistors emerge from the paint booth and proceed toward the unload station. A lifting mechanism in the lower part of the nest raises the transistor as it passes over a ramp so that the unload mechanism can transfer it to the magnetic storage tray. The painted can should not be touched after painting or coating; therefore, the can is raised in the nest in order that mechanical fingers can grasp the transistor by the leads and return it to the magnetic tray.

IV Development

The automatic transistor painting machine program was initiated to paint TO-5 type transistors only. No coating process was planned for the machine initially. Early feasibility studies indicated that the general concept of semi-automatic painting machines would be followed. Transistors would be rotated in the focal area of a paint spray gun. Instead of hand loading the paint fixtures, the machine would use the magnetic tray supply and storage system. Automatic tray handling and transistor loading and unloading would eliminate human contact with transistors before and after painting. The same type of paper masking tubes used in the manual and semi-automatic processes were to be used to shield the leads from paint spray. A separate handling system for the tubes was necessary. The machine was designed and built to incorporate three distinct processes: automatic transistor handling, automatic paper tube handling, and automatic painting. Coating TO-5 transistors on the same machine seemed to be feasible, so plans were made to use the same painting cycle to apply a varnish coating with a separate system of spray guns and fluid hose.

During the machine construction a separate machine had been designed specifically for coating 2N559 transistors under PEM Contract No. DA-36-039-SC-72729. This appeared to be a dual effort to accomplish a single purpose. Since Zeus commitments had been substantially reduced, it was decided to combine all TO-18 painting and coating with the TO-5 production into the single Painting and Coating Machine that was already partially constructed. This added several problems to the final construction and prove-in phase, but eliminating the additional machine justified the extra effort. Some problems associated with increasing versatility were:

1. Provisions for two sizes of paper masking tubes included interchangeable tube handling chutes, tube escapements, tube centering devices and nest inserts.
2. Pick-up chuck must be interchangeable to suit TO-5 and TO-18 transistors.
3. Modifications were necessary to adapt tray indexing to suit dual size tray slots.

In addition to the requirements imposed by transistors of different sizes, final prove-in revealed that extensive engineering effort was needed in additional areas to accomplish automatic painting and coating. The following resume describes these major prove-in problems and shows how each was resolved:

1. Transistor Painting Nest Loading

   Inserting 1-1/2-inch-long leads in paint mask holes 7/64 inch to 7/32 inch diameter was a real problem, particularly when bent leads were encountered. A funnel-shaped lead collector that opened and closed with each machine cycle partially solved the problem. The sides of the funnel directed the leads into the apex which served as a guide into the masking tube beneath it. This did not completely resolve the loading problem because the nest clearance permitted the paper masking tubes to position eccentrically about the line of lead entry. A split tube-centering sleeve was made as an extension below the lead collector funnel. This centered the paper tubes with the funnel apex and performed the loading operation satisfactorily.

2. Transistor Tray Loading and Indexing

   Reloading TO-18 transistors into trays from the painting nest required the addition of special guide rails to channel spread or bent leads into the 1/8-inch tray slots. Tray indexing was also hampered by crooked leads. Adding clearance in the tray track improved indexing.

3. Fail-Safe Indexing

   A special air operated tray sensing device was developed to detect the presence of a tray in the guide track at a critical time. This eliminates mistiming and provides fail-safe indexing.

4. Improving Transistor Sensing

   Several pneumatic detect stations were built into the machine. It was found that some were unnecessary, and others would not function as intended. This was corrected by eliminating or modifying the stations.

5. Transistor Lifting for Removal After Painting

   Several attempts were made to lift the transistors 3/8 inch and hold them until pickup. An air lifter was tried first. Magnets were mounted in the nest to support the transistors after the air raised them. This was not positive. The next step was to lift the moving transistors with ramp rails under the cans. This worked better but interfered with coated undersides of the transistors. Then, too, the inertial shock of indexing sometimes shook the transistors back into the nest. Nothing could be built into the nests to raise the transistors because used masking tubes must be ejected down through the nests. Later developments obviated the paper tubes and permitted a built-in transistor lifter to be installed in each nest. A ramp now raises the lifter and holds it and the transistor in an elevated position as the index turret moves into the unload station. This development is 100 percent reliable.

6. Transistor Removal After Painting or Coating

   No contact with the can is permitted after painting or coating. For this reason, several attempts at unloading transistors ended in stalemate. The design approach was a scissors type compression spring that was intended to enter the leads and provide gripping force. This did not work. A magnetic lifter was then tried with partial success. Later a light coil spring lifter was tried. The leads, in this case, were to enter the spring coils. This was a step closer to reliability. Finally a positive finger type mechanism was made that synchronizes with the travel of the transfer mechanism. This is most successful, because it provides enough force to control the action of the transistor until it is seated in the magnetic tray.

7. Development of Permanent Paint Masks

The use of paper masking tubes created a constant source of trouble. Jamming, continuous stopping of the machine, and intermittent nest malfunctions were common problems caused by the tubes. In addition, a noisy air vibrator was required to provide a flow of paper tubes. At least seven special mechanisms were necessary to take care of tube handling and disposal; difficulties were experienced with each mechanism. Experiments were finally conducted to determine whether there was a real need for disposable paint masks. The results showed that masks could be reused indefinitely, so a permanent mask concept was developed. Besides eliminating the tubes and the related equipment, the permanent masks (Figure 3.12-2) provide interchangeability and permitted the use of the improved transistor lifter described in Item 5.

8. Spray Gun Cleaning Technique and Equipment

To clean the spray system, a paint solvent is forced through the paint line from a pressurized cleaner. Cleaning was first accomplished by attempting to exhaust the solvent and waste into the paint booth - the method used for most semi-automatic paint machines. This was unsatisfactory because the solvent dripped through cracks in the hood platform, onto the index turret and gummed-up the paint nests. A solvent drain was installed about 12 feet from the paint booth; so longer hoses were purchased to reach from the paint booth to the drain. In this way the gun could be taken to the solvent drain and cleaned without fear of damage to the machine. Separate valves were also provided to permit controlled, manual triggering of the spray gun. Since spray equipment must be cleaned daily, the improved solvent exhaust system will prove beneficial.

V Machine Performance

The Painting and Coating Machine capability program was completed by conducting a group of tests to evaluate the mechanical reliability of the automatic transistor handling equipment, as well as the performance of the fully mechanized spray equipment. Some of the tests were attempted before the paper masking tube system was replaced by the permanent mask. The results of the first trials were quite unsatisfactory because of the problems associated with handling the masking tubes. Of 1,200 transistors that were fed into the machine, 240 were troublesome, mostly because of malfunction of the mask dispenser and failure of the mask ejector to dispose of the used masks. A mask detect device had been provided to stop the machine when a tube failed to drop into the nest. This functioned properly, but caused the machine to stop repeatedly. This condition created spray gun problems, because the best results are obtained only when spray equipment is triggered continually. Extended time lapses in the process destroy the quality of the finish and hamper spray gun control. The unsuccessful performance of the machine, under these conditions, led to the realization that too many handling operations were being attempted. Consequently, the masking tubes and all the associated mechanisms were removed after developing a modified masking system. This system was installed and evaluated. The evaluation indicates that the permanent masking system developed is completely satisfactory.

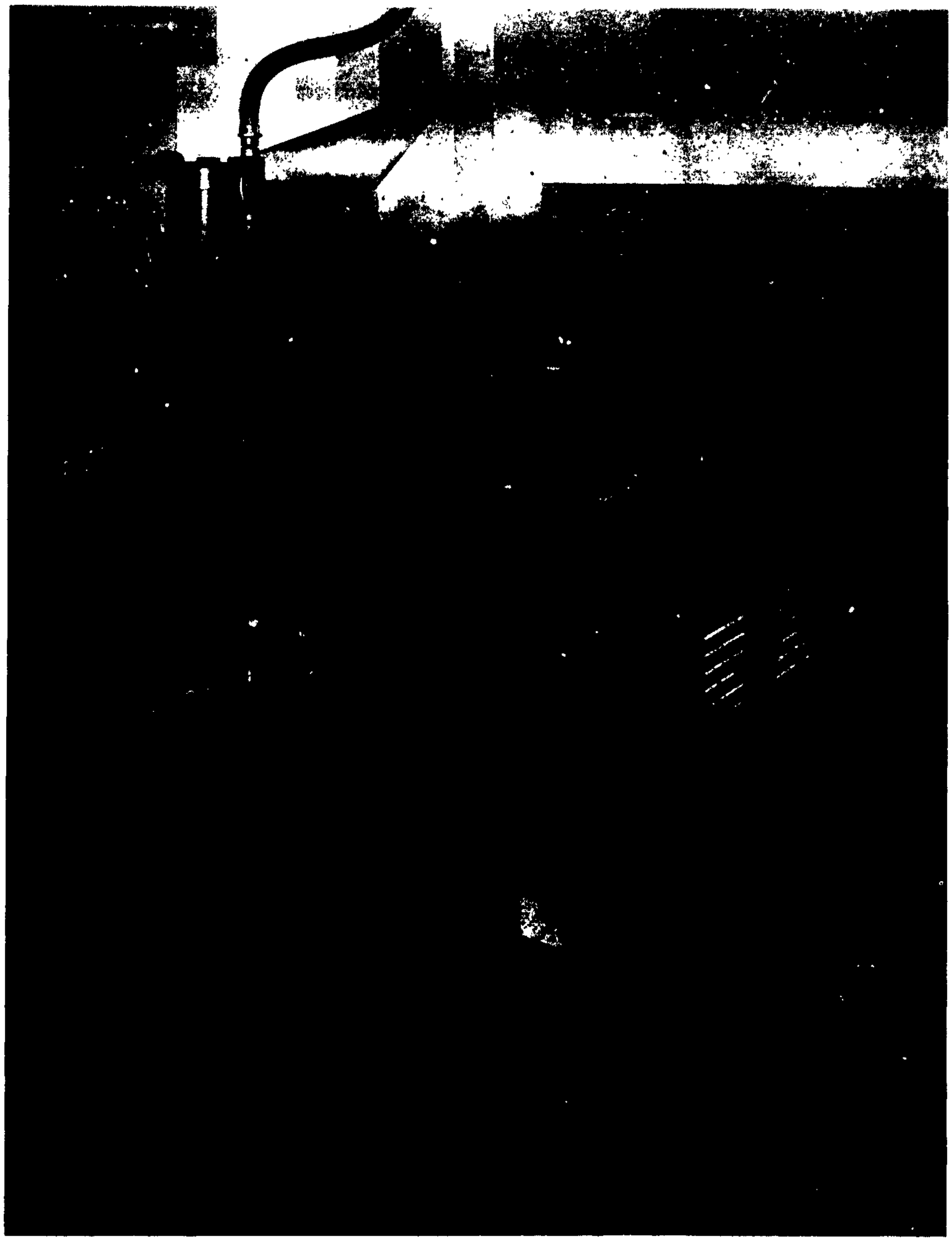
The sample transistors used in these tests were specially loaded in magnetic trays for the demonstration. Extra care was taken to assure that the leads were reasonably straight. This improves the mechanical yield of the process. Nevertheless, the results are significant and show that the machine is functional when proper conditions are maintained.

VI Conclusion

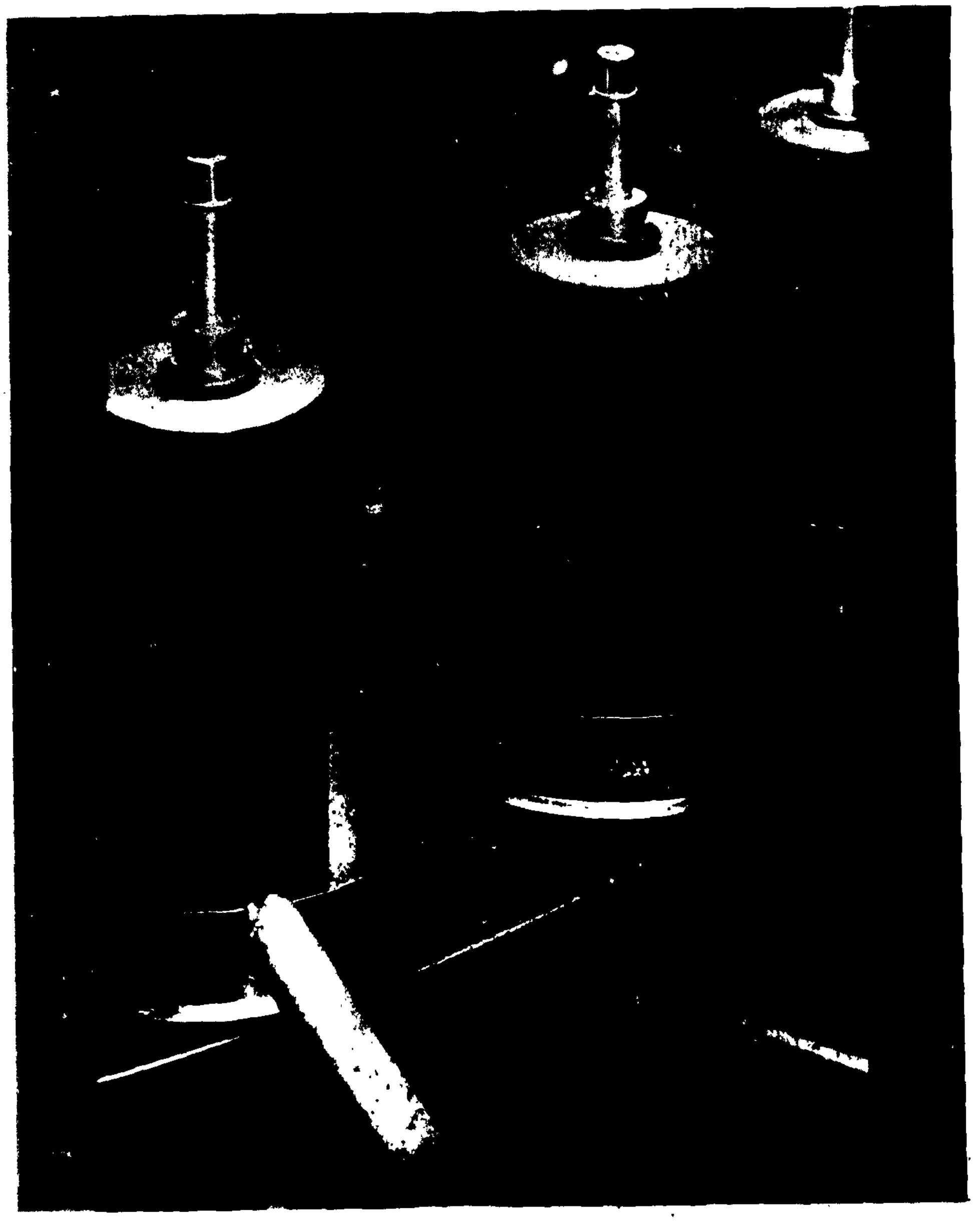
The completion of the automatic Painting and Coating Machine indicates that high speed, fully mechanized, fluid finishing is accomplished readily for TO-18 as well as TO-5 transistor codes.

Changeover time for any requirement is less than 1/2 hour. The output of the machine is twice that of the semi-automatic painting equipment. These facts show that the original engineering goals, for painting and coating, have been expanded and satisfied.

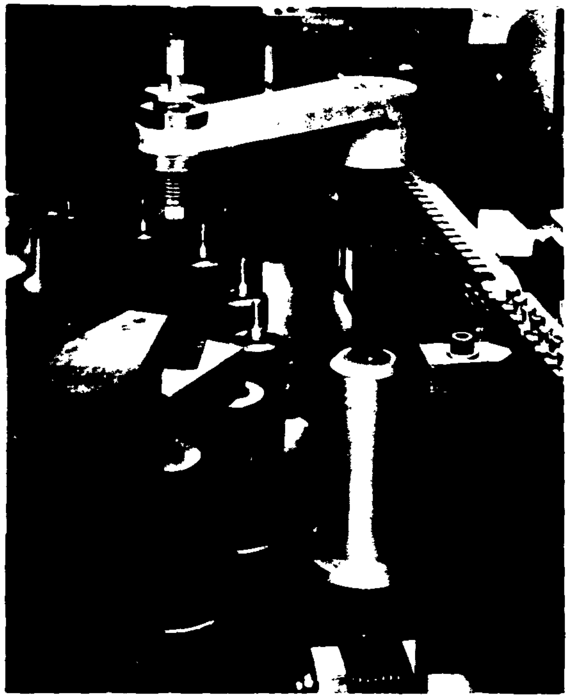
Phase 2 of this program may bring refinements to mechanical transistor handling. Any change in concept that would promote a simplified and more effective mechanized transistor transport would improve the performance of the Painting and Coating Machine.



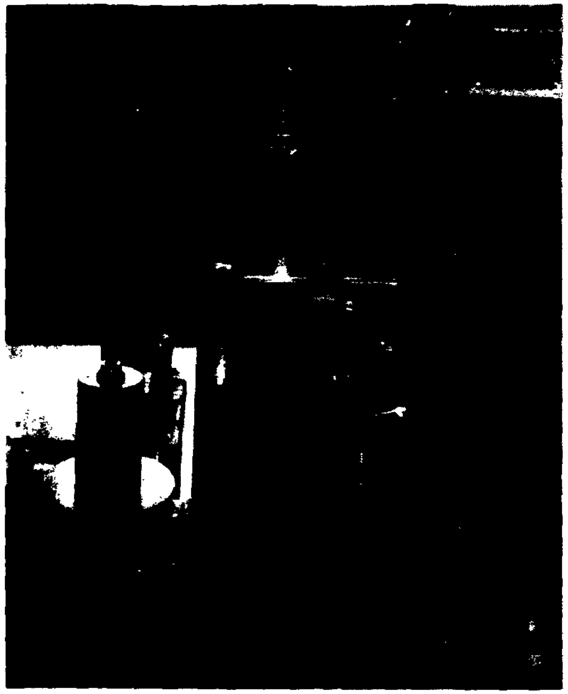
PAINTING AND COATING MACHINE
FIGURE 3.12-1



PERMANENT PAINT MASKS AND NESTS OF PAINTING AND COATING MACHINE
FIGURE 3.12-2



NEST LOADING OF PAINTING AND COATING MACHINE
FIGURE 3.12-3



NEST UNLOADING OF PAINTING AND COATING MACHINE
FIGURE 3.12-4

PAINT SPRAY GUN OF PAINTING AND COATING MACHINE
FIGURE 3.12-5

VARNISH SPRAY GUNS OF PAINTING AND COATING MACHINE
FIGURE 3.12-6

SECTION 3.13

CODING

C. A. Lowell

CODING

I General

Coding is part of transistor identification. The operation occurs near the end of the mechanized transistor production process. Letters and figures indicating code number and date of manufacture must be imprinted on the body of TO-5 and TO-18 transistor cans. In some instances black numbers are printed on gold plated cans. A more common practice is to print white numerals on black enamelled cans. Early in the mechanization program, code markings were embossed into the cans with steel punches and dies. For economy and legibility, the use of ink stamping was adopted for transistor identification.

Mechanized transistor printing employs the basic principles of typography. A light film of ink is transferred from a reservoir to a plate and then to type. The action resembles that of a printing press. By synchronizing the printer with mechanical transistor handling equipment, coding takes on characteristics of a high speed production process.

The following report shows how the Coding Machine applies sound engineering to this phase of semiconductor mechanization.

II Mechanized Coding

The machine is a cabinet type table with the mechanical drives underneath. Figure 3.13-3 shows the machine viewed from the operator's normal station for loading and unloading. The overall machine size is 4 feet long, 4 feet wide and approximately 4 feet high. The magazine and tray handling system occupies one third of the top surface. An air operated index table is mounted adjacent to the tray handling system, with transfer arms conveniently located to carry transistors from tray to index table and back. The coding mechanism is located on the opposite side of the index table from the magazines. Figure 3.13-1 shows the layout of these mechanisms. All exposed surfaces of the table are constructed of stainless steel over angle iron framework. Access doors are located on two sides of the machine. Two sets of "Start and Stop" switches are mounted on opposite sides of the table for convenience and safety.

Transistor coding is accomplished by rolling the printing on the transistor can. To do this, transistors are placed in nests that consist of a pair of back-up rollers with the front open. A small magnet protrudes between the back-rolls and pulls the transistor can into continuous contact with the rolls. Twenty-four such nests are equally spaced about the circumference of an air operated index table (Item 4, Figure 3.13-1). As the table indexes, one nest at a time passes the printing station. This is a Markem side printing coding attachment mounted tangent to the index table as shown by Item 1, Figure 3.13-1. Oscillating motion of the printer is synchronized with the dwell of the index table so that each stroke produces light contact with the transistor and provides both rolling motion and printing action to it. The result is a single revolution of the transistor and a neatly stamped code number on the circumference of its can. The return stroke of the printer matches the index of the table so that no further contact is made with the printer and the transistor.

Loading and unloading can be done by hand; however, the machine is built to place completely assembled transistors in the coding nests, code them and remove them without human contact. A transistor handling system for feeding a continuous supply of transistors to and from the automatic machines was developed, and this system is used on the Coding

Machine. Each holder is a magnetic tray that carries 30 transistors. This tray slips into a magazine that holds 20 trays.

Transistors and trays move in the following manner for mechanized coding: A full magazine is placed in one side of the Coding Machine and an empty one in the opposite side. One magnetic tray moves from the full magazine into a track every 30 indexes of the rotary table. An index pawl engages one of the tray notches and pushes the tray 3/8 inch along the track. A transfer arm, which is synchronized with indexing of both the tray and table, removes a transistor from the tray and places it in the coding nest. Vacuum is used for the pickup force. As transistors are removed, the tray indexes down the track to the point where an unload transfer arm picks a coded transistor from the nest - also by vacuum - and places it in the waiting magnetic tray. When the tray is filled with coded transistors it is pushed into the empty magazine for storage and a new supply tray moves from the full magazine into the track position. This is repeated 20 times per magazine. Items 2 and 3, Figure 3.13-1 show the supply and storage magazines in their respective operating positions. Figure 3.13-2 shows a closeup of the transistor tray (1) in the track with the pawl (2) ready to index in the direction of the arrow. The transfer arm (3) has just placed a transistor in the coding nest (4). The unload transfer arm (5) is shown in the background.

The main power for driving the Coding Machine is furnished by an electric motor; however, compressed air is used for programming the motions of indexing, coding and magazine loading and unloading. Automatic air controls are also used to detect empty and full magazines and to provide fail-safe operation. The main drive motor is equipped with a speed changer that permits dialing machine speeds from zero to top speed. Maximum operation rate is 30 indexes per minute or a production output of 1,800 per hour.

The Coding Machine operator has several duties in addition to putting magazines in place and changing them when the machine has exhausted the supply area and filled the storage area. Periodic inspection on coded transistors must be conducted and overall surveillance of the machine for mechanical defects or malfunction must be maintained. The transistor printer must be supplied with ink, cleaned periodically by brushing the type with solvent, and thoroughly cleaned at the end of the shift.

Although the Coding Machine creates no hazardous atmosphere itself, in the form of vapor or fumes, explosion proof electrical devices, conduit, and fittings are used to provide maximum safety. The extensive use of pneumatic controls also lowers the risk of electrical arcing. These features permit installation of the Coding Machine close to spray finishing or vapor cleaning processes.

Periodic lubrication, with particular emphasis on the pneumatic line oil system is required. Sticking air valves and excessive wear will hamper machine performance if this is neglected.

III Development

At one time embossed markings in metal cans were considered for 2N559 transistors; this coding process finally developed into rubber stamp imprinting. Embossing lacked update flexibility, legibility and optical contrast. Its permanence could not be questioned, but the undesirable features outweighed this and rubber stamp transfer printing supplanted the embossing process. Contrast, clarity, economy and performance were assured by the use of heat curing, marking compounds.

Manual coding operations make use of commercial stamping machines that are designed strictly for printing. Hand loaded holding fixtures were required to make useful transistor coding tools from the printing devices. Manual loading and unloading of commercial printing machines is satisfactory from the standpoint of coding quality and uniformity; however, the material handling requirements of this operation limits the printing machine's output capabilities. Feasibility studies were directed toward combining a commercial printing system with a universal transistor handling system that would completely mechanize the process. Since the magnetic tray handling concept was resolved, the Coding Machine was designed to use it and a Markem Coding Attachment to load, code and unload transistors on a fully mechanized basis.

As the machine neared completion, the transistor coding program was expanded to include marking operations for TO-18 as well as TO-5 transistor codes. This added problems to the project such as providing change-over nests, transfer chucks and tray index modifications for TO-18 trays with smaller slots. Since the original design was to accomodate the TO-5 transistor of larger size, the handling problem was increased when attempts were made to load and unload the smaller transistors in the restricted nest areas. A loading platform with an air blast directed toward the nest (Item 6, Figure 3.13-2) made the nest loading possible. To unload the TO-18 transistors a hook-type vacuum chuck had to be developed to allow the chuck to position over the transistor because of its inaccessible nesting condition (See Item 4, Figure 3.13-2).

Final machine prove-in effort was necessary to provide the following refinements for automatic transistor handling and coding:

1. Increase the Maximum Machine Operating Speed

   The index turret's inability to operate faster than 1,200 cycles per hour limited the machine output to this amount. By modifying a pneumatic control valve, a 50 percent increase in machine speed was achieved.

2. Improve Loading and Unloading Transistors with Bent Leads
   Adding clearance at critical points of transistor travel, in the coding nests and tray guide track, prevented mechanical malfunction when crooked leads were encountered.

3. Eliminate Potential Jam-Ups in the Magnetic Tray Indexing System
   A special air operated, tray sensing device was developed to detect the presence or absence of a tray in the guide track at a critical time. This prevents index jamming and assures effective performance of this part of the machine. Improvements were also incorporated in transistor sensing applications because failure to mechanically load or unload the nest sometimes occurred. Detecting this condition and preventing transistor pile-up was satisfactorily accomplished by perfecting the pneumatic sensing devices.

4. Improve Quality of Stamping with the Markem Coding Mechanism
   The usual rubber stamps used on the Markem commercial side printer proved unfit for mechanized transistor coding. One part of the printer rotated the transistor while a separate level did the stamping. The dual arrangement was difficult to set up, adjust, and change-over because of the level difference. The stamp setup

operation was quite frustrating because pressure for rotating and printing is very critical. To simplify the conditions, a one-piece stamp was made that includes both the rubber driver and the printing type. This combination gives excellent stamping with minimum set-up and adjustment.

IV Machine Performance

Because of a lack of sufficient cleaning equipment no transistor production has been assigned to the Coding Machine. Nevertheless, evaluation tests were conducted to demonstrate the capabilities of the machine. For the latest tests, 1,800 transistors were loaded, coded and unloaded mechanically. Results of the demonstration were divided into two categories to evaluate both the performance of the material handling system and the stamping attachment. The first test was conducted before the dual purpose coding stamp was acquired; in fact, this test demonstrated the need for an improved stamp. Malfunction of the transistor handling system occurred with 160 transistors because of bent leads that would not re-enter the slots of the magnetic trays. The same condition contributed to improper transistor rotation in the coding nest, which caused smudged ink with no printing.

For the second test, cleaning of the type was necessary five times during the demonstration or after every 240 stampings. The coding phase showed a lower yield than the mechanical handling phase because several poor stampings resulted before the cleaning cycle was established. Compressing the cleaning schedule corrected the condition.

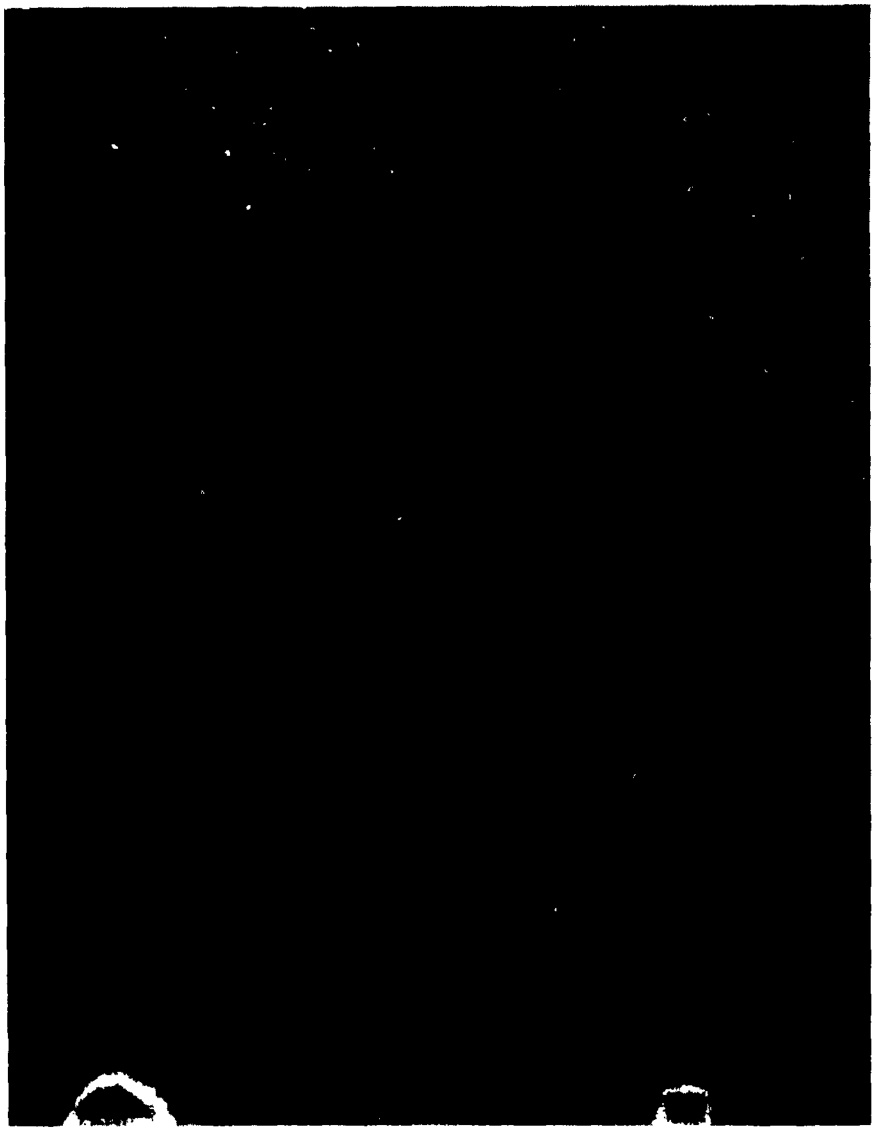
To evaluate the versatility of the Coding Machine, some shop trials were conducted using a manual loading technique. This mode of operation is feasible when the universal material handling system is not used. Short runs or special product sometimes present the need for manual loading. The coding turret, printer and unloader are used for this operation; the magnetic tray material handling system is not used. It was shown in the manual loading trials that an operator can load transistors into coding nests at a rate of 1,000 per hour. The printing and unloading portions of the machine behave similarly with either mechanized or manual loading systems, and the conversion time required for changeover is small.

VI Conclusion

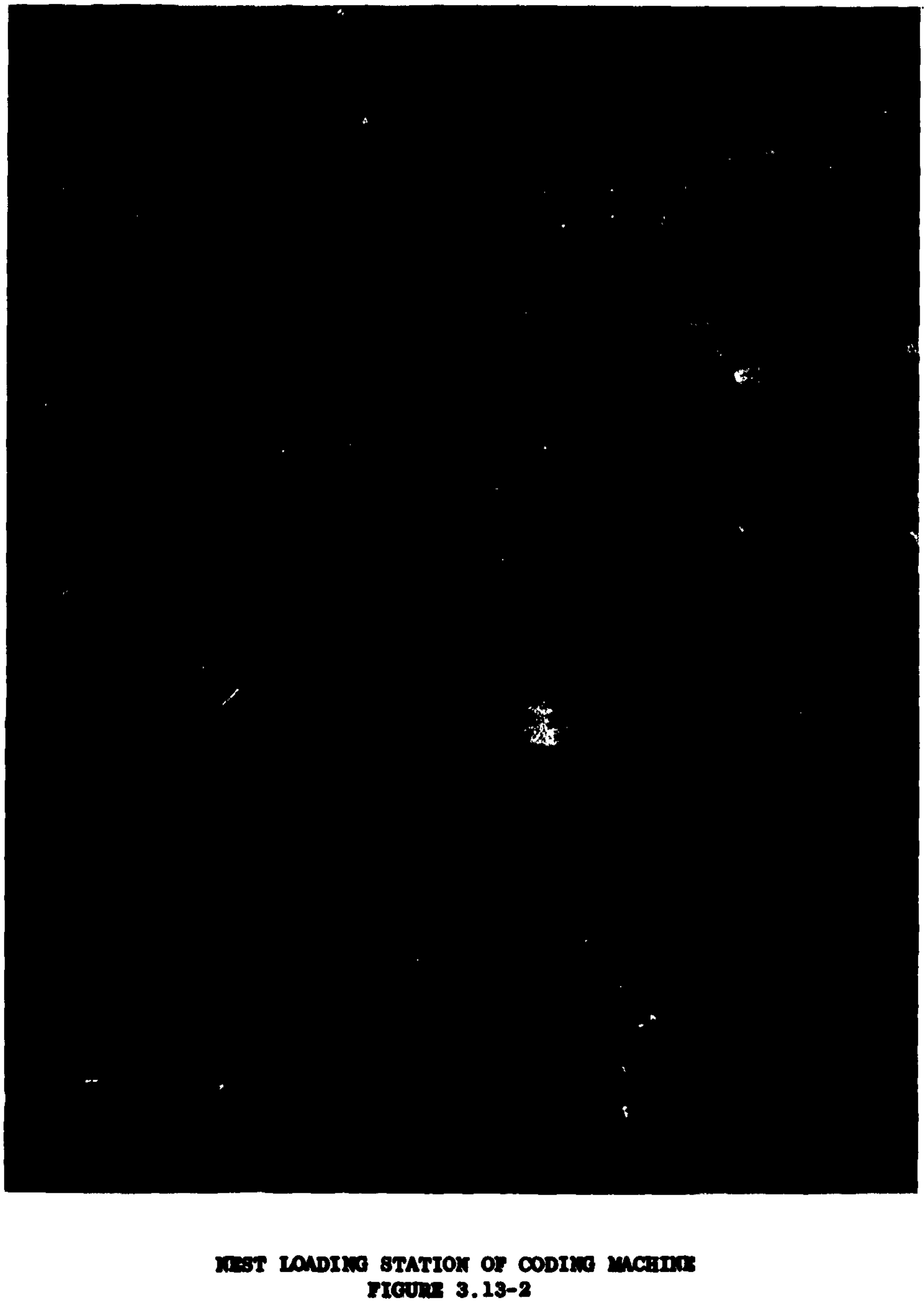
A successful program for mechanized transistor Coding has been completed. In the prototype machine a commercial printing mechanism has been improved and integrated with a universal transistor handling system that was designed for the mechanized production equipment. The combination achieves fully automatic Coding for TO-5 and TO-18 transistors. One operator using the machine fully mechanized can produce seven times the amount produced on a modified commercial printing machine. Manual loading of the machine produces four times the usual production of the commercial coding machines currently in use.

In addition to the increased output, the development of the single unit, combined driver-stamp for the side printer is a definite advance in the art of transistor coding. Cleaner cut stamping, quick replacement and overall economy have been added to mechanized Coding by this modification.

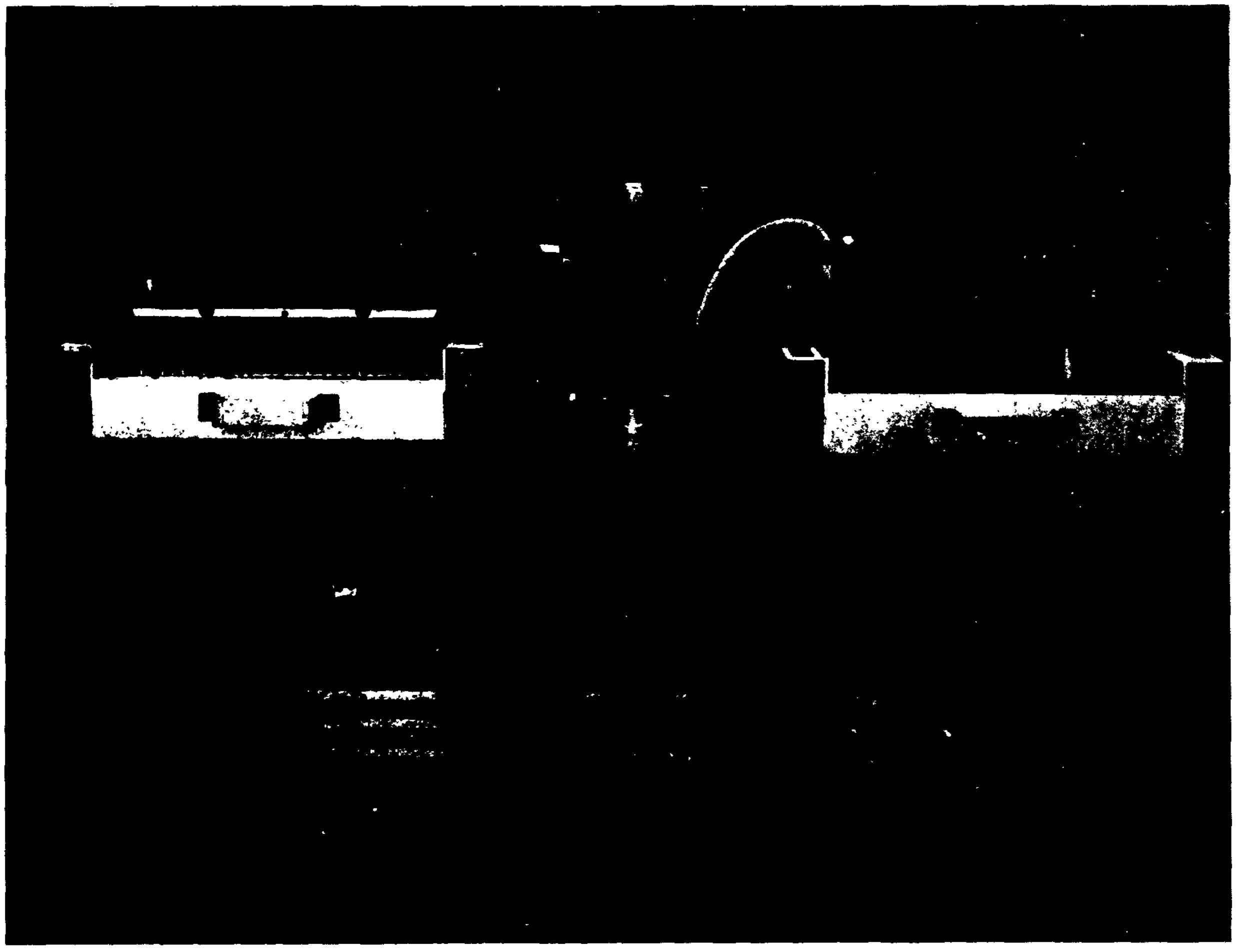
Transistor coding tests described in this report indicate that the main restriction of the mechanized process is the need for halting the operation to clean the stamp after every 200 imprints. Studies have been conducted with marking compounds to find a self-cleaning additive that will prevent ink build-up on the stamp - a cause of poorly defined letters. Perhaps a stamp material can be found that will resist ink build-up. In lieu of either condition, an automatic cleaning brush, synchronized with the printer motion, should be considered. The possibility of development in this area is real and will improve the performance of the present Coding Machine.



TRANSISTOR CODING MACHINE
FIGURE 3.13-1



NEST LOADING STATION OF CODING MACHINE
FIGURE 3.13-2



CODING MACHINE SHOWING LOAD AND UNLOAD MAGAZINES

FIGURE 3.13-3

SECTION 3.14

PACKING

C. A. Lowell (WE)

PACKING

I General

High speed output, 100 percent perfect production, and infallible machine reliability are goals which have been set for this packaging program. The need for these capabilities engendered an engineering challenge: To improve the process and implement it with the necessary mechanization.

Packaging transistors may appear to be less critical than manufacturing them. However, the finished state of the product, at the packing stage, creates a boundary that outlaws lack of control in handling transistors. Machine performance must limit the percentage of scrap to zero. Conformity to such a standard rules out erratic transistor handling and removes the packaging problem from the commonplace. The machine which is described in this report, resolves the problem effectively.

II Mechanized Packing

Strip type packaging of completed 2N560, 2N1051, and 2N1195 transistors is accomplished on the Packing Machine. Each transistor must be individually sealed in a very thin plastic pack. A continuous series of packages is produced with code number and date printed clearly on each plastic package. Cross strip perforations between packages provide a method of separating the strip wherever desired.

The Packing Machine consists of a standard Model A Pak-Rapid Drop Feed Type of Packing Machine and a synchronized hand fed conveyor that drops the transistors into the machine. Figure 3.14-1 shows an overall view of the machine.

Plastic film enters the machine from supply rolls on either side. Printing of the code number and date occurs at the lower right hand side as one plastic strip enters. The plastic films converge over the top of two heated sealing rolls and are formed into a single strip of envelopes as they pass between the rolls. Immediately before sealing, a transistor is dropped at a predetermined spot and carried into the envelope. The strip of packs is perforated and then feeds out of the machine over the inclined conveyor at the left.

The hand feeding attachment consists of a timing belt with nylon buckets mounted outside. An operator places transistors in the buckets as the belt moves to the left. The units are carried into a circular guide that provides a cover until they reach the emptying point close to the heat-seal rolls. A magnetic field controls the units after discharge from the bucket and prevents misalignment of the leads during the transfer to the packing point. The conveyor belt is synchronized with the Pak-Rapid machine by means of a gear system. Speed adjustment to suit the pace of the operator may be made by changing the machine speed regulator.

Figure 3.14-2 shows the general arrangement of the conveyor attachment. Plastic guards cover hazardous portions, leaving an exposed loading area 5 inches wide and 2 feet long. The plastic shelf directly in front of the conveyor affords a material supply area for convenient manual pickup..

Placing transistors in the moving conveyor receptacles is the chief concern of the operator. Best results and greatest speed are attained by handling two units at a time in rhythmic fashion. Periodic pauses for inspection of the quality of the packages allow time for relaxation of the operator's pace. Correct functioning of the critical elements of the process is also assured by maintaining intermittent surveillance of the product.

Criteria for accuracy, in the sense of micro-inch adjustments, present no problems in maintenance of this machine. The important requirements are timing and repeatability of the process. Carelessness in feeding the machine may cause interruption of both these conditions and present a need for adjustment or repair.

III Development

Automatic transistor packaging was the outgrowth of an investigation to determine the package type best suited for transistor users. A commercial Pak-Rapid machine was purchased to provide attractive strip packing at low cost and relatively high speed. Strip type packaging, as such, was acceptable because of the unit separability feature that permits flexibility of shipping container size.

The machine proved to be practical for ordinary production requirements. Its chief limitation was its failure to effectively synchronize the drop feed with package sealing. Units were individually hand positioned in a mechanical gate at the bottom of a 5-inch deep recess. This was a slow procedure that sometimes resulted in unsatisfactory packages and machine jamup. Maximum packing output by this method was 1,600 units per hour.

With expanded production quotas anticipated for Nike Zeus, a feasibility study was conducted to increase the output of the Pak-Rapid machine. Initial studies were directed toward a tray type feeding system for the machine. A design of this system was made, but a cost review indicated that forecasted production quantities did not warrant a completely mechanized feeding system.

Further study of the problem ultimately led to a hand fed conveyor attachment for the Pak-Rapid machine that would provide a continuous flow of transistors to the packing point of the machine. A prototype conveyor that incorporated the bucket principle was constructed. Free drop of the transistor, at the center point between the heat-seal rolls, seemed desirable since this approach required least modification to the Pak-Rapid machine.

During prove-in and shop trial of the conveyor attachment 1 to 3 percent of the transistors were damaged by pinching the leads in the heat-seal rolls. This was due to the unbalanced mass of the transistor and the lack of control during the free-fall into the pocket. Since no damage to completed transistors is tolerable, the concept of the attachment was changed by installing permanent magnets in the packing pockets of one heat-seal roll of the Pak-Rapid machine. The point of discharge of the transistor carrier was moved to the top center of the magnetic roll. This assures full control of the transistor from the operator's hand to the sealed package.

Shop trials indicate that the combination of the commercial packing machine and the feeding conveyor now offers simplicity of operation plus reliable performance at high speed. As a basis for this conclusion 6,000 transistors were packaged with a production yield of 100 percent. The machine performed well at an output speed of 3,000 completed packs per hour with a good possibility of increasing this amount to 4,000, if required.

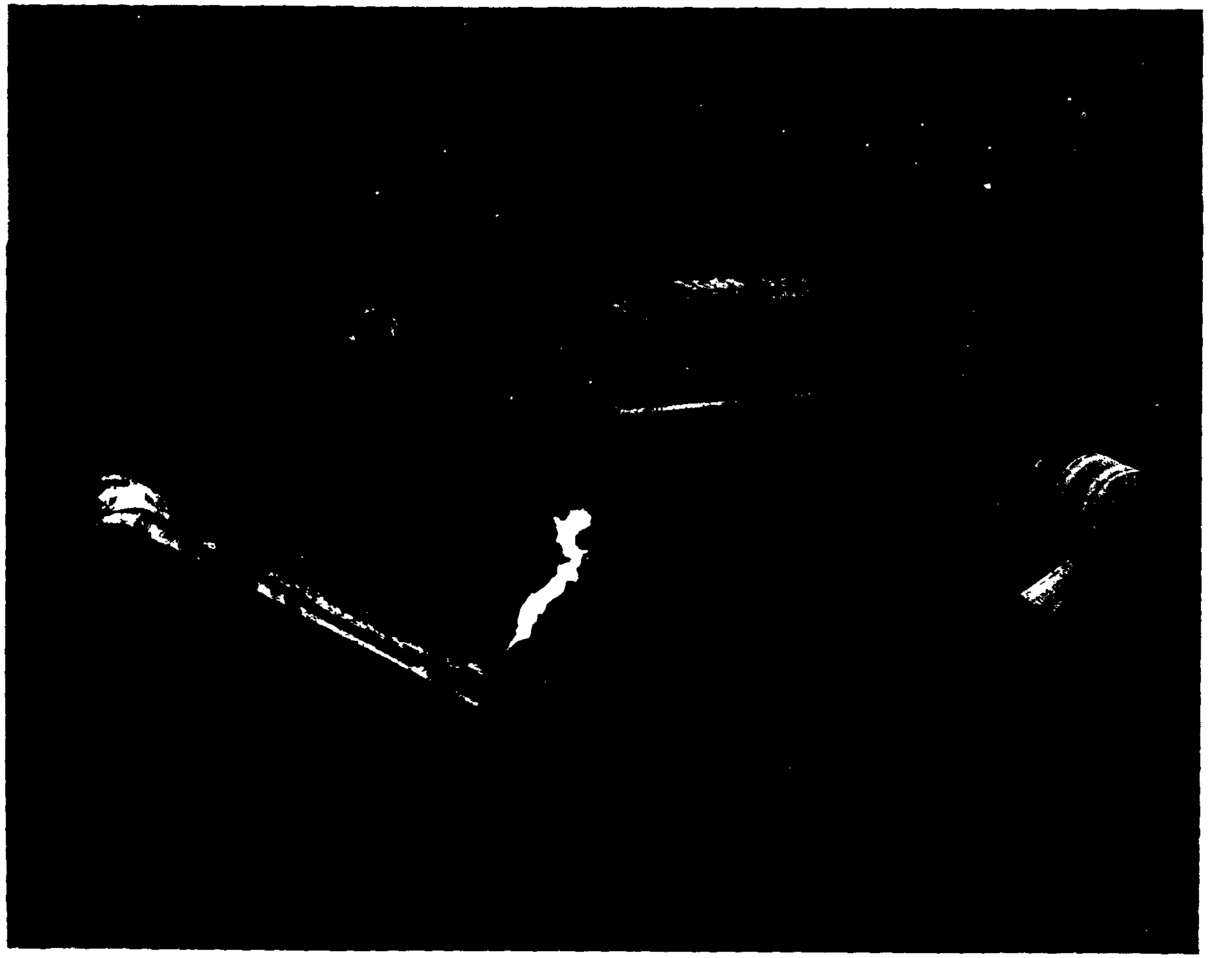
The strip packaging technique is not confined to any particular code. During the prove-in and shop trials the versatility of the hand-feeding attachment was evaluated by packaging a wide variety of semiconductor devices. The use is restricted only by the size and material of the unit. Within the limits of 1/2 by 1/2 by 4 inches, any device with ferrous material at its axis can be packaged with no difficulty.

IV Conclusion

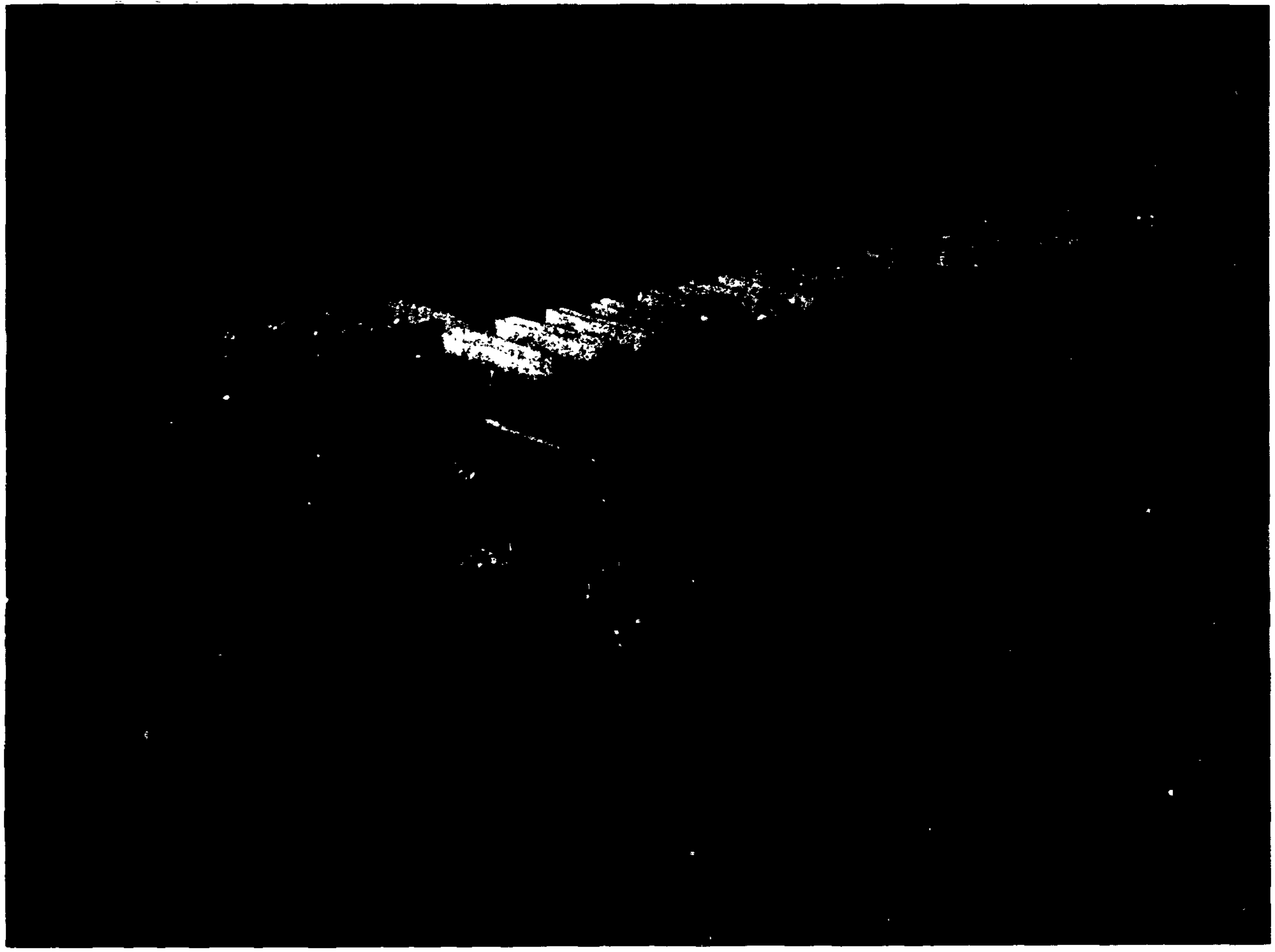
A modern packaging concept has been integrated with a novel feeding idea to produce a reliable method of preparing and protecting transistors for shipment and customer use. Careful handling and attractive wrapping of individual transistors are assured by the process. Features that characterize the completed Packing Machine are:

- 100% reliable packaging of completed transistors
- High output
- Simple to operate and easy to feed
- Little maintenance

The goals reached in this packaging project provide a basis for complete mechanization of the operation. Such a development could lead to placing large quantities of transistors in a chute that will arrange them in a symmetrical fashion and drop them into the conveyor, simulating the hand feeding operation described in this report. Although such a development would replace the efforts of a full time operator, mechanical problems that would decrease reliability could be encountered. In consideration of the usual transistor handling problems and the susceptibility of the product to damage, concept simplicity and minimum mechanical transfer must be assured by any plans for expanded packaging mechanization.



PACKING MACHINE
FIGURE 3.14-1



CONVEYOR ATTACHMENT OF PACKING MACHINE
FIGURE 3.14-2

SECTION 3.15

WAFER SCREENING AND ELECTRICAL PROBE TESTING (2N1072)

C. A. Lowell

G. B. Loughery

P. A. Lajoie

WAFER SCREENING AND ELECTRICAL PROBE TESTING (2N1072)

I General

Electrical testing of semiconductor wafers before assembling them into finished transistors is a sensible and economical procedure in a high production effort. The electrical yield of finished transistors depends on the electrical characteristics of the wafers. For example, if the product yield at final testing is 50 percent, probably 10 to 30 percent of the wafer material was defective before assembly. To prevent this wasted effort, attempts at pretesting the wafers before assembly have proven to be effective. Some pretesting has been accomplished by hand probing and testing alloyed slices before wafering. This is effective but slow.

Application of the probe test process to individual wafers in an automatic wafer screening machine has been accomplished through the 2N1072 Wafer Screening and Electrical Probe Testing development. This machine, which combines optical screening with automatic handling, not only tests wafers electrically, but takes them from a bulk container, turns them over if necessary and places them in trays for storage and further assembly operations. The wafers screened in this machine are relatively large (.030" x .080") which simplifies the probing operation.

A prototype wafer screening machine concept was integrated with a mechanized probe and test set combination to provide an effective means of complete wafer screening. This report describes the mechanics, electronics, engineering effort and machine performance associated with the successful completion of this important phase of semiconductor mechanization.

II Description

The screening machine for 2N1072 wafers has used the wafer handling concept from the prototype 2N1195 Wafer Screening Machine that was developed to orient, screen and load .020-inch-square wafers into wafer trays. The physical construction was altered to allow more table top area and provide space for test set equipment. Instead of converting a vertical screen floor model, optical comparator into a wafer screening machine, a desk type was chosen that is large enough to accept all mechanical and electrical construction and rugged enough to support a Nikon Bench Model Optical Comparator. Figure 3.15-1 is an overall picture of the machine.

The operator's position is at the portion of the desk that is recessed for leg clearance. Wafer handling takes place on top of the desk directly in front of the operator. The optical comparator screen is centered over the desk at the operator's eye level. The desk top is 5 feet long by 3-1/2 feet wide and its height is 2-1/2 feet. The comparator extends 2 feet above the desk top. All manual controls are in front of the operator.

III Wafer Screening

The mechanized 2N1072 Wafer Screening layout is shown in Figure 3.15-2. Two individual handling systems are coordinated in the machine to accomplish the complete screening process: one handles the wafer trays and the other the wafers.

A wafer tray (1) and a wafer tray magazine (2) are shown in the lower right hand corner of the picture. The flow of wafer trays starts at 3 where a full magazine is placed in the receptacle. One tray at a time is pushed from the magazine into the index track (4). Each tray indexes along the track, stops long enough to receive screened wafers in each of 50 wafer pockets, and indexes to the end of the track. At this point a pusher loads the full wafer tray into the waiting magazine at 5. The capacity of each magazine is 6 wafer trays or 300 wafers.

The wafer screening sequence starts at the vibratory bowl feeder in which loose wafers are placed. In Figure 3.15-3 wafers may be seen in the bottom of the bowl (1). Vibratory action of the bowl feeds them in line to the point of pickup at 2. From there the following sequence occurs:

1. A transfer arm (3), with a vacuum needle, picks up the wafer from the track and deposits it in a nest of the nylon index table at 4.
2. The table then rotates 90 degrees and takes the wafer to 5.
3. Here an optical sensing lens assembly scans the wafer to determine whether or not it is stripe-side up. This scanner assembly was removed for photographing because it concealed details of the mechanisms. (6 in Figure 3.15-2 shows the scanner out of position.)
4. If the wafer is stripe-side up, no flipping is necessary; after indexing 90 degrees more, the first flipper needle located in the housing at 6 takes the wafer across the gap to the second nylon rotary table.
5. If the wafer is bottom-side up, it is turned over by the combined action of 6 and 7. The needle located in 6 picks up the wafer and rotates 90 degrees counter-clockwise; at the same time 7 rotates 90 degrees clockwise aligning both needles on the same axis. Vacuum is deactivated at 6 and activated at 7 and both housings

rotate back to position shown, where the wafer is released from 7 into the empty nest of Table 2.

6. Table 2 then indexes 90 degrees bringing the wafer under the lens of the comparator (8) which is also the electrical probe position.

7. The only manual portion of the screening process takes place now. The operator views the wafer on the screen at 100-power magnification. If a defect is apparent, a REJECT button is pushed that sets up a memory circuit and prevents the wafer from being loaded into the tray. Instead, it will be ejected from the nest when Table 2 indexes 180 degrees from the screening position. If the wafer is visually acceptable, the operator aligns the probes with the wafer stripes and starts the electrical tests by pushing the TEST button.

9. The TEST button actuates the probe-test mechanism (part of this is shown at 9 in Figure 3.15-3) which contacts the wafer stripes and initiates the test set to make BV_{EBO} and BV_{CES} (breakdown voltage) tests.

10. The test set automatically programs an ACCEPT or REJECT signal for the wafer and sets up the mechanism to carry the wafer to the tray if good, or eject it at the REJECT position if bad.

11. The wafer tray loading position is shown at 10. The accept or reject signal is no more than the difference between vacuum or no vacuum at 10, so that defective wafers bypass the pickup. The transfer arm makes its

usual stroke each time regardless of whether it carries a wafer or not.

12. Since voids in the wafer tray pockets are undesirable, the tray does not index if a wafer is rejected either by the operator or the test set.

This completes the wafer screening sequence. The entire cycle may take from 4 to 6 seconds per wafer, depending on the speed of optical screening. Details of the wafer probe and test function are described in the Development Section of this report.

IV Development

The possibility of combining electrical and mechanical wafer screening into a single machine was considered for some time. The concept remained dormant during the development of wafer screening machines for .020 and .030-inch-square wafers because of the intricate problems associated with probing the ultra-small stripes of these wafers. The dual machine concept of the 2N560-2N1051 Wafer Loading and Wafer Screening came first. Soon this was refined into the concept of the 2N1195 Wafer Screening Machine which eliminated the need for a separate Wafer Loading Machine. By this time a slice probe testing program had been initiated for the .040 by .080-inch 2N1072 wafers. Each set of stripes on a slice was tested for breakdown voltages on a special machine before the slice was cut into wafers. This was the sole purpose of the machine, but it was a step in the right direction. If probing could be done in the slice state, it was believed that wafers could be given the same tests in a screening and loading machine; so the less desirable features of the 2N1195 Wafer Screening Machine were refined and an experimental probe testing station was developed with the idea of incorporating it into an improved machine. Several tests were conducted with the experimental probe-test station. The results of these are discussed later under electrical test development.

A. Mechanical

Engineering effort during the mechanical design and construction of this machine was directed toward providing the utmost precision and smoothest possible operation for each mechanism, because inaccuracies and vibration add trouble to wafer handling. Special attention was devoted to improvement in the following areas:

1. Cams

   Smooth operation of each mechanism actuating the rotary tables, transfer arm, and flipper depends on cam configuration and size. Optimum performance was achieved by increasing cam size as much as possible and designing them for simple harmonic motion. Cam size had been limited by restricted space in the prototype machine; every effort was made to avoid this on the subject machine. This meant making room for larger cams by increasing the available space; redesigning the drive assembly and associated framework accomplished this. Face groove type cams were provided wherever possible to constrain the followers to positive drive action. Precision fitting of cam grooves to cam followers reduced lost motion to a minimum.

2. Linkages

   Cam follower tolerances can be magnified excessively in the transmission of force from cam to application point by carelessness in designing and making the connecting linkages. Care was taken to reduce this error or to compensate for it by providding adjustable links and positive stops. In some instances, corrections were necessary after initial construction because the exact nature of the clearance problem could not be predetermined.

3. Accurate Wafer Nest Location and Construction

A definite breakthrough was made in achieving an effective method of machining the .040 by .080 inch wafer nests in the rotary index tables. Precision swaging was tried successfully on sample material; the results were so gratifying that the same method was applied to the nests in the table. Maximum accuracy was obtained for nest dimensions and location. The simplicity and economy of this procedure makes it practical for use wherever wafer pockets of any size are required.

4. Positive Electrical Contact and Vacuum Seal at Screen and Probe Station.

During the dwell of the screening index table at the probe and screen position, current must be supplied to the wafer nest for testing. An improved concept was designed during machine construction that provided a positive connection to the nest insert for intermittent rotary contact. Positive wafer holding is also provided at this station by applying vacuum through the nest; a space problem in the nest area resulted from the combination. Rearranging the electrical contacts, at the same time they were improved, left more space underneath the nest for the vacuum supply line and seal.

5. Vibratory Bowl Feeder

At its best the vibratory type wafer feeder is a problem. Its use on this machine followed the concept established for the 2N1195 Wafer Screening Machine; no better means of feeding loose wafers has been found. To feed wafers satisfactorily required a good deal of experimentation. Consistent performance was finally achieved by modifying the straight portion of the track leading to the wafer pick-up point, and by changing vibratory frequency from 60 to 75 cycles per second.

6. Positive Positioning of Transfer Arm and Flipper

After construction of the wafer transfer subassemblies, a test run was made as part of final machine assembly and prove-in. This indicated the need for positive positioning of the transfer arm at both ends of its stroke, and to limit the flipper travel to zero deviation from a predetermined point. A general build-up of tolerances in the linkage and roller arms caused inaccuracies in transferring wafers. By installing fitted pins in the transfer and flipper assemblies and mounting a slotted guide plate beneath them for the pins, the motion of the two assemblies was restricted so that accurate positioning was possible at each end of their strokes.

7. Plastic Wafer Trays

The .040 by .080-inch wafer presented another problem: No wafer trays were available for this size wafer. Previous wafer screening machines had been provided with stainless steel trays. Since new trays were required for the 2N1072 wafers, feasibility of plastic trays was investigated. The first plastic trays were made by injection molding at considerably less cost than the equivalent in steel. The necessary accuracy for screening and subsequent operations was achieved by using special curing and cooling techniques. Successful trials with the plastic trays during the prove-in of the 2N1072 Wafer Screening Machine resulted in adopting them for continuous use with the machine.

Mechanical prove-in of the 2N1072 Wafer Screening Machine was minimum because progressive prove-in was coordinated with the construction phase. Some minor problems in timing and adjusting vacuum control were resolved as well as a modification to the projector mounting system. Attempts to focus the lens indicated the need for adjusting the working distance. A simple device was made that permits the operator to change focus conveniently by turning a hand knob on the control table in front of the projector.

During prove-in a rather extensive test was run to check the operation of the wafer handling system. Wafers were picked up by the pick-up needle and indexed through all stations and finally inserted in the wafer trays. During these operations records were obtained which show the drop-outs sustained at each operation. Two groups of wafers (quantity: 200 and 500) were run separately on different days to obtain representative data. The results of these tests are tabulated in Figure 3.15-9. Most of the drop-outs are caused by the vibratory feeder which is quite difficult to keep properly adjusted. Relatively little trouble is noted for the flipping mechanism.

B. Wafer Sensing

The mechanism to flip wafers so that all would be stripe-side up for screening and probing was conceived after it was determined that side orientation of a wafer can be sensed. The original work was done with 2N1195 wafers and then applied to 2N1072 wafers. After examining wafers under a microscope, it became apparent that there is a difference in the reflective properties of the wafer surfaces which might be utilized for sensing. An optical-photocell system was devised which discriminated between the stripe-side and back of a wafer by sensing the intensity of reflected light. Here it must be understood that what the human eye sees and what a photocell sees is quite different. The photocell is a photoconductive element, the electrical resistance of which is related to the average intensity of the light reaching its surface. It cannot distinguish shapes or contrasts on a particular surface but it can distinguish minute differences in the average intensity of two surfaces examined separately. The human eye, on the other hand, can distinguish shapes and contrasts on a particular surface but has a difficult time distinguishing the difference in the average intensity of two separate surfaces unless the difference is great. This became quite obvious during the development of the sensing system and care had to be taken when wafers were examined under a microscope.

Sensing the 2N1072 wafers presented a problem when it was observed that the back-to-front intensity ratio was precariously near unity. Several types of photoconductive cells were tried each with a different spectral response distribution, but not until the light was filtered to pass only a portion of the spectrum was the problem solved. A ratio of anywhere from 3:1 to 4:1 is satisfactory because then there is little likelihood of intensity variation overlap and a margin can be established.

C. Electrical Testing

Feasibility studies on wafer probing are complete and results are discussed. To date, only BV_{CES} and BV_{EBO} have been studied. It is expected that h_{FE} and $V_{CE}(sat)$ will be worked out after additional development work is completed. The prototype probing mechanism is shown temporarily installed in Figure 3.15-4. This mechanism and associated equipment was set up for the experiments as shown schematically in Figure 3.5-6.

It was decided that the testing sequence should begin with the BV_{EBO} measurement because the measurement of BV_{CES} involves power dissipation of up to 100 milliwatts. If the test sequence is reversed, heating of the small wafer would be appreciable during BV_{CES} measurement and the reading of the subsequent BV_{EBO} test could be affected significantly. It is also important that the ambient light be low, since these devices are photosensitive. A power supply that is adjustable from 0 to 150 volts was used so that the proper bias currents could be accurately set. This supply was set to zero before the probes were moved or the switch changed. For this experiment, the probing mechanism was provided with two limit switches so that the probes could be lowered onto, and removed from, the stripes in a uniform manner for all wafers. The probing mechanism would, therefore, change from one stable state (probes retracted) to its other stable state (probes down on stripes) upon momentary contact of a third switch.

Osmium tipped phonograph needles were used for probe contacts. The tips were given a 0.002-inch radius so that stripe pressure was not excessive. The effective weight on each probe tip was adjusted to suitable values by means of two 10-24 bolts whose effective length determined the moment applied about the probe pivot bearings. Probe overtravel was adjusted so that a small wiping action occurred on the stripes. The slight plowing of the aluminum stripes was not objectionable. In an effort to minimize variable probe weight, Litz wire was used to connect the phonograph needles to a terminal strip on the main carriage of the mechanism. This wire was clamped to the probe fingers near the pivots to further reduce undesired moments. Collector contact is furnished by a gold plated copper nest inserted in a bakelite base.

Test specification limits to be used during probe testing are:

BV_{CES} (I_C = 1mA) --- 60 V min.

BV_{EBO} (I_E = 30μA)--- 2 V min.

whereas test specifications of the completed device specify:

BV_{CES} (I_C = 1mA) --- 75 V min.

BV_{ECO} (I_E = 100μA)--- 6 V min.

In order to eliminate an added variable, it was decided that BV_{EBO} should be measured at 30 microamperes for wafer probe testing and also for the testing of the completed device.

Before any testing was started, each wafer was cleaned and put in a clean numbered bottle. Identity was carefully maintained through all processes down to the completed transistor. Before the cleaned wafers were measured, the probing mechanism was adjusted using uncleaned wafers. A great degree of intermittency was observed in the readings of many of these wafers. Increasing contact force lessened the condition somewhat but some readings remained unstable. It was felt that dirty junctions caused a majority of the trouble. One hundred eight scrap wafers were obtained of which 50 were selected by visual inspection to be used in this experiment. Of the 50 wafers selected for probe evaluation, seven dropped out before being wafer bonded. Two of these were too wide for the probing fixture nest; three were lost; one had smeared tripes, and one exhibited "foldover" on the BV_{CES} test and could not be measured. After processing, one transistor had an open emitter. Therefore, 8 out of the original 50 or 16 percent are not being considered.

After wafer probing measurements were completed and results tabulated, it was found that about 10 to 12 percent of these devices exhibited intermittent readings on either or both parameters. The completed transistors showed about 38 percent intermittent readings on either or both parameters. It, therefore, appears that probe-stripe contact was satisfactory.

Readings of the 42 units are plotted in Figures 3.15-7 and 3.15-8. Since wafer probe readings are plotted versus completed device readings, any points to the left of the diagonal line represent devices which were degraded by the various shop processes. Any points below the line represent devices which improved on that particular parameter after these manufacturing processes. Points falling on the line, of course, represent devices which gave the same reading at wafer probing and at final test. Figures 3.15-7 and 3.15-8 are plots which show overall results obtained. The dots indicate devices which never exhibited intermittency on either parameter; the X's indicate devices which showed an intermittent reading on the particular parameter, either at probing or final test - or both.

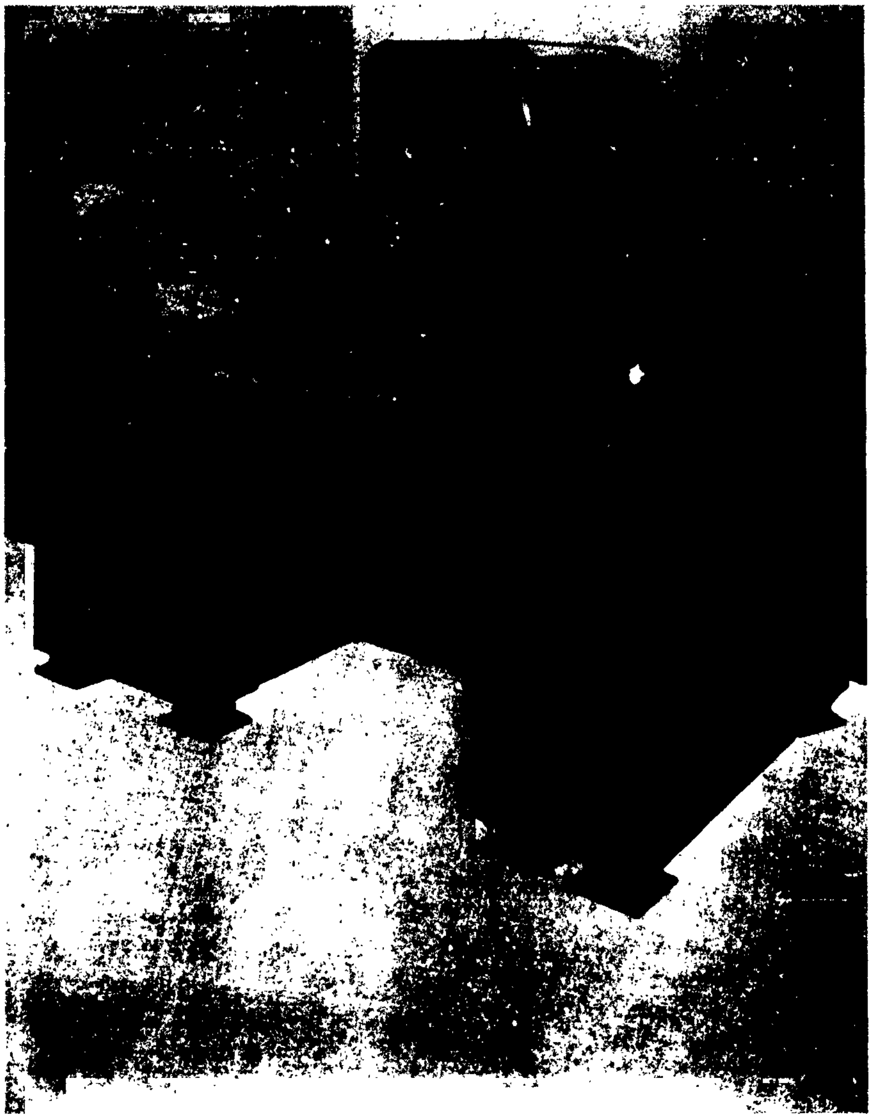
The results of this experiment indicate that a method of wafer probing is a valuable addition to this screening machine. To realize maximum benefit it may be necessary to probe test using higher specification limits. It can be seen from any one of the curves that devices very rarely improve after additional shop processes; therefore, using a limit just somewhat below the final limit should constitute the best test; bad material will always be rejected and good material will not be wasted.

The two test modules (Figure 3.15-5) are designed for accurate stable go no-go operation, with adjustable limits. The control circuitry of these test modules is such that when the operator presses the test button (after optical inspection) the first test module makes its measurement and if the reading is "go", the second module is permitted to test. If this second reading is "go" the wafer will be routed to the waiting wafer tray. If either test was no-go, the wafer will be ejected into the scrap reservoir. As implied above, if the first module gets a no-go reading the wafer is scrapped without the second test. This interlocking of test circuitry speeds overall operation considerably.

V Conclusion

The goal of combining wafer screening with electrical probe testing has been achieved. The machine with its integrated test sets is capable of operating at a speed of 600 wafers per hour, thereby taking the place of 2 or 3 operators. This operating speed is 6 to 8 times faster than the same combination of manual operations. The machine is further enhanced by the fact that scrap wafers will be virtually eliminated at this operation.

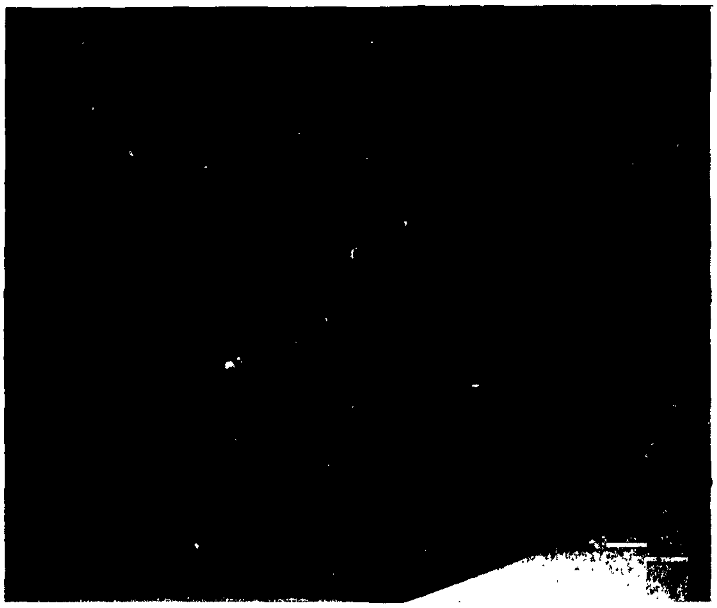
During Phase 2 it is planned that work will be done on reducing the size of the probing mechanism, increasing the reliability of the vibratory wafer feeder, and making any other changes deemed necessary.



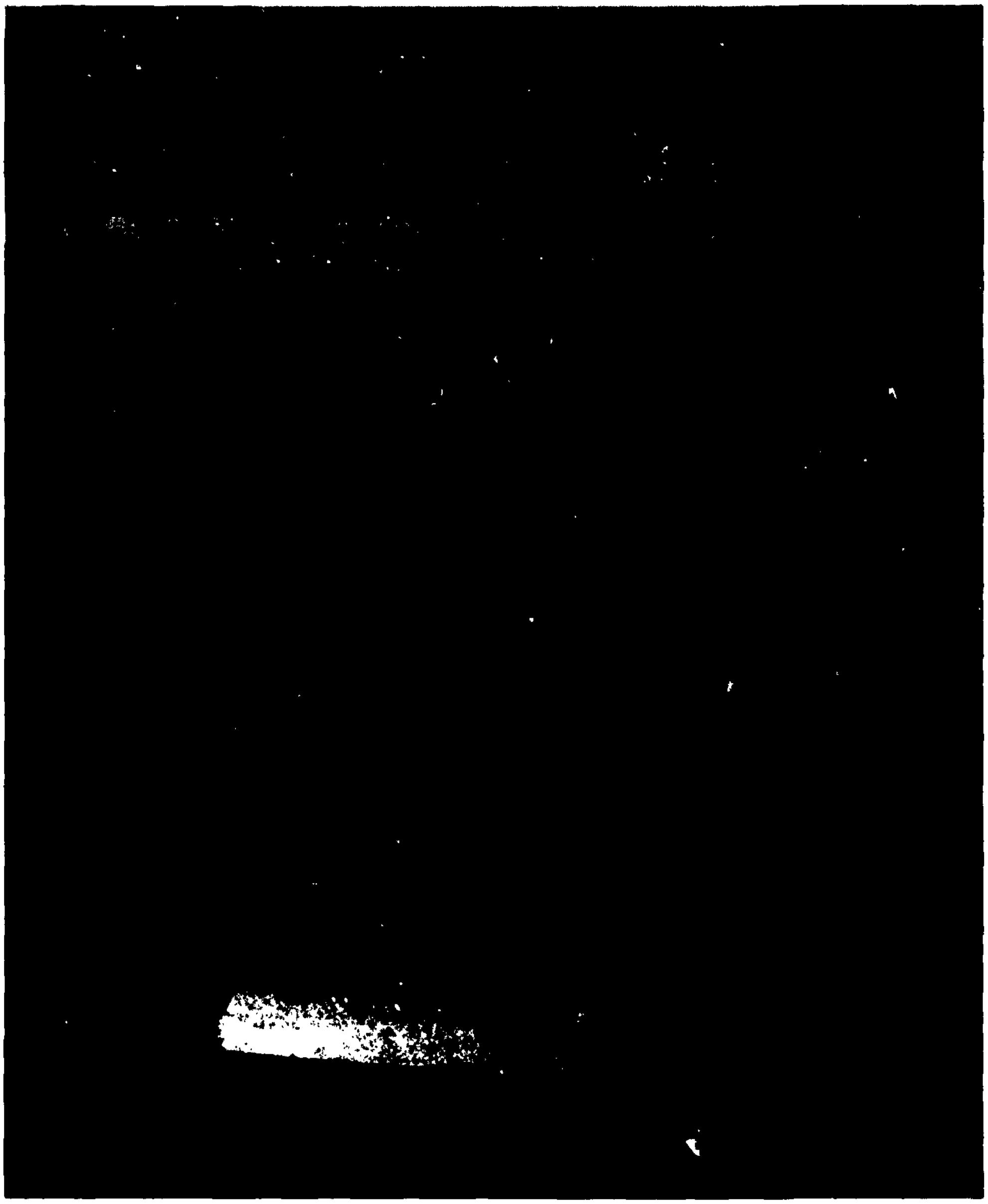
2N1072 WAFER SCREENING AND ELECTRICAL PROBE TESTING MACHINE
FIGURE 3.15-1

WORK AREA OF 2N1072 WAFER SCREENING AND ELECTRICAL PROBE TESTING MACHINE
FIGURE 3.15-2

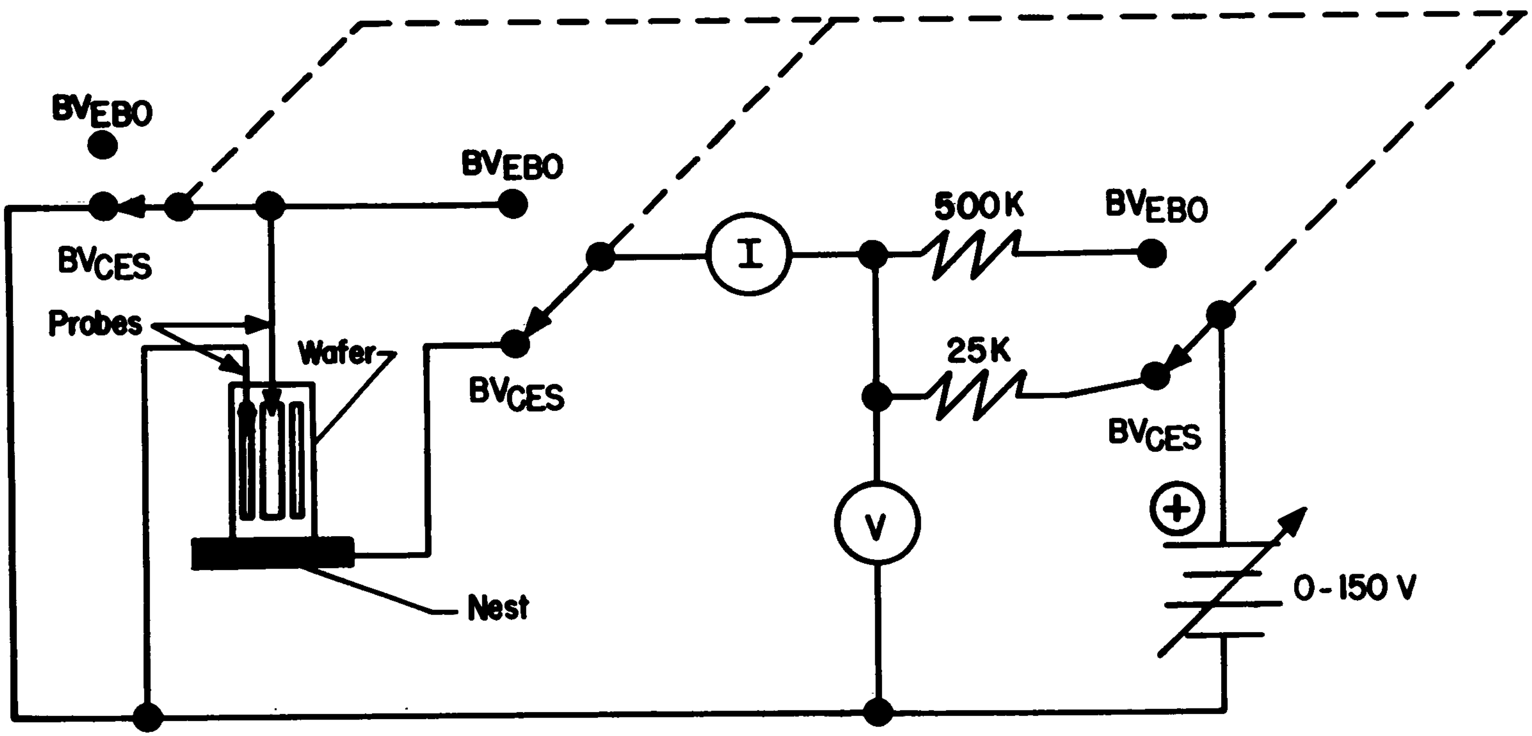
WAFER HANDLING MECHANISMS OF 2N1072 WAFER SCREENING AND ELECTRICAL PROBE TESTING MACHINE
FIGURE 3.15-3



PROBING MECHANISM OF WAFER SCREENING AND ELECTRICAL PROBE TESTING MACHINE
FIGURE 3.15-4

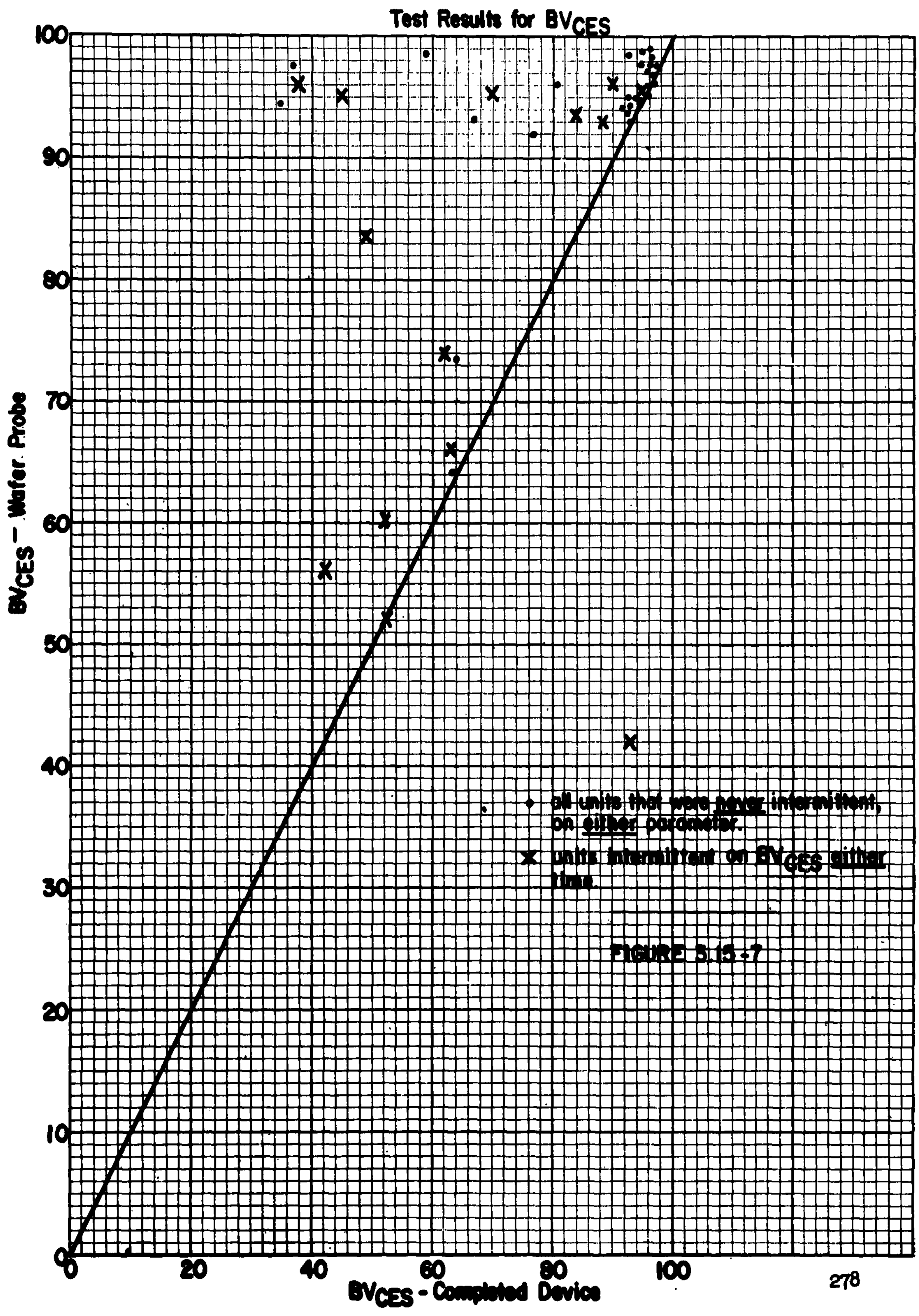


TEST MODULES OF WAFER SCREENING AND ELECTRICAL PROBE TESTING MACHINE
FIGURE 3.15-5



Schematic of Probing Mechanism and Associated Equipment as used for Preliminary Wafer Probing Tests.

FIGURE 3.15-6



Test Results for BV_{CES}
BV_{CES} - Wafer Probe
BV_{CES} - Completed Device
0
10
20
30
40
50
60
70
80
90
100
0
20
40
60
80
100
• all units that were never intermittent, on either parameter.
X units intermittent on BV_{CES} either time.

FIGURE 5.15-7

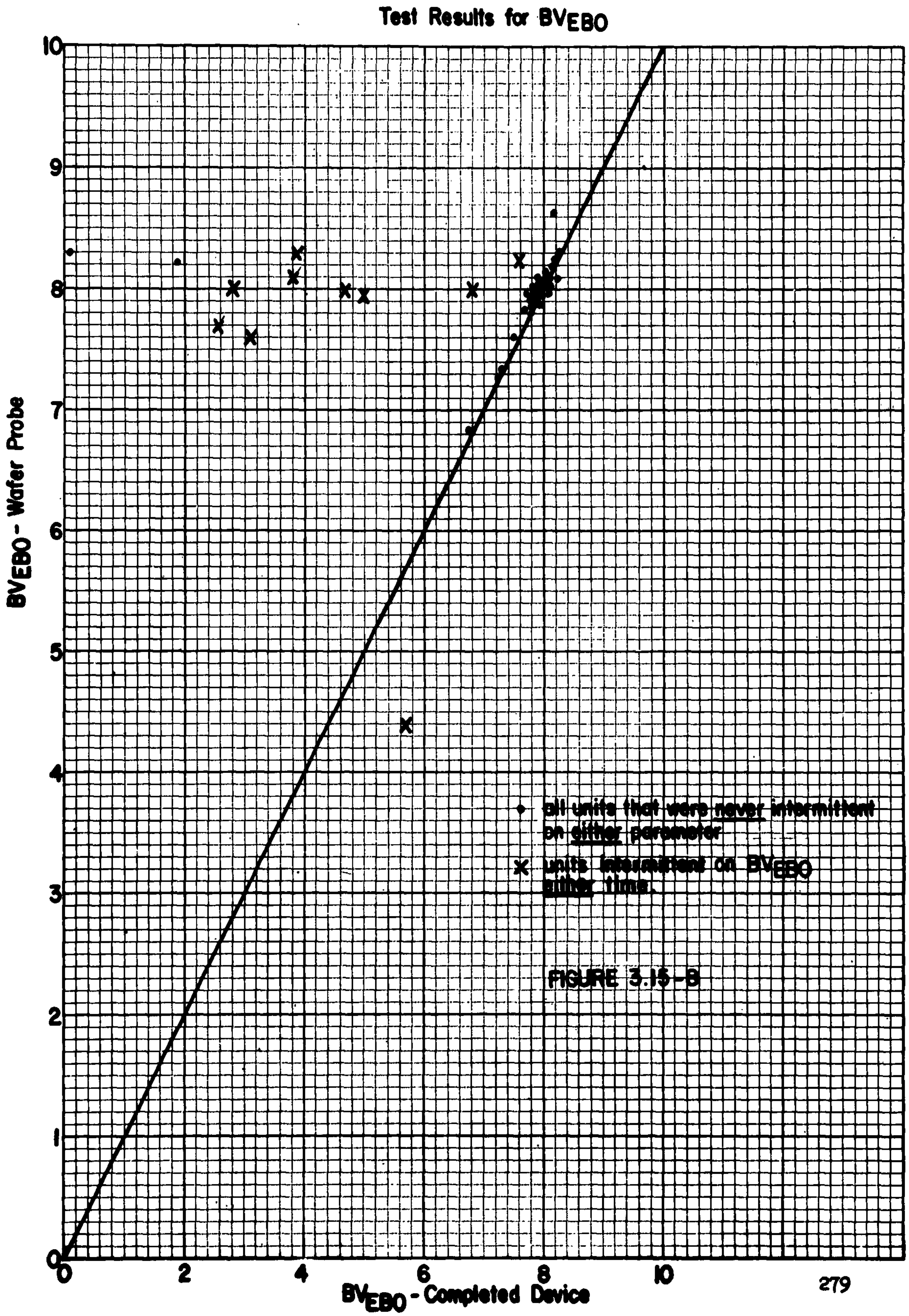

Test Results for BV_{EBO}
BV_{EBO} - Wafer Probe
BV_{EBO} - Completed Device
0
1
2
3
4
5
6
7
8
9
10
0
2
4
6
8
10
• all units that were never intermittent on either parameter
x units intermittent on BV_{EBO} either time.

FIGURE 3.15-B

RESULTS OF WAFER HANDLING TESTS

Handling Conditions	No. of Wafers Lot #1	No. of Wafers Lot #2
Wafers started	200	500
Properly loaded in Tray	176 (88%)	451 (90.2%)
Not picked up from Vibratory Feeder	4 (2%)	13 (2.6%)
Broken at Pickup	1 (0.5%)	2 (0.4%)
Double Wafers picked up	6 (3%)	7 (1.4%)
Improperly seated in Nests of Table 1	0 (0%)	1 (0.2%)
Not picked up by Flipper Mechanism	2 (1%)	2 (0.4%)
Double Wafers in Tray	2 (1%)	4 (0.8%)
Broken during Flipping and Tray Loading	2 (1%)	7 (1.4%)
Estimated Loss at Flipper and Tray Loading	- (3.5%)	- (2.6%)
Total Loss	- (12%)	- (9.8%)

Figure 3.15-9

SECTION 3.16

SPECIAL TEST SET (2N1072)

K. C. Whitefield

SPECIAL TEST SET (2N1072)

I General

The Special Test Set performs six D-C and two Switching Time tests on 2N1072 transistors in manually loaded test sockets. An in-line conveyor provides a testing rate of 500 to 1,500 per hour; rejected transistors are extracted directly after each test station and good transistors are extracted at a final Accept station. Six spare test stations are available for addition of other tests.

This test set was designed and built by the Philco Corporation, Lansdale, Pennsylvania, to the following specifications:

1. ±1 percent accuracy on D-C tests.
2. ±4 percent accuracy on Switching Time tests.
3. 25 ±3°C junction temperature maintained on h_{FE}, V_{CE}(sat), V_{BE}(sat) and Switching Time tests by pulsed operation.

II Description of the Machine

This test set (Figures 3.16-1 and 3.16-2) consists of two major portions: the mechanical system which indexes the transistors past the test stations and extracts them on signal from the electrical test circuits, and the electrical test system which compares the transistor test results to the test limits.

Mechanical System

This contains the following portions:

1. Frame

   The machine frame has a very strong, rigid central portion that mounts the conveyor index mechanism, the conveyor idler sprocket, and associated mechanisms. Extensions from this central frame provide mountings for the test cabinets, the loading platform, and machine covers.

2. Test Sockets and Conveyor

The driven sprocket for the double chain-link, in-line conveyor is mounted directly on the barrel-cam type rotary index drive. This index drive also has a continuously rotating auxiliary drive shaft which powers the associated mechanisms for test probe contact and transistor extraction. The rotary index drive provides a conveyor dwell during 270 degree rotation of the auxiliary drive shaft and conveyor index during the other 90 degree rotation of this shaft; it is driven by a 440-volt, 60-cycle, 3-phase motor through a variable speed belt drive for speed adjustment. This motor has a built-in brake which is applied when the motor is turned off to reduce coasting during emergency stops. The idler sprocket for the conveyor is located at the loading platform end of the test set frame.

The transistor test socket frames (Figure 3.16-3) are mounted on vertical plates which span each pair of double chain links. The test socket doors are hinged at the bottom of these frames and are fabricated from insulating material. The doors have open lengthwise slots at their outer ends for separating the transistor leads when they are manually combed over this portion. The transistor lead ends are then manually inserted into the slots in the white plastic portion until the transistor can contacts the outer end of the door. Cross-wise slots on the test socket door, one at the outer end and one further in, provide space for test probe contact to the transistor leads at each test station. The lower set of contacts (see Figure 3.16-4) is used for test conditions and the upper set is used for checking test limits. The fact that test probe contacts are made directly adjacent to the transistor body permits use of the test set for higher frequency test conditions.

The test socket door is latched manually, by the loading operator, into the vertical position before leaving the loading platform. The conveyor cover, at this point, is hinged to operate an emergency stop switch under very light pressure to provide for safety to the loading operator.

3. Test Boxes and Actuator

At each test station, a completely enclosed sheet copper test box is provided for mounting the silver-alloy test contact probes and test circuit comparator components. This box is silver-plated to assure shielding continuity and a good ground; it is mounted in an easily removable manner on a common actuator frame. Actuation of this common frame to move the test probes into and out of contact position is accomplished by a cam on the auxiliary drive shaft for maximum use of the conveyor dwell period.

Each test box is resiliently mounted by cantilever wire springs and contains two hardened steel locating pins that engage locating holes in each test socket frame. This aligns the contact probes with the transistor leads and provides for consistent reliable contact at each test.

The outer end of the common actuator frame is stabilized against vibration by an air cylinder damped linkage.

4. Extraction System (See Figures 3.16-4 and 3.16-5)

The test socket door must be unlatched from its vertical test position to provide for extraction of transistors. This is accomplished at the start of the next dwell at the next station after the extraction signal is received during any test. The extraction signal causes the extraction solenoid to withdraw a latch and permits an upward push on the test socket door latch release rod. This not only releases the door latch but also gives the door a cammed push outward.

A test socket door lowering bar is provided to restrict the initial free motion of any released door and then to lower the door gently to the extract position between the extractor fingers. After the dwell in the extract position, this bar further lowers the door to its horizontal position for reloading. This bar is cam actuated from the auxiliary drive shaft and the outer end of the box is stabilized against excessive vibration by an air damped linkage.

A two-fingered extractor for each test station (see Figure 3.16-4 for door moving to extract position) is mounted on a common bar which is actuated by a cam on the auxiliary drive shaft. These extractors are designed to have their fingers just below the transistor can flange during the dwell of the test socket door in the extract position. With the door in this position, the extractor lifts the transistor by its flanges to pull its leads from the door. A gate on each extractor (Figure 3.16-5) keeps the transistor from sliding down off the inclined extractor fingers until the extractor is raised above the chute leading to the reject bin or the accept station. At this point, the gate is pivoted to allow the transistor to slide out of the extractor fingers and down the chute. This gate is so shaped to push the transistor off the extractor fingers if this is necessary.

Electrical Test System

The following portions are integrated into an electrical test system (see front panels of test cabinet in Figure 3.16-2) that continues the test of each transistor until it is rejected or accepted:

1. Central Power Supplies

   These are commercial power supplies that supply regulated and unregulated D-C and A-C voltages and are required for the electrical test circuits, indicating lights, and extractor solenoids. They are located in the bottom left and center of the electrical test cabinets shown in Figure 3.16-2. These power supplies are connected to a main power supply chassis which facilitates maintenance by permitting central voltage monitoring during any phase of operation. A separate complete main power supply is provided for bench testing of the D-C test modules when they are removed for maintenance and service checking.

2. Electrical Tests and Test Modules

The electrical test modules are mounted on individual slide out chassis for convenience in servicing and are housed in the three test cabinets. The comparator portion and the test contacts for each test circuit are located in the test box at each test station and are connected to the test modules by flexible cables. These flexible cables terminate in a strain relieved connector at each test box to facilitate its removal or replacement.

Application of bias voltages and currents to transistors under test and test circuit signals to associated devices is controlled by a test sequence cam timer.

The test stations are located on the opposite side of the test set from the electrical test cabinet doors with the first test station located nearest the conveyor exit from the loading platform. The electrical tests are made as tabulated on the next page.

The base current pulses on Tests 5 through 9 are supplied by electronic pulse generators. The sampling frequency in Tests 8 and 9 is adjustable up to 1000 megacycles pulse repetition frequency. Since the digital read-out of test limits is common for Tests 8 and 9, the test sequence cam timer makes Test 8 at Station 8 in the first half of each test dwell with its test read-out made at the end of this half; Test 9 at Station 9 is then made with its read-out

2N1072 TEST STATIONS AND TEST CONDITIONS

Sta. No.	Test	Type Test	Test Limits
1	Continuity		Lead in each slot
2	BV_{CES}	D-C	75 Vdc at I_C = 1 mA
3	BV_{EBO}	D-C	6 Vdc at I_E = 100 µA
4	I_{CBO}	D-C	0.1 µA at V_{CB} = 5 V
5	h_{FE}	(See Note 1)	20 min. at I_C = 750 mA, V_{CE} = 5 mA
6	V_{CE}(sat)	(See Note 1)	0.5 Vdc min. 2.0 Vdc max. at I_C = 750 mA and I_B = 75 mA
7	V_{BE}(sat)	(See Note 1)	0.7 Vdc min. 1.8 Vdc max. at I_C = 750 mA and I_B = 75 mA
8	$t_d + t_r$ (turn-on time)	(See Note 2)	100 sec; Method A; R_C = 25 Ohms
9	$t_s + t_f$ (turn-off time)	(See Note 2)	300 sec; Method A; R_C = 25 Ohms
10-15	Spare	-	-
16	Accept	-	Pass all tests

Note 1: D-C Test with base current pulsed to maintain 25 ±3°C junction temperature.

Note 2: Base current pulses, with separately controlled sampler, to maintain 25 ±3°C junction temperature.

occurring all through the second half of the test dwell.

3. Test Sequence Cam Timer

This is an in-line assembly of cam-operated switches whose cams are chain driven at the same speed as the auxiliary cam shaft.

The important functions of these switches are:

1. To remove shorts from constant current supplies and apply test voltage after test probes contact transistor leads and vice versa before probes break contact.
2. To control time sharing between Tests 8 and 9.
3. To initiate shift register memory advance and to start a new memory for each transistor entering Station 1.
4. To initiate test read-out and to set and operate the extraction solenoids and counters for each test period.

4. Memory and Shift Register

Each transistor test socket is followed through each test station electrically by the memory and shift register function.

The shift register consists of 20 magnetic coil-diode memory cores and a driver to add a "one" state to the first core by a pulse for each transistor entering the first station. Transistor test sockets entering any station with the doors horizontal will trip a switch to prevent the driver or shift pulse from adding a "one" state to the core representing that socket at that station.

Silicon controlled rectifiers, SCR's, are used to record the test results in this system. In case of a reject at any station, the test comparator output relay fires the SCR for that test to pull in a pair of reed relays. These relays set the counter and extractor solenoid to be ready to operate on call from the test sequence cam timer switch. The fired SCR will also inhibit (cancel) the "one" state representing the rejected transistor in the memory core for that test station; since no energy is available to be shifted to the next core, a "zero" state will thereafter travel from core to core as the transistor moves from test station to test station.

For a transistor that meets all test limits, the "one" state will enter the last core to fire the accept station SCR for counting and extraction there. Since a "zero" state accompanies any empty socket, no register will be made on any subsequent counter after a reject occurs or for any test socket door entering the first station in a horizontal position.

5. Test Action Indicating Lights

On the front panel of each test module (see Figure 3.16-2) there is a green accept and a red reject light for each test limit with appropriate reset pushbuttons. These indicating lights are used during initial set-up of the machine and for periodic check-out. There are also a number of "power-on" indicating lights on the test module control panel side of the machine for the main control, test modules, and important circuits.

An over-all test action indicating light panel is located on the rear of the test cabinet above Stations 1 through 3. There are "Off" and "On" indicating lights for each test to indicate those in use. The test action for each test limit is indicated by a light which normally glows red; it is turned off at the start of each test dwell and will stay off to the end of the test dwell if test limits are met. In case of a reject, it will glow red again at the test read point before the end of the test dwell.

6. Reject and Accept Counters

These are electrically operated counters located at each test and accept station. This count chiefly provides a performance indication for the production line but also can initiate test module performance in case of sudden yield change at ny one station.

III Operation and Maintenance

1. Operation

The test set loading platform provides a bench height surface to hold transistors and steady the loading operators during the loading operation. Space is provided for more than two operators during operator training. An emergency stop pushbutton is located within easy reach of the loading operators in case of loading difficulties.

Operation of this test set should be under observation of an operator qualified to do minor trouble shooting and to analyze sudden reject changes at any one test.

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Operation of this test set should be under observation of an operator qualified to do minor trouble shooting and to analyze sudden reject changes at any one test.

In addition to rather complete protective housing of the mechanisms and electrical test and control circuits, the following safety features are supplied:

1. Off-condition bake on main drive motor to reduce coast on emergency stop or jogging.
2. Three emergency stop pushbuttons, one each at the main control panel in the left hand test cabinet, the loading platform, and the accept station.
3. Emergency stop switch operated by hinged cover at conveyor exit from loading platform.
4. Electrical test cabinet door locks to restrict access.
5. Transparent plastic covers over test box actuator and extraction mechanisms so action can be observed with covers in place.

2. Maintenance

All of the electrical test modules, power supplies, and control circuits were designed for mounting on slide-out and easily removable chassis to facilitate maintenance and service check. A bench-type separate power supply is provided for bench test of all D-C test modules. All of the test set common power supplies are routed through the main power supply terminal board for ease of monitoring.

The various lubrication provisions either allow extended operating periods or are easily accessible. This also applies to mechanism and electrical test module adjustments.

IV Development Review

A feasibility study was requested in late 1960 from the prospective supplier to cover mechanized testing of the 2N1072 transistor with:

1. 5/16-inch long pre-can leads and 1-1/2-inch and 3-inch long leads
2. The current 2N1072 Test Specification requirements
3. A testing rate of 1000 per hour for 72 hours per week
4. Go no-go action on each test limit
5. $\pm 1\%$ accuracy at 25 $\pm 3^{\circ}C$
6. Two spare test stations
7. Extraction of rejects after each test

The early 1961 report on this feasibility study indicated adequate transistor testing knowledge and practical transistor transfer mechanization from test to test by proposing the following:

a. A variable speed intermittent index drive for a chain-type conveyor carrying test sockets with test occurring during the dwell period.

b. Individual test modules for each parameter on slide-out supports with go no-go testing to $\pm 1\%$ on D-C tests.

c. Measurement of switching time to $\pm 4\%$ accuracy by sampling action for conversion to a suitable voltage.

d. Magnetic memory and shift register to electrically carry test results (go no-go) along with each test socket.

e. Extraction of rejects after each test and accepts at a final station.

f. A suitable acceptance test for demonstrating test set performance to specified requirements.

In addition, this feasibility study reported a comparison of switching time measurements by two controlled sampling means and one analog voltage means and recommended one sampling method. An evaluation report on the proposed test socket showed it was electrically suitable.

During the design stage, the following 2N1072 product processing changes were made:

a. Elimination of 3-second ramp time to reach I_C during BV_{CES} test.

b. Elimination of pre-can test with 5/16-inch long leads.

c. Change to use of 1-1/2-inch leads for most production.

d. Addition of C_{ob} test.

And the following changes were made by the supplier to the design proposed in their feasibility study for design or planning reasons:

1. Change to actuated probe contact with test socket door hinged at the bottom.
2. Specification of higher frequency type of test box at each station.
3. Addition of four more spare test stations.
4. Rearrangement of test set for easier monitoring, adjustment, and maintenance.
5. Specification of electronic pulse generators for pulsed power testing.

During the prove-in stage, much of which was combined with acceptance testing to take advantage of the extensive operation required, the following changes resulted:

a. Added resistors in pulsed-power D-C test circuits to stabilize test limit responses.

b. A large storage capacitor was added to solenoid and counter power supply for operation without blowing the input fuse.

c. Timing cams #3 and #4 were modified for more abrupt switch action on the time sharing between Tests 8 and 9.

d. Excessive vibration of the outer ends of the two oscillating mechanism frames was eliminated by air damped linkages.

During acceptance testing, pre-measured transistors were used over and over during the 12,000 pre-shipment transistor tests for an average of 70 trips per transistor including both loading and extraction. To reduce the lead fatigue, the 30,000 post-installation acceptance tests were made without extraction and re-loading. Repeatability of test decisions within ±1 percent was maintained for the D-C tests and ±4 percent for the switching time tests for reasonable periods. Because the electrical test circuit component characteristics were affected by operating temperature, it was found most practical to keep the test set continuously energized. The straight D-C tests drifted only slightly with use while the base current pulsed D-C tests experienced more drifting with age of the test circuit components, particularly the differential amplifier tube, over a period of a few weeks. The switching time test module required at least weekly checks for readjustment on the basis of stable standard test transistors with less frequent recalibration of all its circuits.

The most frequent maintenance items were:

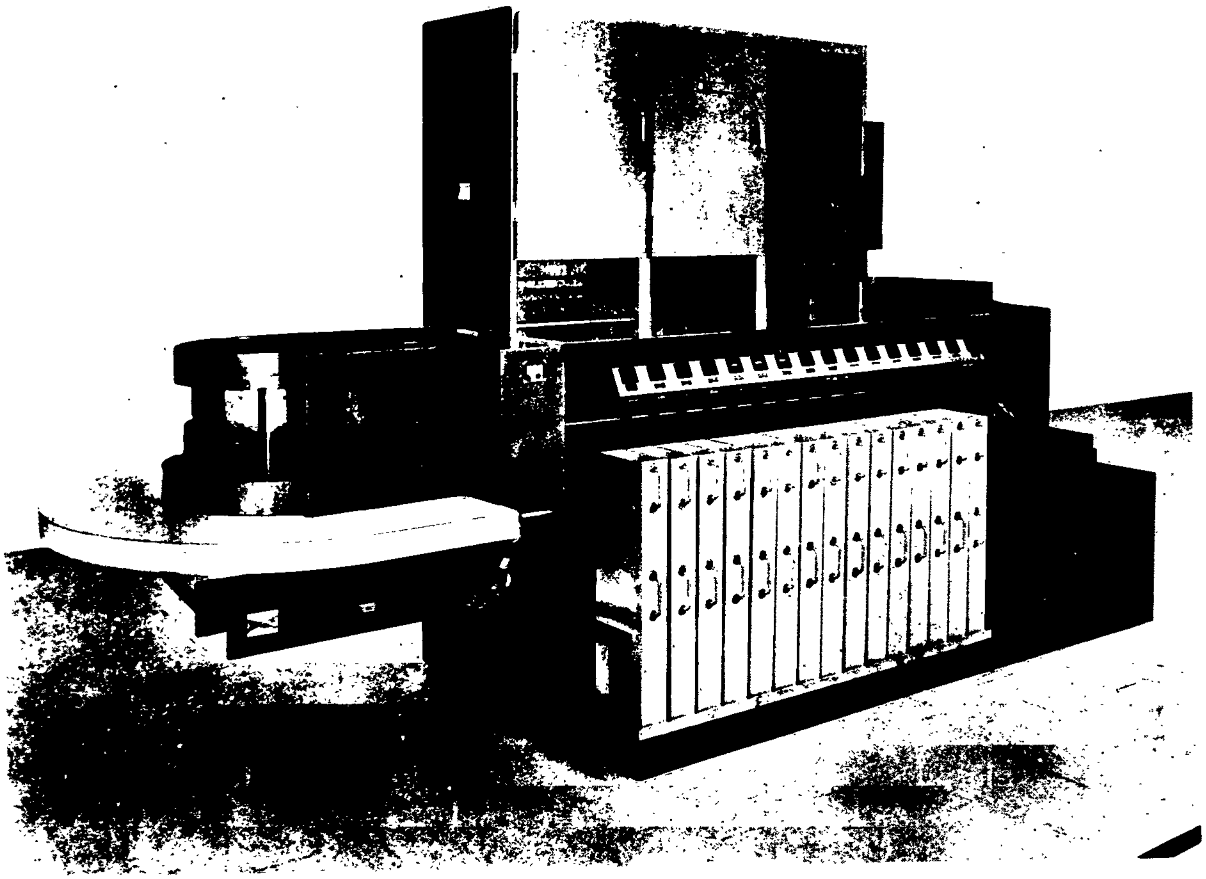
a. The weekly check on switching time test module,

b. The need for lubrication of test box locating pin holes in the test socket frames,

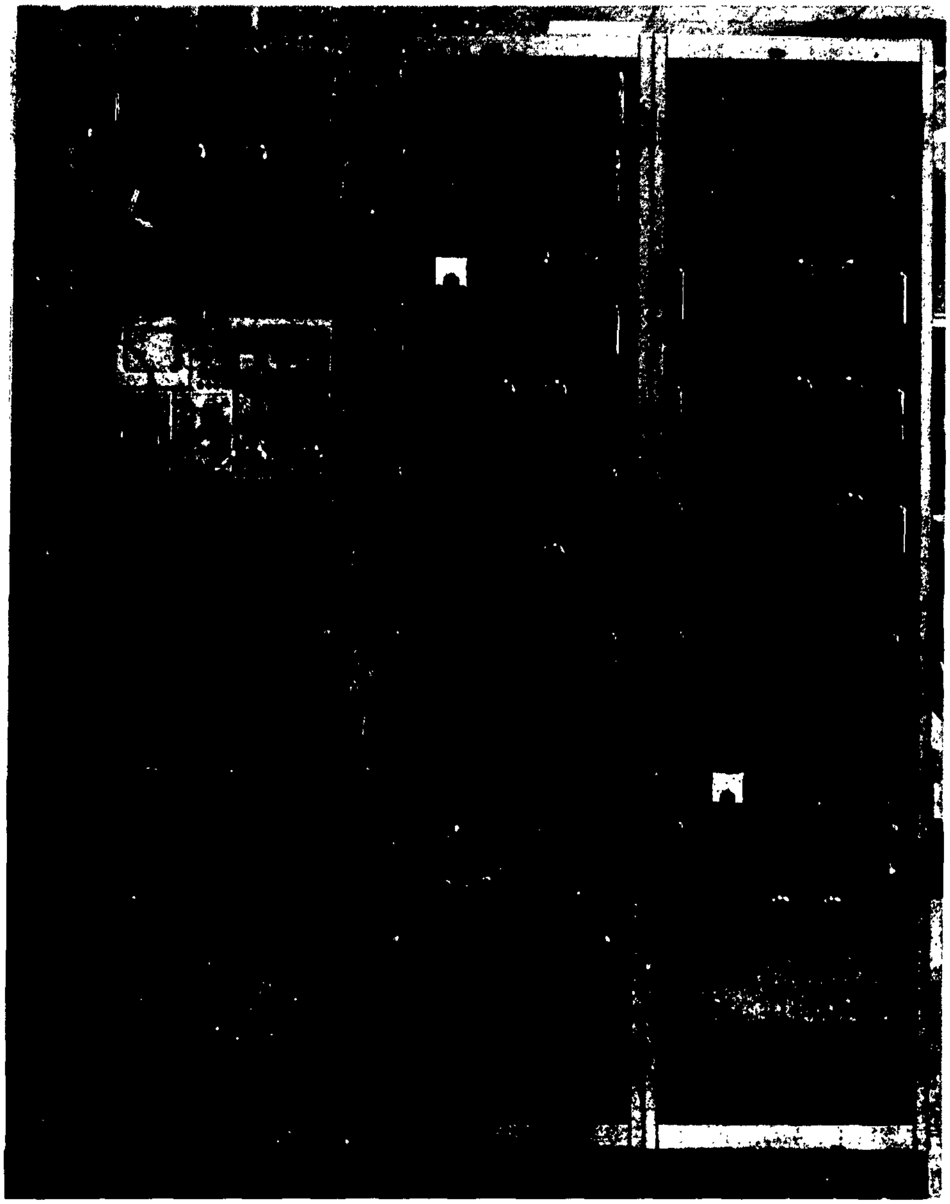
c. The need for pre-aged tubes, particularly the 12-AX-7A tube in the differential amplifiers.

VI Conclusion

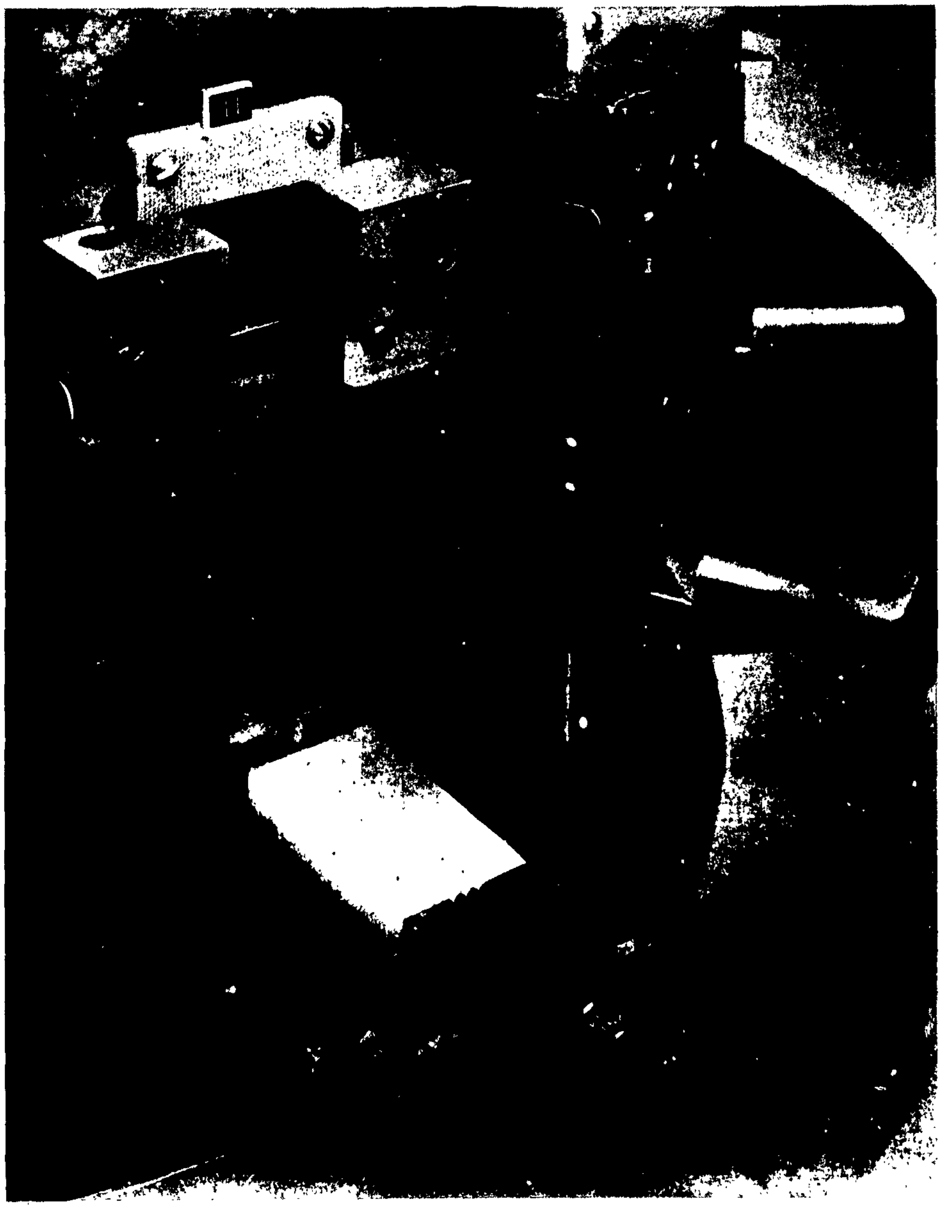
The extensive acceptance testing demonstrated that the test set met its original goal of providing mechanized testing of the 2N1072 transistor with the required accuracy, testing rate, and reliability. Its successful testing of switching times, on one of only a few switching time modules in the industry on a mechanized test set, also demonstrates its capacity to do testing up to 50 megacycles.



SPECIAL TEST SET (2N1072)
FIGURE 3.16-1



TEST MODULES AND CONTROLS OF SPECIAL TEST SET (2N1072)
FIGURE 3.16-2



TEST SOCKET DOOR OF SPECIAL TEST SET (2N1072) IN LOADING POSITION
FIGURE 3.16-3

TEST SOCKET OF 2N1072 SPECIAL TEST SET AT START OF EXTRACTION WITH DOOR UNLATCHED
FIGURE 3.16-4

2N1072 TRANSISTOR ALIGNED WITH REJECT CHUTE OF SPECIAL TEST SET AFTER EXTRACTION
FIGURE 3.16-5

SECTION 4

MECHANIZED DIODE PRODUCTION LINE

D. H. Lockart

MECHANIZED DIODE PRODUCTION LINE

I General

The major requirement of Phase 1 of the .4 Watt Diode mechanization portion of PEM Contract No. DA-36-039-SC-81294 is provision of high volume production equipment required to develop and install a limited production line directed towards producing 30,000 diodes conforming to the applicable specifications per two shift, eight hour, five day week. In addition to specific machines, this capability includes the provision of associated tooling and facilities. To meet this requirement, a production line capable of manufacturing 1N664, 1N665, 1N666, 1N667, 1N668, 1N669, 1N673, 1N675, 1N697, and 1N701 diodes has been designed, fabricated and installed.

Normal practice requires that pilot production runs be made over manufacturing facilities to verify machine performances and line capabilities. In this case, however, pilot runs were not made a requirement under the terms of the PEM Contract for the following reason. During the period following installation and prove-in of the .4 Watt Diode mechanized line, production requirements of these devices were sufficiently large to permit the operation of the line with regular product. Mechanized production runs were made, therefore, rather than so-called pilot runs. The devices resulting from these runs were used to satisfy the data requirements of the Contract.

II Mechanized Line Operations

Phase 1 of PEM Contract No. DA-36-039-SC-81294 limited the development of high volume production equipment to specific quantities and types of machines and tooling. It was not intended that all manufacturing operations be mechanized, but that machines would be built for those operations and processes which could be made more reliable or required a high degree of skill by the operator. As a result, the limited production line is a "hybrid" line consisting of a mixture of mechanized and unmechanized equipment.

For purposes of this discussion, the subject production line is divided into two parts as follows:

1. Semiconductor Material Preparation
2. Diode Assembly

Each part will be discussed in sufficient detail to provide an understanding of the relationship of the various items of mechanized equipment to the unmechanized operations and the production line as a whole.

Preparation of semiconductor material starts with the growing of a "P" type single crystal silicon ingot. This ingot is grown from a molten charge of polycrystalline silicon doped with boron or a boron alloy. A properly oriented "P" type seed is used to start the growing process. After the ingot is grown, it is tested for proper crystal orientation and resistivity.

The ingot is next prepared for slicing. It is mounted for feeding into a machine which cuts it into individual slices. The slice surfaces are lapped in order to remove roughness and mechanical strain. After lapping the slices are cleaned to remove physical contaminants. Another resistivity test is made at this point to obtain readings on individual slices. With the information obtained from this test, the slices are categorized and diffusion conditions are selected for each category.

Prior to diffusion, slices are cleaned to remove organic and inorganic contaminants. Diffusant solutions are added to the slice faces using essentially a "paint-on" process. The slices are then placed in a diffusion furnace where the conditions of temperature and time determine the depth to which diffusion occurs. One side of the slice is painted with a boron solution. This side becomes the "P+" side of the slice. The other side is painted with a phosphorus solution and becomes the "N" side of the slice. Following diffusion the depth of diffusion into the slice for each material is checked.

A conducting surface is added to the diffused slice by means of electroless plating with nickel. The nickel is sintered to level out the plating and to form a bond between the nickel and the silicon. Following sintering a second electroless nickel plate is applied. This second plate provides a surface capable of receiving a subsequent gold plating and prevents the gold from diffusing into the silicon during later high temperature operations. The gold plate is applied to provide a corrosion resistant surface and a surface compatible with thermal compression bonding of the wafer to the stud and the internal wire lead to the wafer during stud-wafer-lead assembly.

The gold plated slice is mounted on a glass slide with Lakeside cement and cut into wafers using ultrasonic cutting techniques. Following cutting, the wafers are removed from the slide by dissolving the adhesive, and the resultant wafers are cleaned and evaluated in preparation for bonding to the diode studs. A flow diagram showing diode silicon material processing is shown in Figure 4-1.

Diode assembly starts with the introduction of gold plated studs and leads into a stud lead welding operation. The lead has been previously formed at one end into a nail head configuration. These leads are purchased commercially and are gold plated when received. The studs are purchased commercially but are cleaned and gold plated in the Laureldale plant on a batch basis. Equipment for performing the welding operation was bought commercially. In this operation the formed end of a lead is welded to the center of the bottom of a stud. The stud is the base on which the semiconductor material will be mounted, and the lead forms one of the external contacts of the completed diode. Following welding, the stud lead assemblies are cleaned in the Stud Lead Cleaning Machine, Item 2-2-1 of the PEM Contract. This machine automatically cleans and dries the assemblies to remove greases and oils in preparation for gold bonding.

The Gold Bonding Machine, Item 2-2-2 of the Contract, automatically thermocompression bonds the stud, wafer and internal lead wire in one operation. Stud lead assemblies are automatically loaded into the machine from handling racks. Pre-oriented wafers supplied to the machine in tubular magazines are automatically placed in position on top of the studs. Gold wire, .006 inch in diameter, is fed from spools into the machine, a gold ball is formed on the end of the wire by radio frequency induction heating and the balled end of the wire is positioned to contact the center of the top surface of each wafer. At this point the gold wire is cut to length. By use of radio frequency heating and pressure the wafer is bonded to the stud and the balled gold wire is bonded to the wafer simultaneously. The "P+" wafer surface is adjacent to the stud and the wire is attached to the "N" surface.

The next operations are performed by the Etching, Oxidizing, Cleaning and Drying Machine, Item 2-2-3. This machine performs controlled clean up etching of the exposed periphery of the silicon wafer, oxidizes the etched area, rinses the subassemblies, partially dries them with acetone and completes drying in an oven with a nitrogen atmosphere. Etching is accomplished with a mixture of nitric, hydrofluoric and acetic acids. Oxidizing is done with hydrogen peroxide. Rinsing with deionized water is used to stop etching and oxidizing and to remove excessive oxide. Subassemblies are handled automatically by the machine during the above operations. They are, however, manually transferred from the machine to the oven for drying.

After the subassemblies are thoroughly dried, a sample is taken to predict the final electrical characteristics of the devices being processed. This sample is evaluated by looking at a display of voltage versus current throughout the entire range of the diode under test. Depending on the yield obtained on this sample it is decided whether or not 100 percent testing is required. Normally sample testing is adequate. If the yield is at a sufficiently high level, the production devices are processed to the next operation. If not, for certain defects, they can be re-etched to correct these faults.

The next operation is accomplished on the Assembling Case to Stud and Welding Machine, Item 2-2-4. This machine automatically assembles the stud-wafer-lead assembly to the tubulated case and welds them together. Case assemblies, one of the inputs to this machine, are produced by joining a metal sleeve, a piece of glass tubing and a metal tubulation. The parts are manually placed in molds and processed to a glassing furnace where the glass tubing is melted and a glass-to-metal seal between the parts is effected. The tubulation is electrically insulated from the sleeve by the glass seal. Following cleaning the tubulated cases are cleaned and processed to the Welding Machine.

Following welding the assemblies are evacuated through the tubulation, a mixture of nitrogen and helium is inserted into the evacuated assembly and the tubulation is sealed by means of a pinching operation. Helium is used as a tracer element to detect minute leaks in the case to stud weld, in the glass-to-metal seal of the case assembly, or in the tubulation pinch-off. Leak detection is done normally on a sample basis.

At this point the second external lead of the diode is attached. This operation is accomplished by a machine which performs a second pinch-off of the tubulation to provide positive contact with the internal gold lead, feeds the lead wire, flattens the end of the wire, bends it into an "S" shape, welds it to the end of the pinched-off tubulation of the case to stud assemblies. This in effect provides an external contact through the tubulation and the internal balled lead, which extends through the tubulation to the pinch-off, to the "N" side of the silicon wafer. The "S" bended lead is manually soldered to the tubulation in a subsequent operation. In order to remove traces of flux, the assemblies are rinsed in deionized water and air dried.

The assembled diodes are temperature aged in an oven to stabilize their electrical characteristics. Following aging they are temperature cycled between 200°C and -65°C in order to develop stresses which will reveal potential "out-of-spec" devices. They are then soaked in alcohol to pick up devices with gross leaks through the weld, the pinch-off or the glass-to-metal seals. Large magnitude leaks are not detected in helium leak check since the helium is exhausted by the time the check is made. After alcohol soak the diodes are rinsed and dried and immediately subjected to a process test. All Group A parameters in the applicable specification are measured to separate "out-of-spec" units from the production lot. The presence of alcohol in any devices is detected at this point, since the electrical characteristics of these devices are adversely affected. Good diodes passing this process test are power aged using a constant current of 100 milliamperes in an ambient temperature of 125°C. Power aging further stabilizes the electrical characteristics of the assembled diodes.

tubulation pinch-off. Leak detection is done normally on a sample basis.

At this point the second external lead of the diode is attached. This operation is accomplished by a machine which performs a second pinch-off of the tubulation to provide positive contact with the internal gold lead, feeds the lead wire, flattens the end of the wire, bends it into an "S" shape, welds it to the end of the pinched-off tubulation of the case to stud assemblies. This in effect provides an external contact through the tubulation and the internal balled lead, which extends through the tubulation to the pinch-off, to the "N" side of the silicon wafer. The "S" bended lead is manually soldered to the tubulation in a subsequent operation. In order to remove traces of flux, the assemblies are rinsed in deionized water and air dried.

The assembled diodes are temperature aged in an oven to stabilize their electrical characteristics. Following aging they are temperature cycled between 200°C and -65°C in order to develop stresses which will reveal potential "out-of-spec" devices. They are then soaked in alcohol to pick up devices with gross leaks through the weld, the pinch-off or the glass-to-metal seals. Large magnitude leaks are not detected in helium leak check since the helium is exhausted by the time the check is made. After alcohol soak the diodes are rinsed and dried and immediately subjected to a process test. All Group A parameters in the applicable specification are measured to separate "out-of-spec" units from the production lot. The presence of alcohol in any devices is detected at this point, since the electrical characteristics of these devices are adversely affected. Good diodes passing this process test are power aged using a constant current of 100 milliamperes in an ambient temperature of 125°C. Power aging further stabilizes the electrical characteristics of the assembled diodes.

Following power aging the diodes are processed to the Lead Straightening and Racking Machine, Item 2-2-5 of the Contract. This machine automatically straightens the external leads of the finished diodes and places them in racks for further processing. The next operation is performed by the Low Temperature Reverse Current Testing Machine, Item 2-2-6. This machine monitors diode reverse current as the diodes are cooled from room temperature to -40°C. Good units passing this test are processed to the Gold Plating Machine, Item 2-2-7. Here the diodes are cleaned and an electroless gold plate is applied to all unplated surfaces. After hot air drying the plated diodes are ready for coding and coating.

Coding is accomplished on the Coding Machine, Item 2-2-8. This machine applies alpha-numeric code designations to the diode case and racks the coded units for oven drying and subsequent coating. Coating is done on the Coating Machine, Item 2-2-9. This machine applies a clear varnish coating to the body of the diode. Coated diodes are also oven dried.

The next operation is performed by the Final Electrical Testing Machine, Item 2-2-10. This machine automatically tests all contract diode codes, on all Group A parameters specified, on a go no-go basis. The machine rejects "out-of-spec" units at the first test failed. This permits separation of these devices by parameter failed.

Good diodes passing all tests are submitted to a final inspection which is done on a sample basis. The various samples are submitted to electrical and environmental tests as determined by the applicable specifications.

If the diode lot passes final inspection, the individual diodes are packaged on the Packaging Machine, Item 2-2-11. This machine automatically loads the diodes into styrofoam blocks, 24 diodes to a block, and places them in a cardboard box containing 500 diodes for shipment to stock. Individual blocks are manually inserted into protective cardboard sleeves for small quantity shipments. A flow diagram of all diode assembly operations is shown in Figure 4-2.

As noted earlier in this report, the mechanized diode production line is to be capable of manufacturing any of ten diode codes. Since eight of these codes are voltage regulator diodes, one is a rectifier diode, and one is a switching diode, it follows that there are some variations in processing between codes. This sub-section has been written so as to describe the operations performed on the majority of .4 Watt Diodes.

III Material Handling

Several unique material handling components were provided to support the various items of mechanized equipment developed under the PEM Contract. These components are used to support diode elements either during the time they are in the machines, during storage periods between operations, or both. They are also used to maintain orientation of elements, to make handling easier, and to protect the elements from physical damage.

In this subsection all material handling components developed under the Contract will be described in detail. Illustrations have been included to aid in clarifying these descriptions. The relationships of the various components to the contract machines will be emphasized.

The first material handling component used in diode assembly is a "Teflon" rack holding 24 diodes or diode components on 1/4-inch centers. This rack is first used as the output carrier of the stud-lead welding operation. It is subsequently used throughout all the operations performed by the Stud Lead Cleaning Machine, the Gold Bonding Machine and the Etching, Oxidizing, Cleaning and Drying Machine with the exception of the drying operation. It cannot be used during drying because the temperature to which it would be subjected is higher than "Teflon" can withstand. The chemical inertness of "Teflon", however, makes it ideal for use in the presence of the acids, oxiding agents and cleaning agents employed during the early phases of diode assembly.

The "Teflon" rack has been designed with end configurations which allow the racks to be linearly indexed and still maintain 1/4-inch spacing between the last unit in one rack and the first unit in a following rack. In addition, when racks are nested with their long axes parallel, they have a mating configuration which clamps the diodes or diode components in the racks. As a result of this clamping action the racks when grouped may be inverted to permit insertion of components into various chemical baths. These "Teflon" racks also serve the purpose of maintaining the straightness of the diode external lead during processing. This is very important to reliable mechanized operation.

An aluminum magazine holding 30 "Teflon" racks has been provided. This magazine serves the purpose of supporting the racks and protecting the diode components in the racks during storage between operations. It also makes possible easy transport of 720 components at one time. An individual "Teflon" rack is shown in Figure 4-3, and the aluminum magazine containing "Teflon" racks is shown in Figure 4-4. A set of four nested racks illustrating the lead clamping action mentioned previously is shown in Figure 4-5.

An aluminum rack of essentially the same configuration as the "Teflon" rack was provided for use during the drying operation following etching, oxidizing and cleaning. It was determined, however, that it was not practical to use this rack for this operation due to the mass of metal involved. The time required to heat and cool the rack compared to the time involved in heating and cooling the diode components was too excessive. As a result, an alternate method of supporting the components during drying was developed. The aluminum rack, however, is still used in the Assembling Case to Stud and Welding Machine. It is pictured in Figure 5.4-7.

Diode subassemblies come to the drying operation after etching, oxidizing and cleaning mounted in the "Teflon" racks described earlier. They are removed from these racks for drying by means of a set of drying combs. These combs slide under the diode studs and physically lift them out of the racks. They are designed to hold 720 subassemblies, the same number of units held by a magazine load of 30 racks. These combs have considerably less thermal mass than a corresponding group of 30 aluminum racks would have, so their use in the drying operation is justified. The combs are illustrated in Figure 5.3-4.

From case to stud welding to the lead straightening and racking operation the majority of operations are performed on a batch basis. To handle components during these operations, since the diode is sealed and is not particularly subject to damage, a bulk handling basket was developed. This basket is made of stainless steel and holds approximately 1800 units. Orientation of devices is maintained by this basket.

The output carrier of the Lead Straightening and Racking Machine is a rack developed by the Conforming Matrix Company. This rack was designed to be used with the Coding and Coating Machines which are modified commercial items. The rack holds 48 diodes and is constructed of aluminum. In addition to the machines mentioned above, the Conforming Matrix rack is used as the input carrier to the Final Electrical Testing Machine.

A magazine holding 25 racks during storage between machines has been developed by the Conforming Matrix Company. The rack is illustrated in Figure 4-6 and the magazine is shown in place on the Coating Machine in Figure 5.9-1.

Between the lead straightening and racking and the coding operations, the assembled diodes are transferred into the "Teflon" racks for processing. Both the Low Temperature Reverse Current Testing and Gold Plating Machines use these racks. The first of these machines is designed to use a rack made of a material with electrical insulating qualities. The second machine requires a rack made of a chemically inert material. The "Teflon" rack meets both these requirements. The diodes are transferred from the "Teflon" racks to the Conforming Matrix racks by the Coding Machine since oven drying after coding requires the use of a metal rack. They are put back in the "Teflon" racks again by the Final Electrical Testing Machine and used as an input to the Packaging Machine.

During Phase 2 of the Contract material handling will be further evaluated. Effort will be applied toward possibly reducing the number of different material handling components used in the mechanized production line. Improved fixturing will be considered to provide for faster and more reliable transfer from one type of material handling component to another.

IV Mechanized Production Runs

As stated earlier in this report, no pilot runs as such were required under the terms and conditions of the PEM Contract. Instead a mechanized production run was made using all diode machines developed under the Contract. Diodes representing all contract codes were processed in varying numbers.

The mechanized run was made during the last quarter of 1962.

Silicon material and diode components were earmarked for the production run, and instructions were issued to process these components over all items of mechanized equipment. All of the good diodes resulting from the run were used to meet the data requirements of the Contract. The production run also permitted a thorough evaluation of all manufacturing equipment developed with contract funds.

Several normal and anticipated problems arose and were met during the mechanized run. Operators of the various items of mechanized equipment required training over and above that given during shop trial and/or production trial phases. Machines experienced periods of downtime due to maintenance requirements and due to the need for minor changes and adjustments. Variations in semiconductor material and piece parts were found which adversely affected the operation of some of the mechanized equipment. As anticipated, all diode elements must be made with as little variation as possible, since the mechanized equipment will not accept wide fluctuations in parameters.

In general, the results of the mechanized production run met all expectations and the machinery functioned well. No problems arose during the run which could not be solved within a reasonable period of time.

V Test Data

The PEM Contract requires that test data be provided from a mix of 1000 diodes. No specific number of each of the ten codes involved is required. The number of diodes from which data was accumulated and the number of parameters involved are listed below. Actually, data on 1209 diodes was submitted, since this was the number of good devices resulting from the mechanized production run.

Device Type	Number of Devices	Number of Parameters
1N664	69	5
1N665	82	5
1N666	111	5
1N667	109	5
1N668	116	5
1N669	131	5
1N673	240	3
1N675	121	5
1N697	123	6
1N701	107	5

The applicable military specifications for these devices are:

Device Type	Applicable Specification
1N664, 1N665, 1N666, 1N667, 1N668, 1N669, 1N675 & 1N701	MIL-S-19500/150 (SIG C) dated November 8, 1960
1N673	MIL-S-19500/149(Sig C) dated November 8, 1960
1N697	MIL-S-19500/141(NAVY) dated February 7, 1961

In order to make the raw test data more understandable, distributions of parameter values were plotted. The total number of devices as shown above for each code were used in determining the distributions.

The distributions of the various parameter values are shown in Figures 4-7 to 4-55 inclusive. The device type, the test parameter, bias conditions, specified maximum and/or minimum test values, and the number of devices in the distribution are given for each figure.

The ordinate of each distribution shows the central values of the cells selected for plotting the distribution. For example, the I_R

distribution for the 1N664 diode, Figure 4-7, lists values of .025, .075, .125, etc. The first cell includes values from .000 to .050, the second cell includes values from .050 to .100, and so on. In the event a reading is obtained which coincides with the boundary value between two cells, for example .050, this device will be counted in the lower valued cell, the .025 cell.

Cell widths and the number of cells used have been selected on the basis of providing the most meaningful distributions. In doing this, it became impractical to list all the cells required to show the position of all units, since the test values on certain devices show considerable departure from the norm. HI and LO categories were added to pick up these devices. These categories do not indicate "out-of-spec" devices, since all units used in accumulating the data met the applicable specifications.

Diodes are stockpiled after Group A final testing and submitted to final inspection on a lot basis. The final inspection organization takes random samples of the device lots and subjects them to the various Group B tests. In certain cases the test is an examination of the physical characteristics of the sample. A check of the dimensions of the completed diodes is an example of this case. In other tests, the sample is subjected to certain environmental conditions, following which the devices in the sample are subjected to end point electrical tests. Moisture resistance evaluation is an example of this latter type of Group B test.

All the diodes used for data collection were submitted to Group B inspection as one lot, a total of 1209 diodes. This was done since the number of diodes for a particular code was not large enough to provide all the required samples. For some subgroups samples of two different codes were submitted. In cases where identical subgroups are found in all three applicable specifications only one sample was tested. The resultant Group B data is still valid, however, since the methods of manufacture for all contract diode codes are essentially the same. The results of this inspection are given in Figure 4-56.

VI Evaluation

Evaluation of the degree of success obtained in providing a mechanized production facility meeting the terms and conditions of the PEM Contract can best be made by considering the results of the mechanized run. This run represented an opportunity to evaluate the performance of the individual machines, the contributions of unmechanized processes to the various device parameters, the ability of the various material handling components to perform their particular functions, and the results of testing and final inspection of the completed diodes.

The mechanized run was basically successful. While many problems arose, none were of sufficient magnitude to require complete termination of production. The experience of this run, however, dictates that certain safeguards be established to insure that diodes can be manufactured at the required production rate. These safeguards are listed below:

1. Skilled operators with the ability to use good judgment should be used. These operators should be thoroughly familiar with the operation of their machines or equipment.
2. Quality control measures should follow all operations which affect the product in any way. High capacity production lines are especially vulnerable to variations caused by machine maladjustments or operator error.

3. Critical operations, whether mechanized or partially mechanized, should be controlled automatically, whenever possible, rather than being placed under operator control.

4. Special efforts should be made to insure that all piece parts meet specifications consistent with mechanized production. Effort should also be applied to insure that all variables are covered by specifications.

These safeguards are not unique, since they should be a part of any production line. It is important, however, that they be enforced and continually checked for improvement, particularly when applied to high-volume production lines.

The mechanized diode equipment developed under the PEM Contract was operated for the duration of the mechanized production run. The performance of these machines is discussed in detail in the various individual machine reports. In summary, a list of the diode machines developed under this Contract together with the Western Electric Company drawing numbers and the operating and maintenance specification numbers for the machines is given in Figure 4-57.

The distributions of the electrical test values for the various diode codes shown in Figures 4-7 to 4-55 are for the most part normal distributions. They have been carefully compared to distributions plotted from data on diodes made using the processes in force prior to the development of the mechanized equipment. In all cases but one, the distributions are comparable, with the sole exception being those which show the results of measuring I_S on the regulator diodes. These distributions show that saturation currents for devices made over the mechanized equipment are lower than for manual production devices. This, of course, is advantageous since it improves the blocking action of the diodes and exhibits better forward to reverse characteristics. It is indicative of a cleaner junction which normally assures better reliability.

Yields which resulted from the mechanized production run are not discussed in this report since they are considered proprietary data by the Western Electric Company. These yields, however, were normal for this type of operation.

Evaluation of Group B inspection results, Figure 4-56, indicates that the diode lot behaved in normal fashion. In no case were the allowable number of failures exceeded for any examination or test. In only two cases were the allowable number of failures equaled. The 1N673 showed two failures on Subgroup 3. Both these units had saturation currents near the high valued end of the distribution before being subjected to the specified examination. In all probability the failures were due to over-diffusion which resulted in "punch-through" of the diode junction. The 1N697 showed two failures on Subgroup 5. These devices were cut open for examination of the gold bonding of the wafer to the stud and the internal lead to the wafer. In both cases the gold bond between the wafer and the stud had failed. On one unit the cause was poor gold plate on the wafer. Large areas where the gold plate had pulled off the wafer were visible. On the second unit a poor bond had been made. The bond was off center and incomplete. In only the second instance can the failure be attributed to an item of mechanized equipment, the Gold Bonding Machine. This failure will serve to provide additional information toward making the gold bonding operation more reliable.

While the mechanized diode production line is a reality and has been operated in production, it is not claimed that all machines are problem-free or that all processes are optimized. Considerable effort is planned for Phase 2 of this portion of the PEM Contract to update certain machines and to refine certain processes. An additional mechanized production run will be made at the end of 1963 to evaluate the progress made during this phase.

VII Conclusions

The following conclusions are gathered from this report:

1. A mechanized diode production line consisting of prototype machines and associated tooling and facilities with a capacity meeting contract requirements has been provided.

2. A mechanized production run was made on the mechanized line. This run resulted in an output of good diodes meeting the applicable specifications. As proved by the run, the line can be operated and will produce good product.

3. Distributions of test parameter values for all codes are normal.

DIODE SILICON MATERIAL PROCESSING

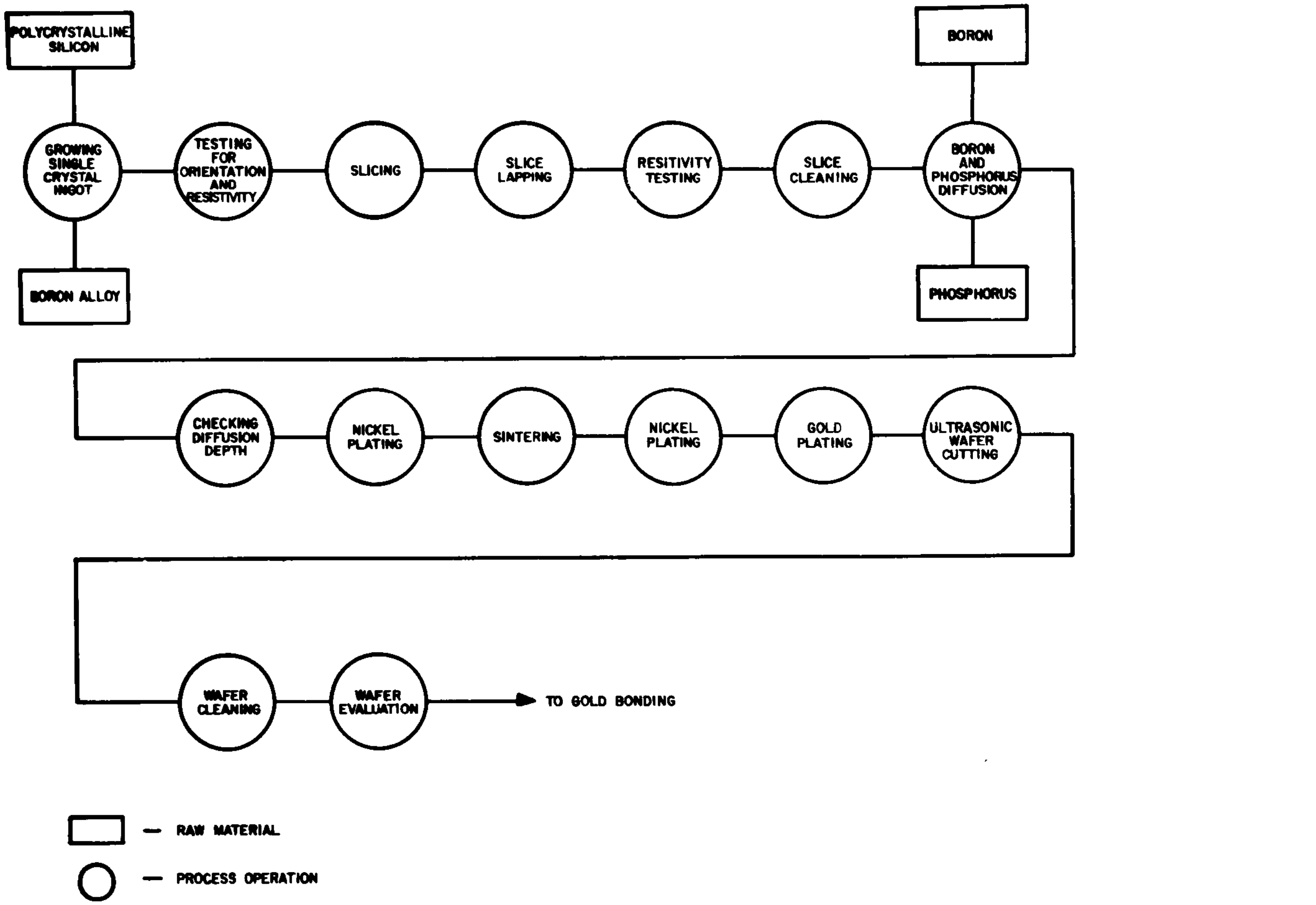


FIGURE 4-1

DIODE ASSEMBLY OPERATIONS

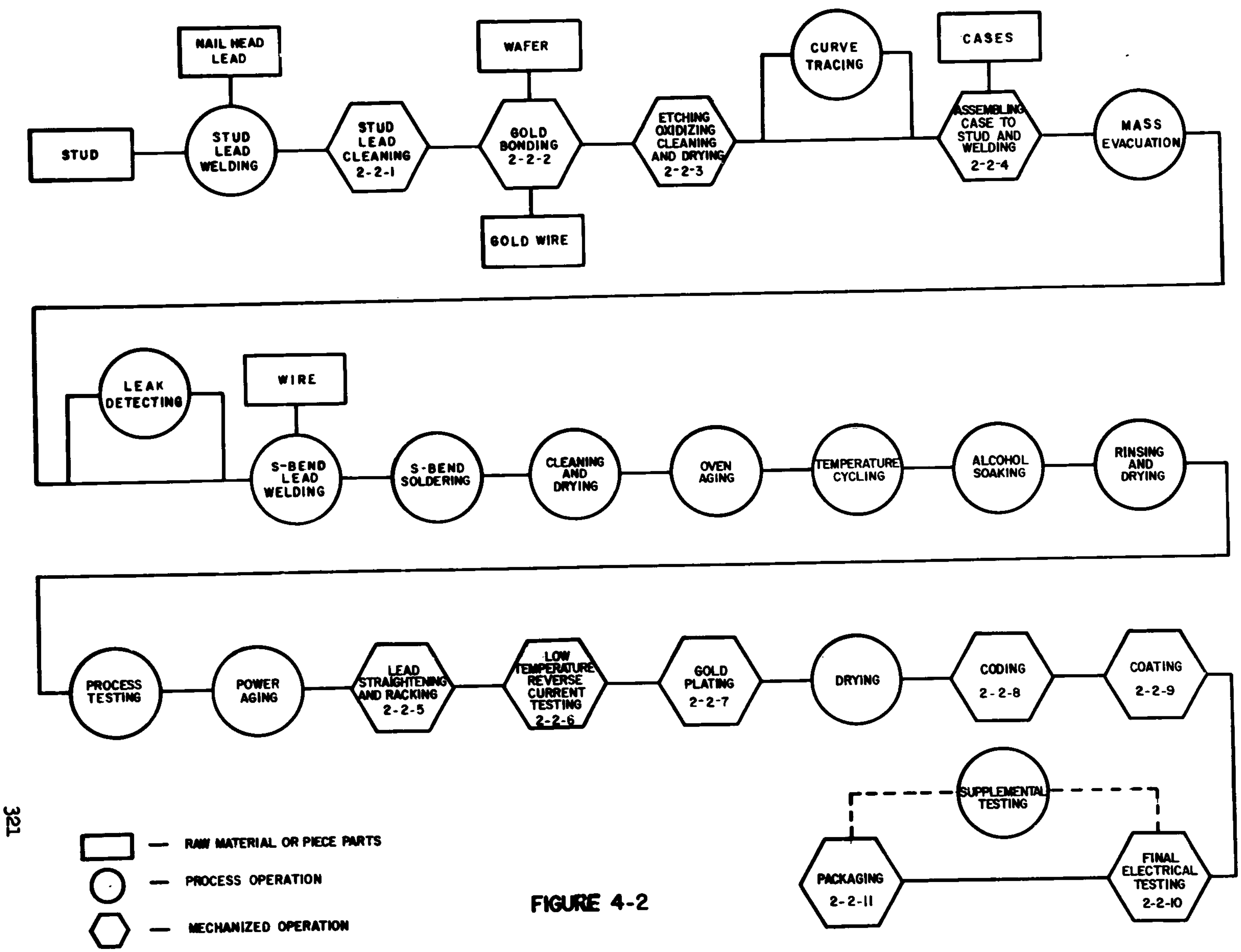
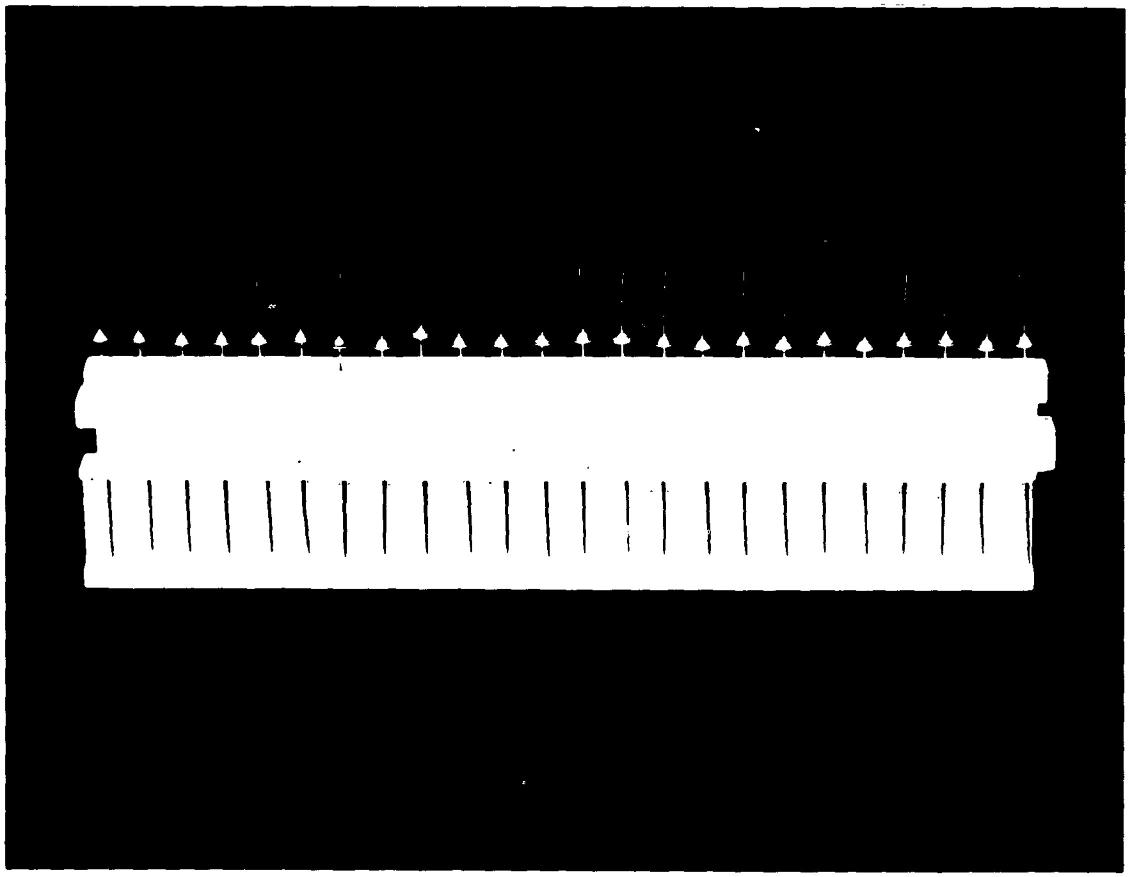
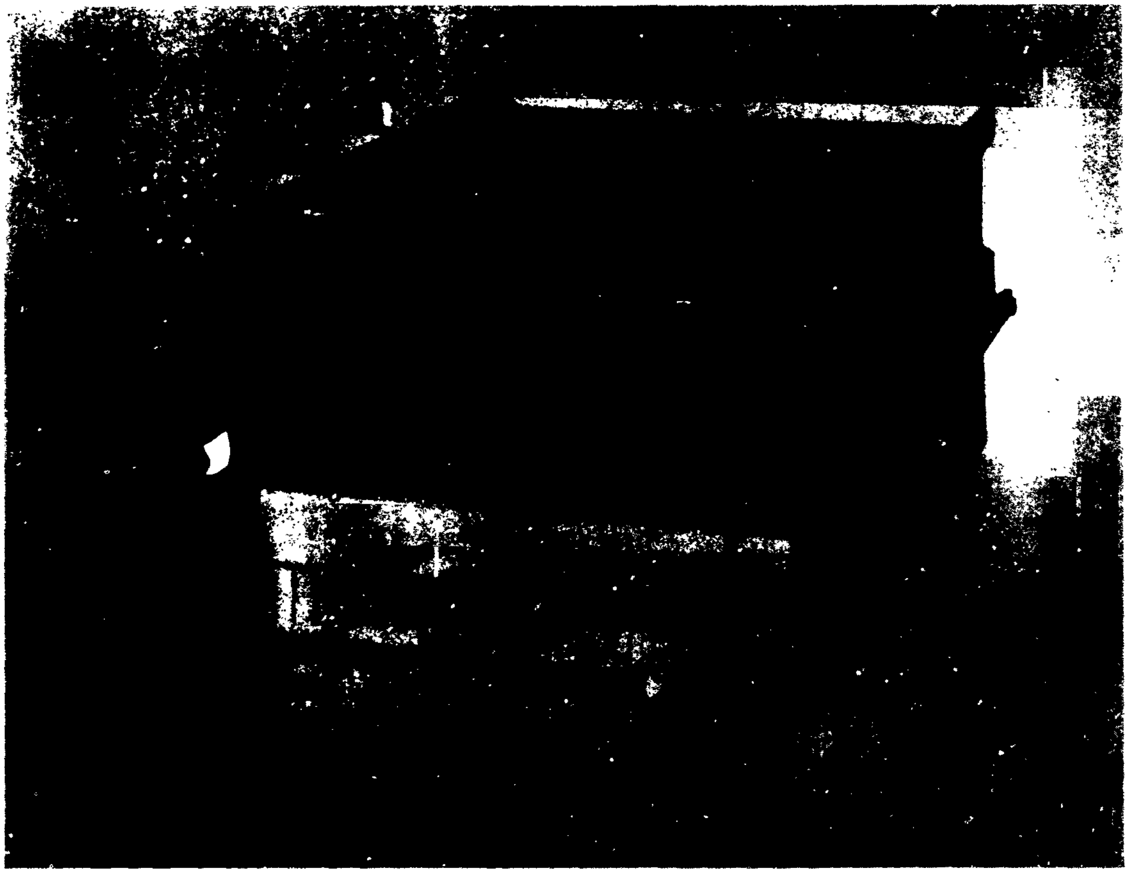


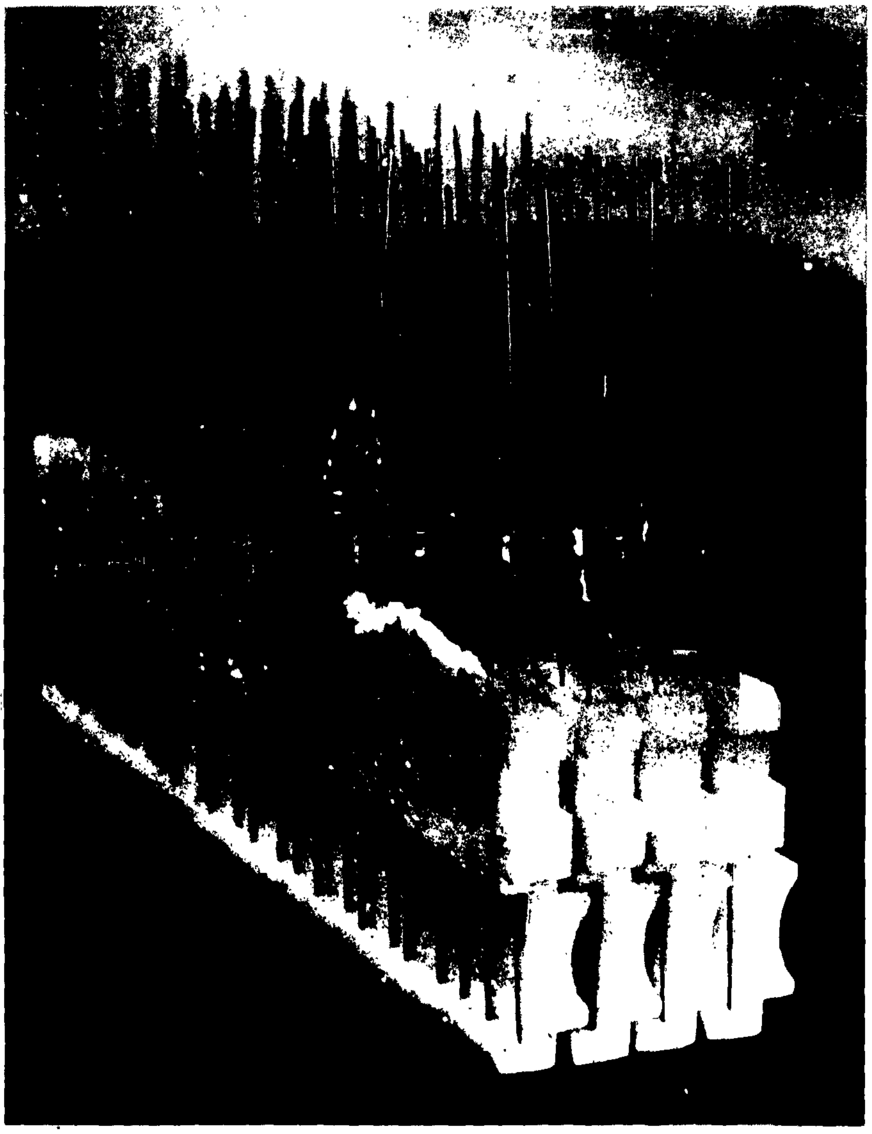
FIGURE 4-2



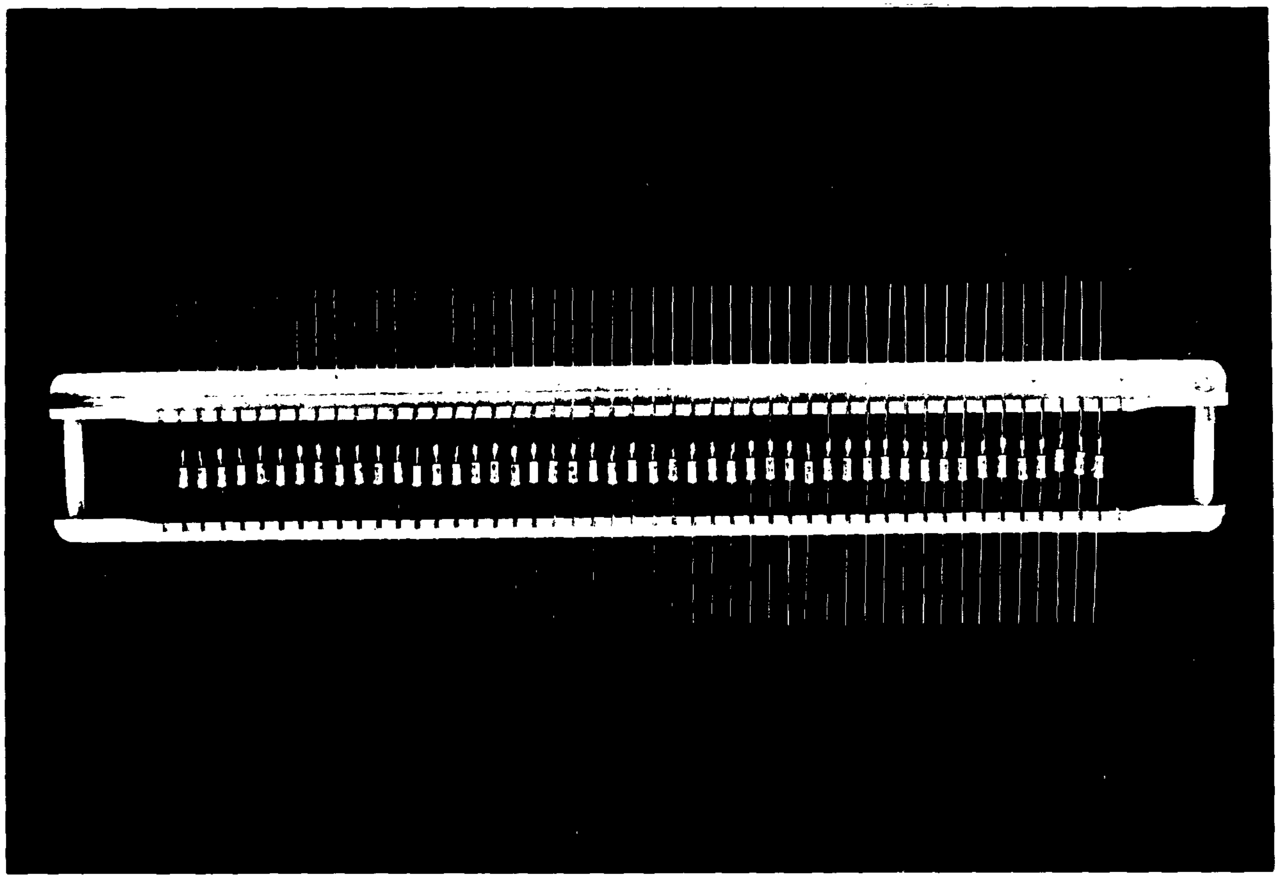
GOLD BONDED SUBASSEMBLIES LOADED IN "TEFLON" RACK
FIGURE 4-3



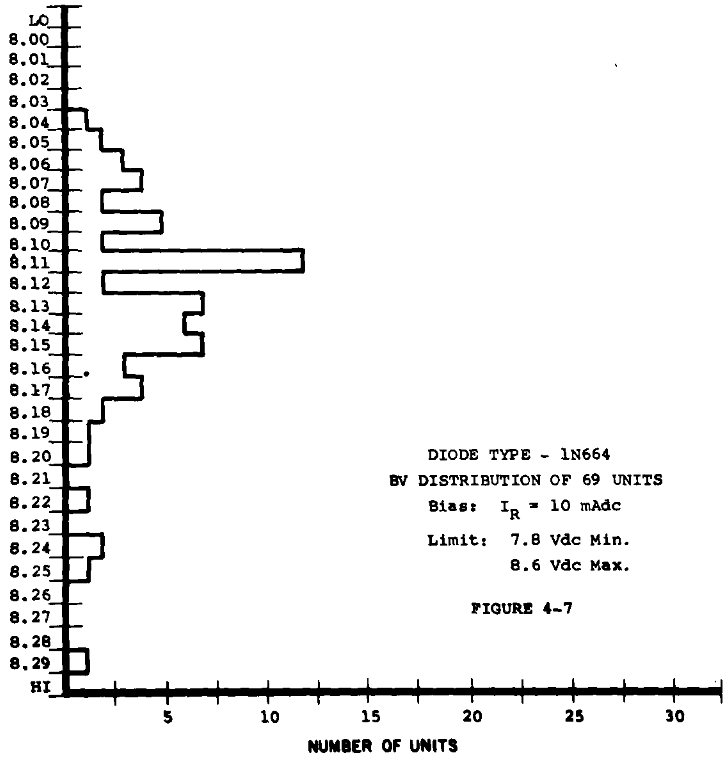
ALUMINUM MAGAZINE LOADED WITH "TEFLON" RACKS
FIGURE 4-4



"TEFLON" RACKS NESTED TO SHOW LEAD CLAMPING ACTION
FIGURE 4-5

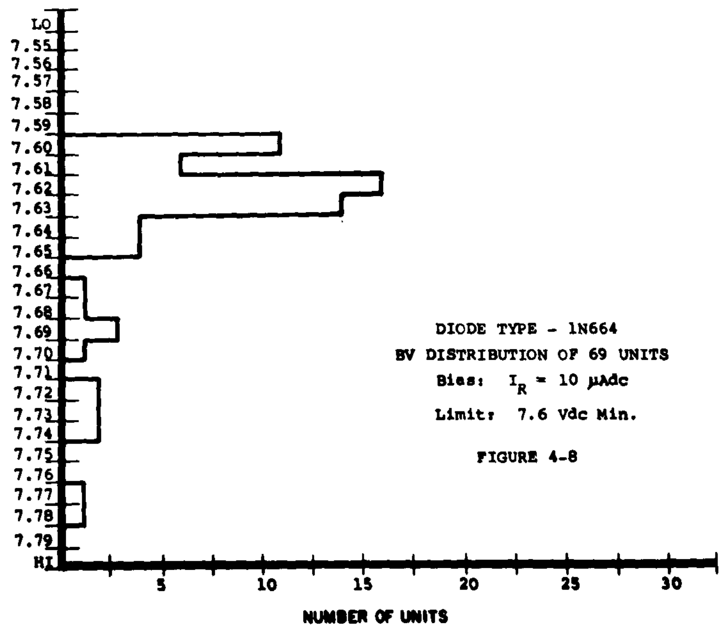


CODED DIODES LOADED IN CONFORMING MATRIX RACK
FIGURE 4-6



DIODE TYPE - 1N664
BV DISTRIBUTION OF 69 UNITS
Bias: I_R = 10 mAdc
Limit: 7.8 Vdc Min.
8.6 Vdc Max.

FIGURE 4-7



DIODE TYPE - 1N664
BV DISTRIBUTION OF 69 UNITS
Bias: I_R = 10 μAdc
Limit: 7.6 Vdc Min.

FIGURE 4-8

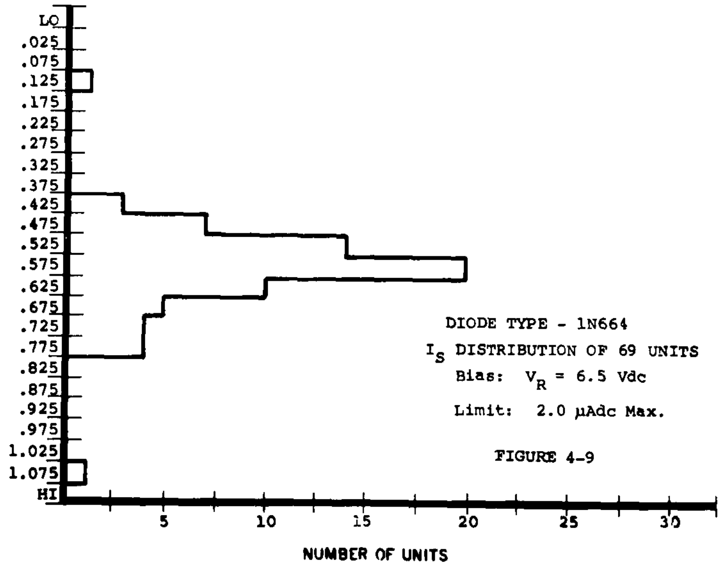


FIGURE 4-9

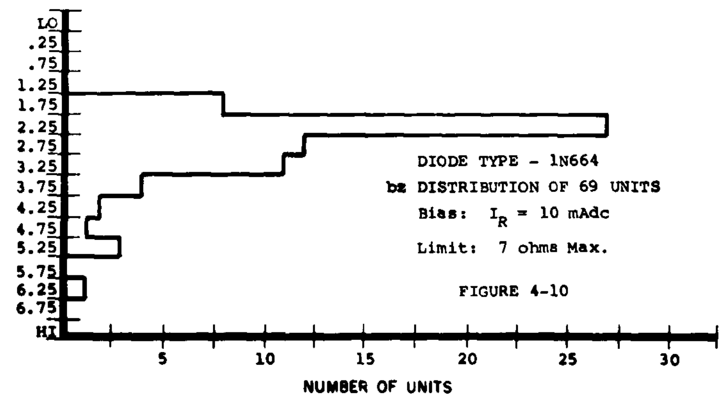


FIGURE 4-10

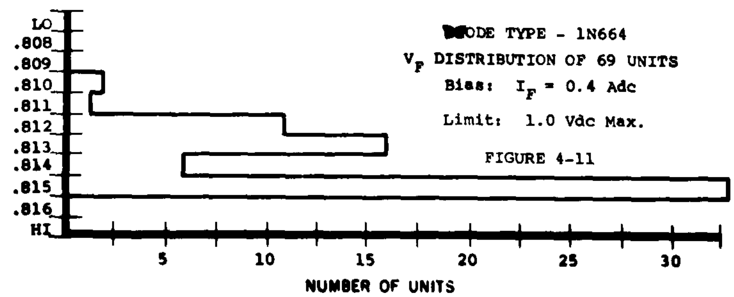
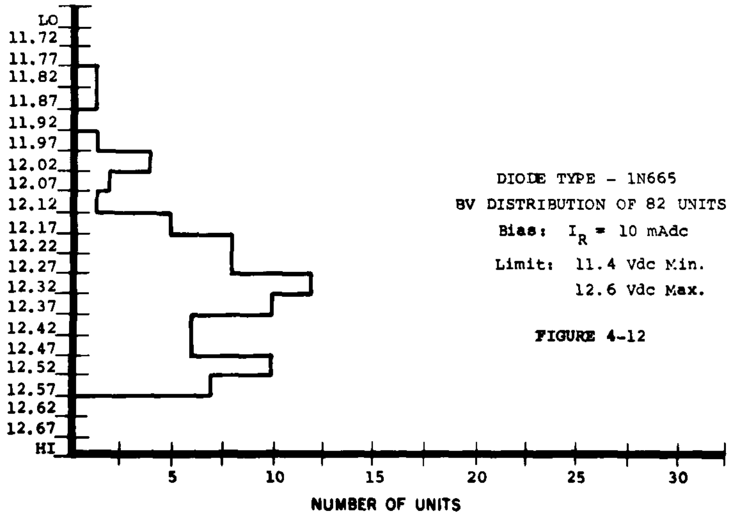


FIGURE 4-11



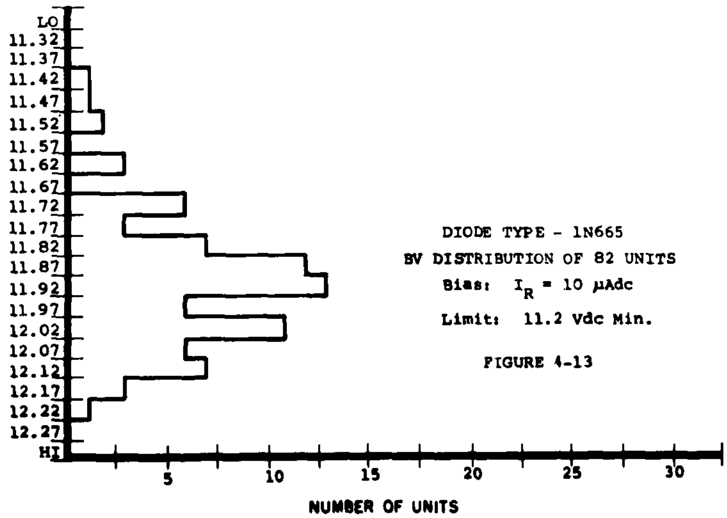
DIODE TYPE - 1N665

BV DISTRIBUTION OF 82 UNITS

Bias: I_R = 10 mAdc

Limit: 11.4 Vdc Min.
12.6 Vdc Max.

FIGURE 4-12



DIODE TYPE - 1N665

BV DISTRIBUTION OF 82 UNITS

Bias: I_R = 10 μAdc

Limit: 11.2 Vdc Min.

FIGURE 4-13

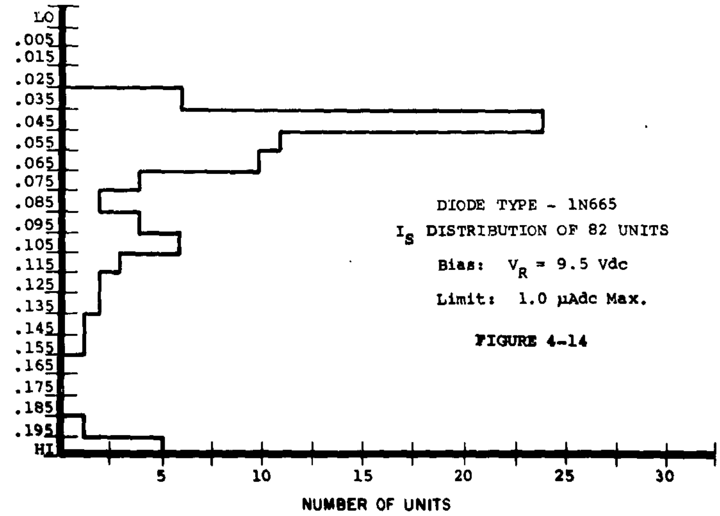


FIGURE 4-14

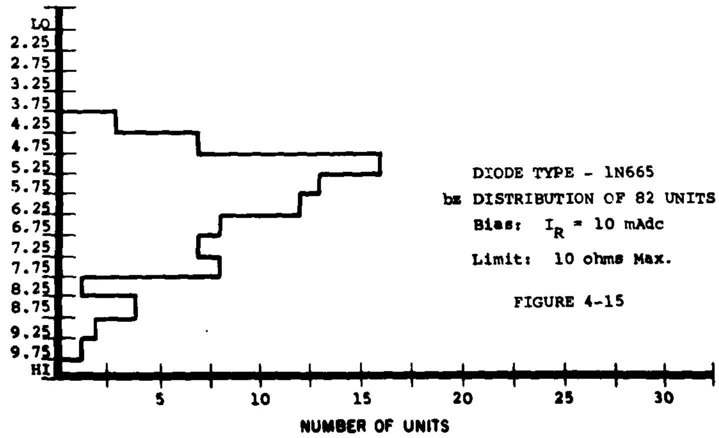


FIGURE 4-15

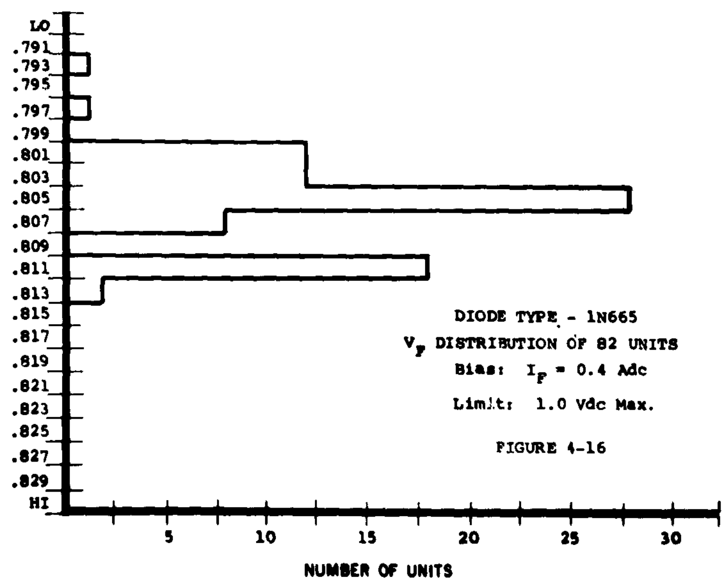


FIGURE 4-16

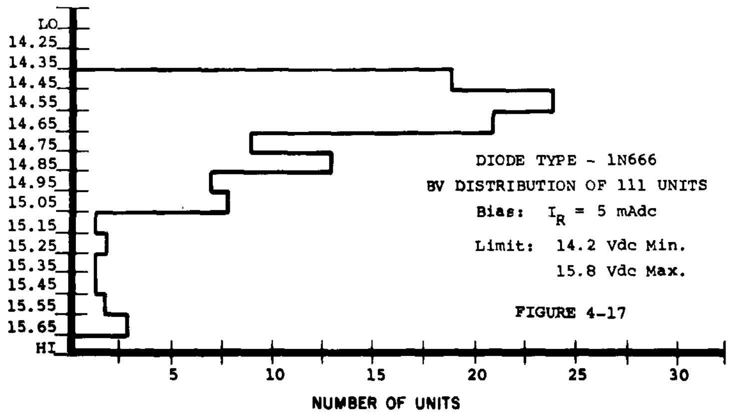


FIGURE 4-17

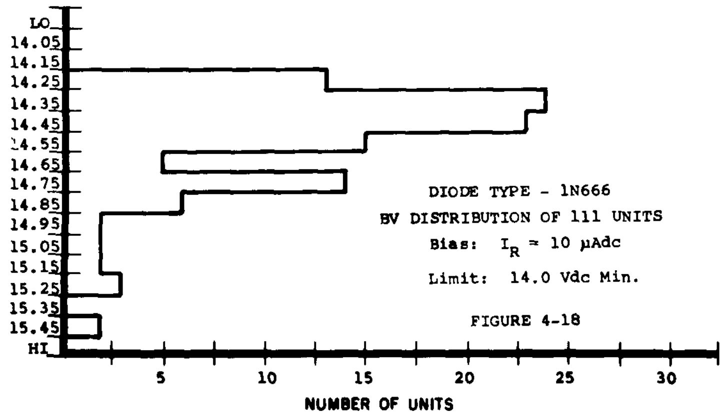


FIGURE 4-18

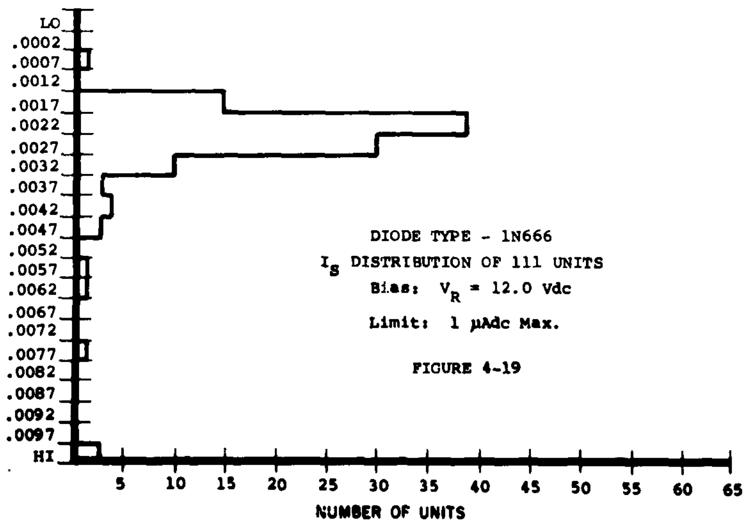


FIGURE 4-19

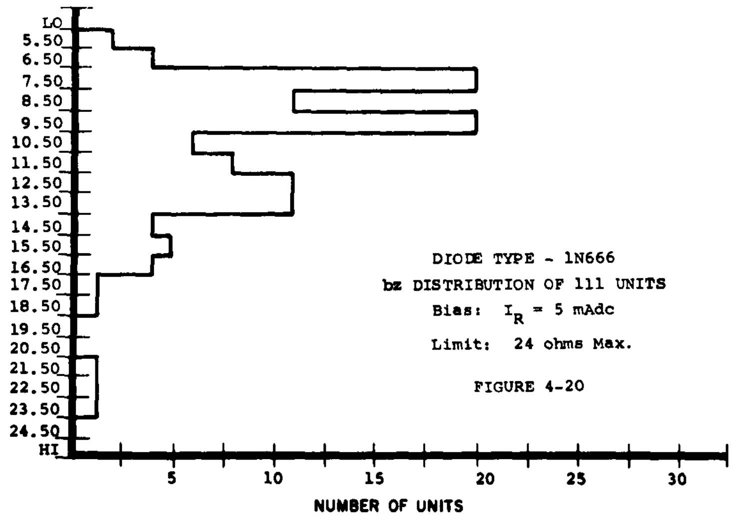


FIGURE 4-20

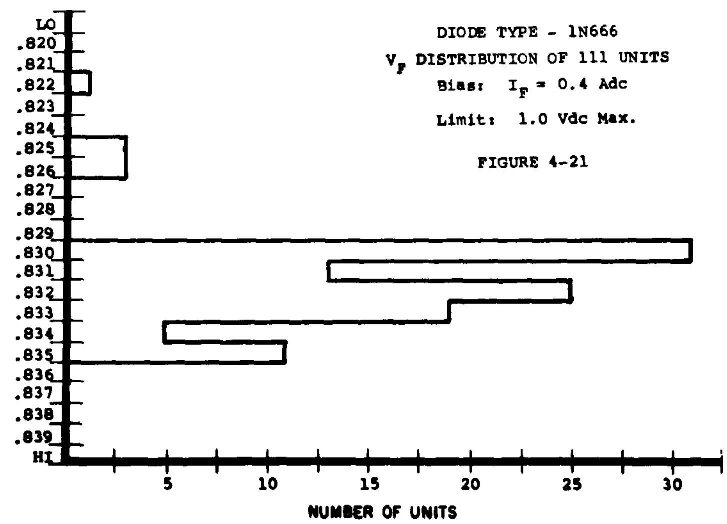
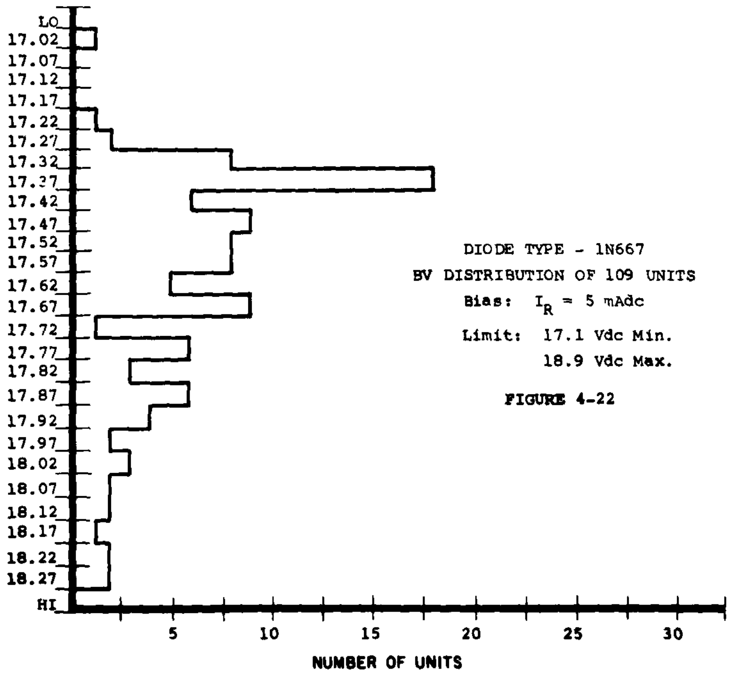


FIGURE 4-21



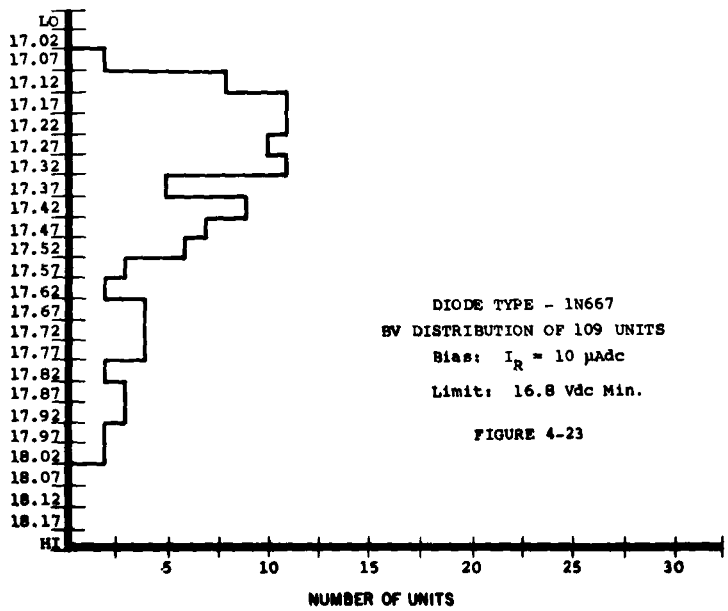
DIODE TYPE - 1N667

BV DISTRIBUTION OF 109 UNITS

Bias: I_R = 5 mAdc

Limit: 17.1 Vdc Min.
18.9 Vdc Max.

FIGURE 4-22



DIODE TYPE - 1N667

BV DISTRIBUTION OF 109 UNITS

Bias: I_R = 10 μAdc

Limit: 16.8 Vdc Min.

FIGURE 4-23

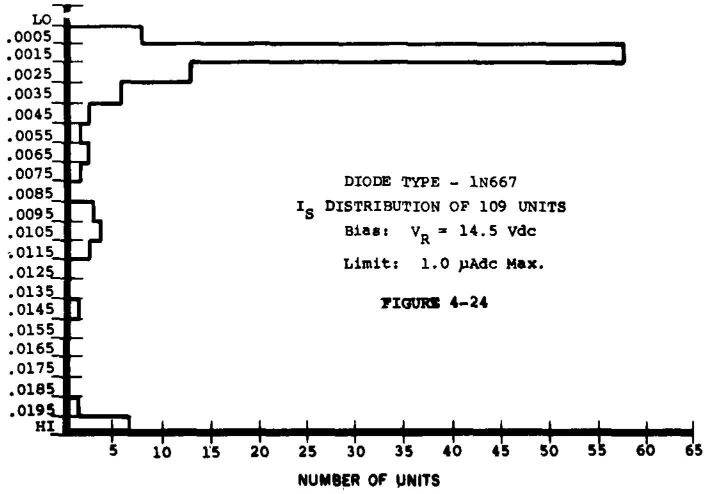


FIGURE 4-24

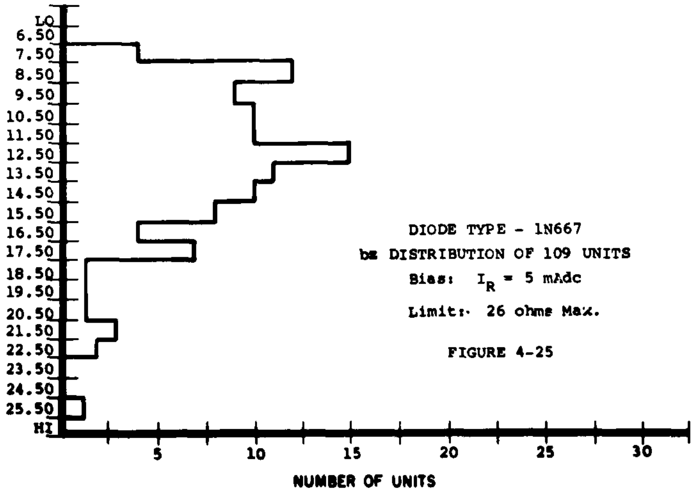


FIGURE 4-25

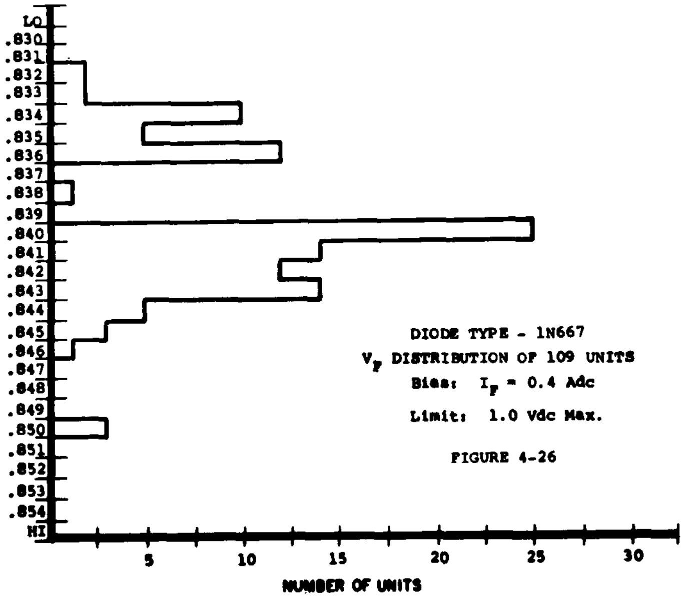


FIGURE 4-26

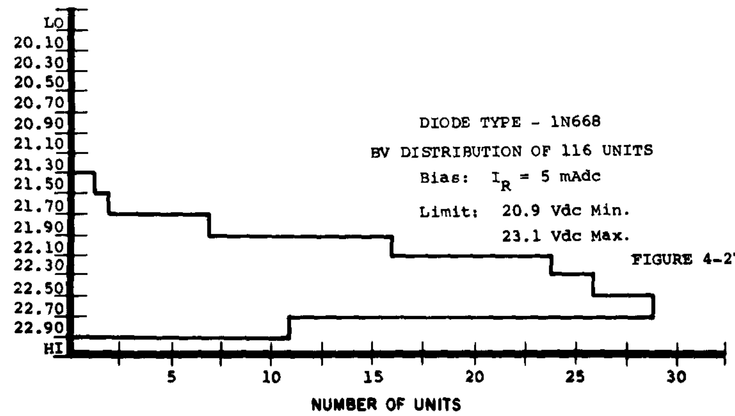


FIGURE 4-27

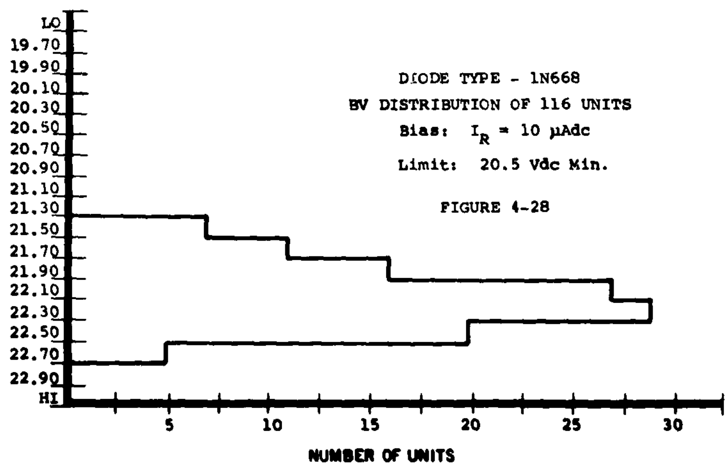


FIGURE 4-28

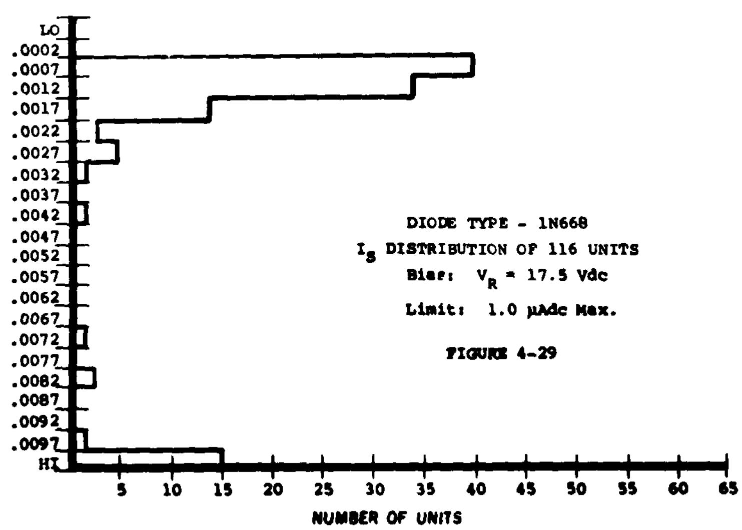
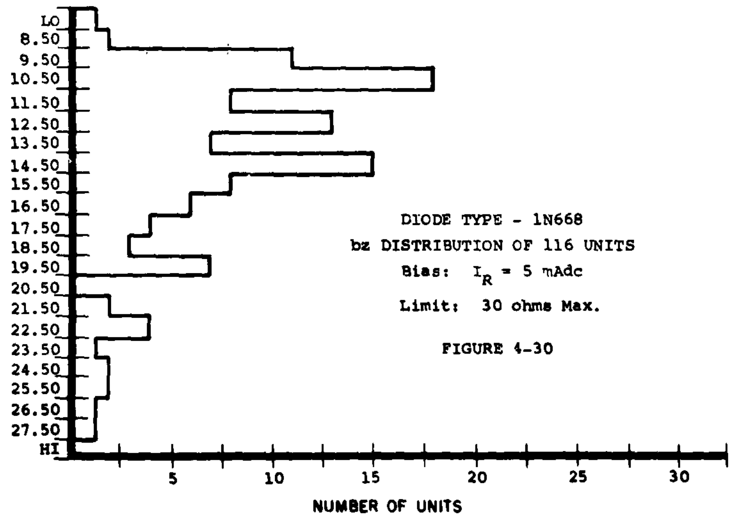


FIGURE 4-29



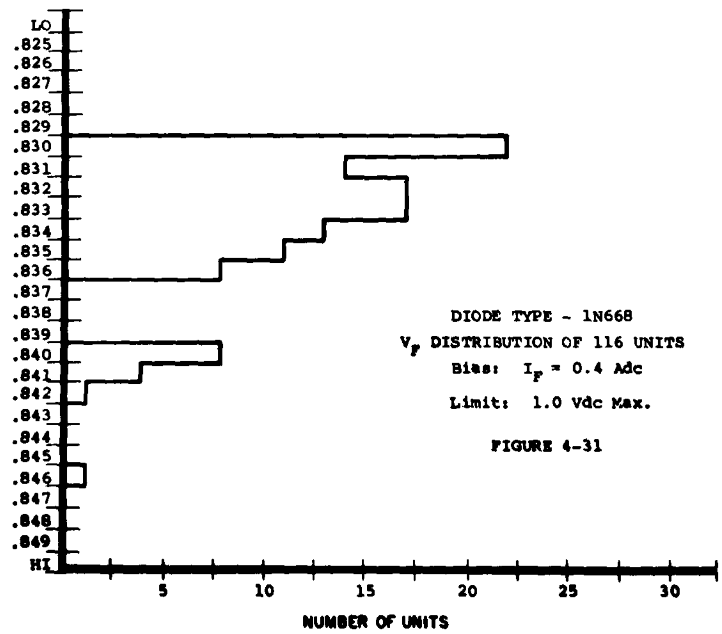
DIODE TYPE - 1N668

bz DISTRIBUTION OF 116 UNITS

Bias: I_R = 5 mAdc

Limit: 30 ohms Max.

FIGURE 4-30



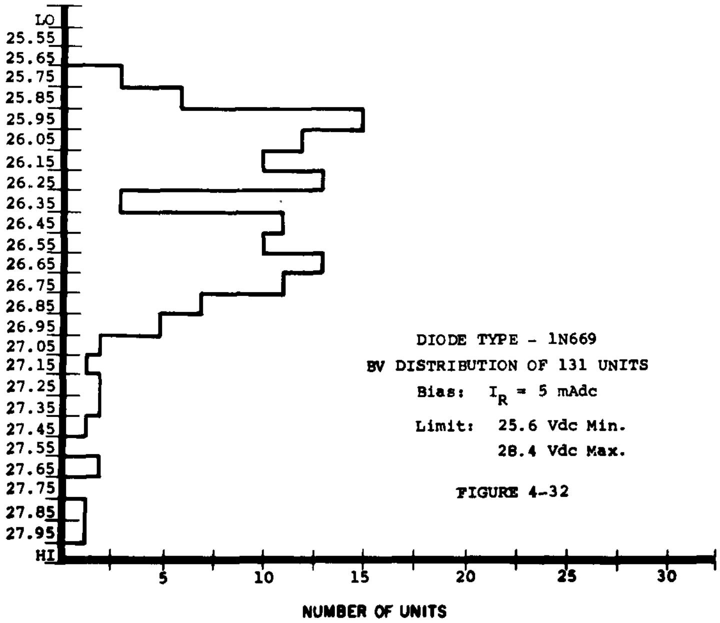
DIODE TYPE - 1N668

V_F DISTRIBUTION OF 116 UNITS

Bias: I_F = 0.4 Adc

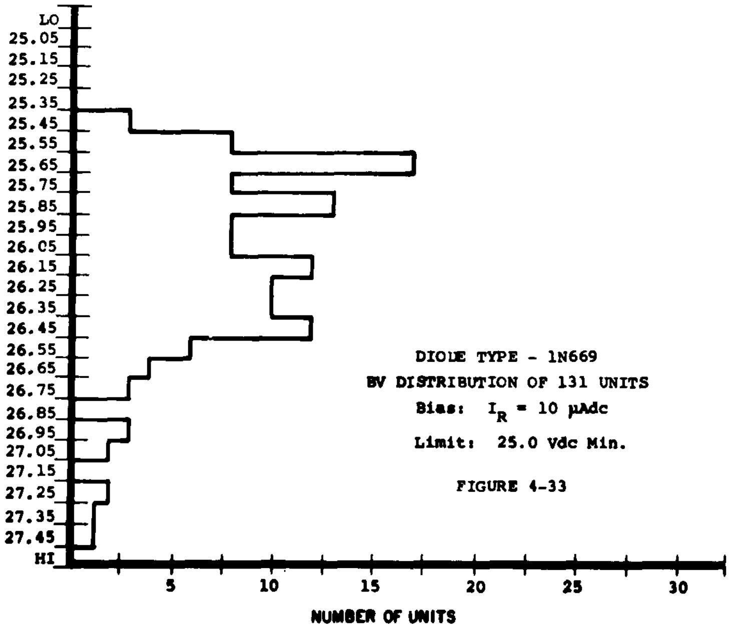
Limit: 1.0 Vdc Max.

FIGURE 4-31



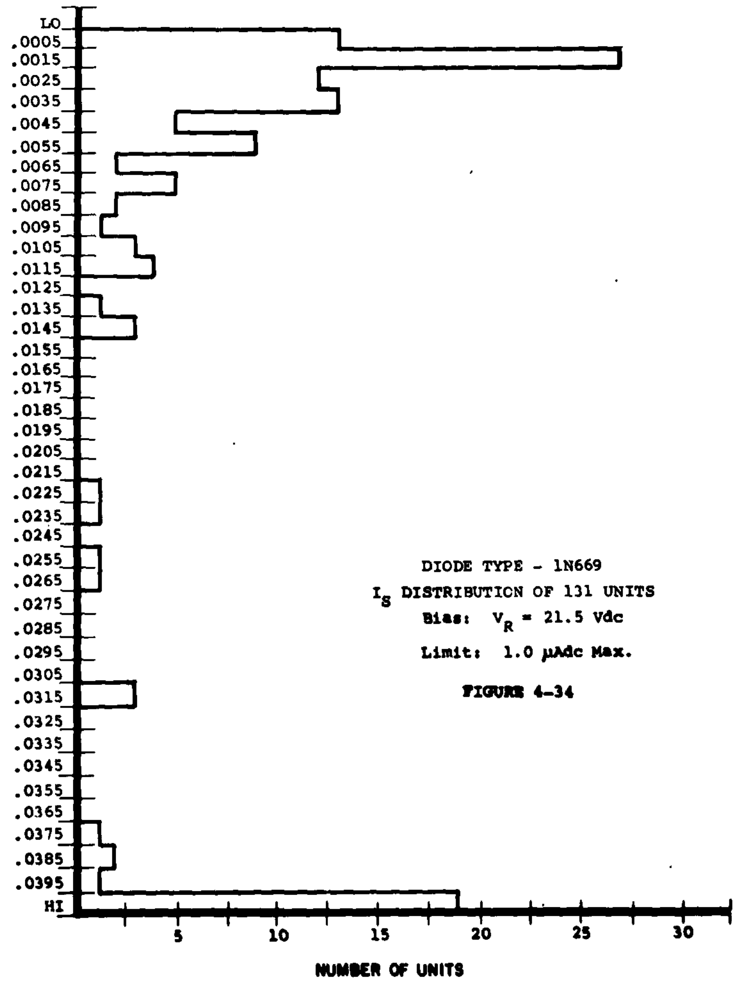
DIODE TYPE - 1N669
BV DISTRIBUTION OF 131 UNITS
Bias: I_R = 5 mAdc
Limit: 25.6 Vdc Min.
28.4 Vdc Max.

FIGURE 4-32



DIODE TYPE - 1N669
BV DISTRIBUTION OF 131 UNITS
Bias: I_R = 10 µAdc
Limit: 25.0 Vdc Min.

FIGURE 4-33



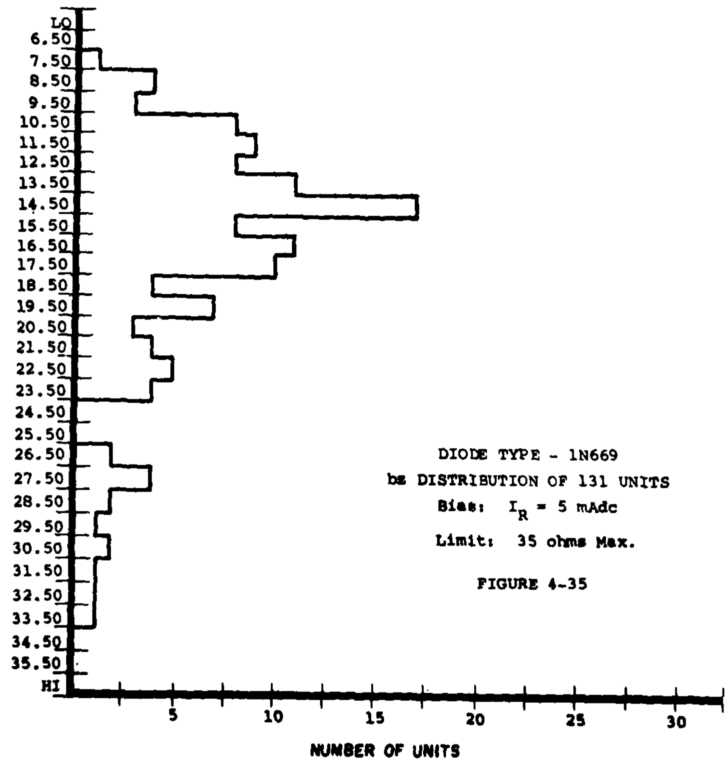
DIODE TYPE - 1N669

I_S DISTRIBUTION OF 131 UNITS

Bias: V_R = 21.5 Vdc

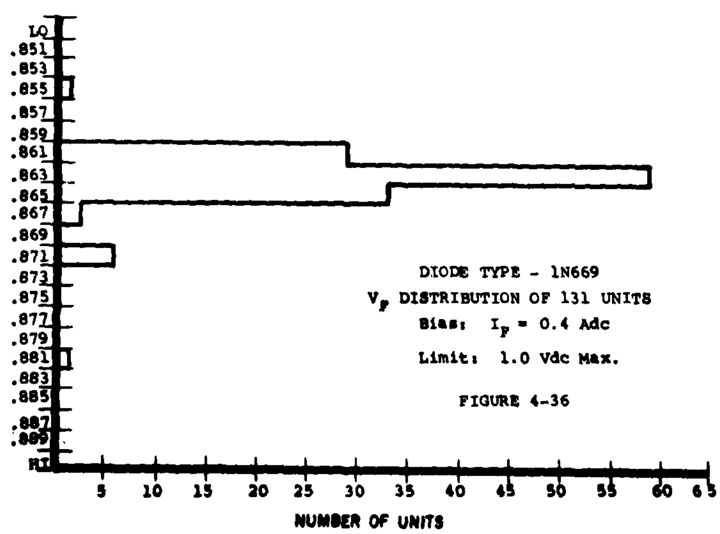
Limit: 1.0 μAdc Max.

FIGURE 4-34



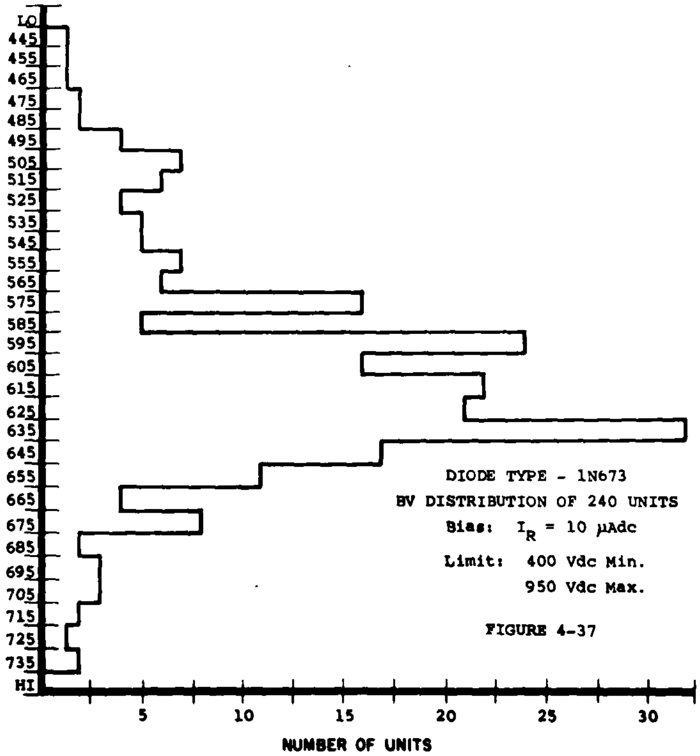
DIODE TYPE - 1N669
bs DISTRIBUTION OF 131 UNITS
Bias: I_R = 5 mAdc
Limit: 35 ohms Max.

FIGURE 4-35



DIODE TYPE - 1N669
V_F DISTRIBUTION OF 131 UNITS
Bias: I_F = 0.4 Adc
Limit: 1.0 Vdc Max.

FIGURE 4-36



DIODE TYPE - 1N673

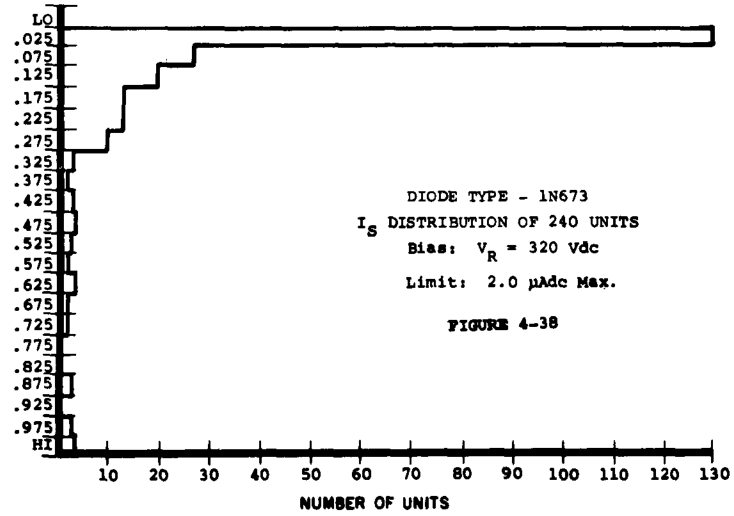
BV DISTRIBUTION OF 240 UNITS

Bias: I_R = 10 μAdc

Limit: 400 Vdc Min.

950 Vdc Max.

FIGURE 4-37



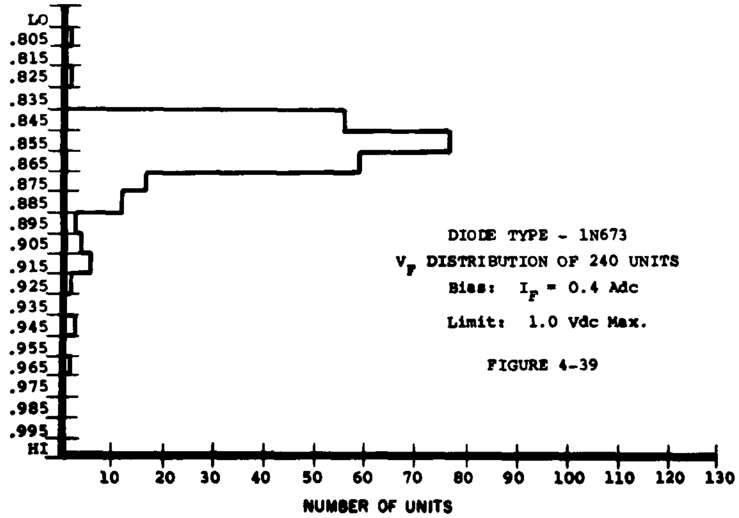
DIODE TYPE - 1N673

I_S DISTRIBUTION OF 240 UNITS

Bias: V_R = 320 Vdc

Limit: 2.0 μAdc Max.

FIGURE 4-38



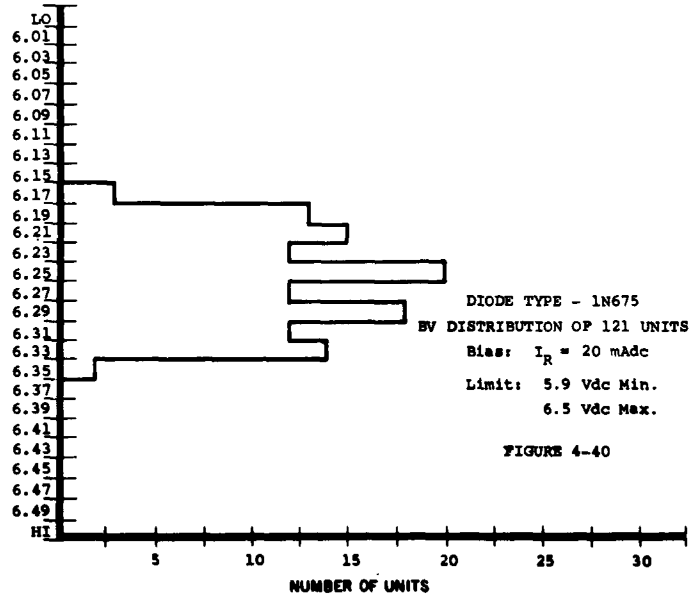
DIODE TYPE - 1N673

V_F DISTRIBUTION OF 240 UNITS

Bias: I_F = 0.4 Adc

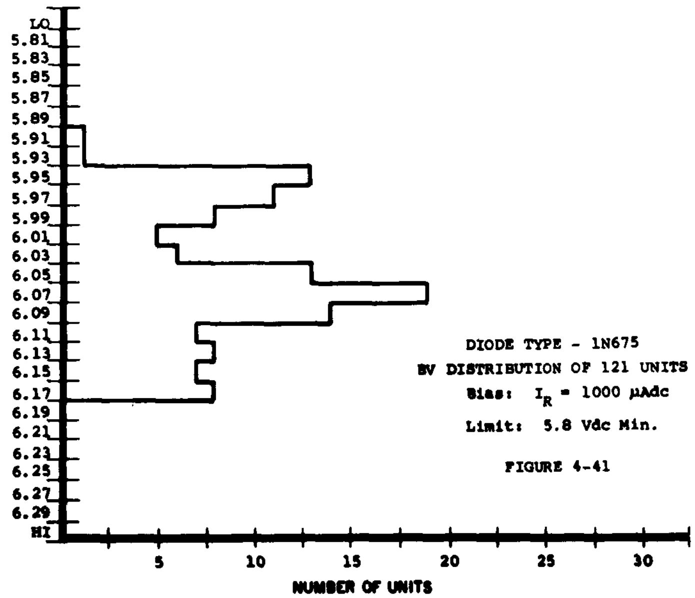
Limit: 1.0 Vdc Max.

FIGURE 4-39



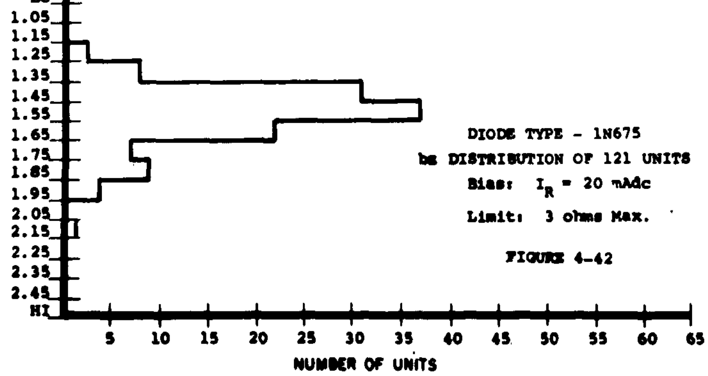
DIODE TYPE - 1N675
BV DISTRIBUTION OF 121 UNITS
Bias: I_R = 20 mAdc
Limit: 5.9 Vdc Min.
6.5 Vdc Max.

FIGURE 4-40



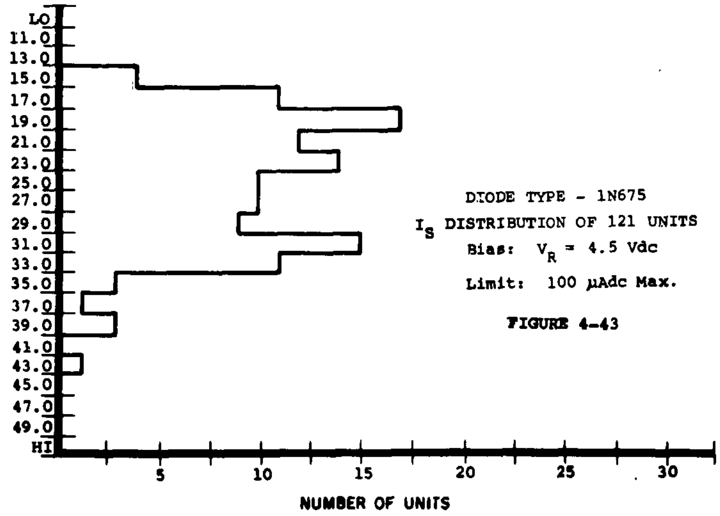
DIODE TYPE - 1N675
BV DISTRIBUTION OF 121 UNITS
Bias: I_R = 1000 μAdc
Limit: 5.8 Vdc Min.

FIGURE 4-41



DIODE TYPE - 1N675
bz DISTRIBUTION OF 121 UNITS
Bias: I_R = 20 mAdc
Limit: 3 ohms Max.

FIGURE 4-42



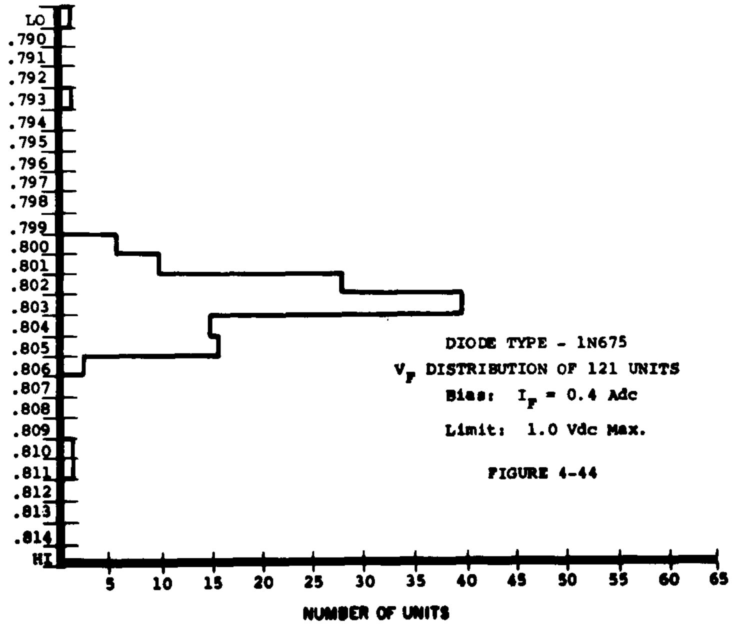
DIODE TYPE - 1N675

I_S DISTRIBUTION OF 121 UNITS

Bias: V_R = 4.5 Vdc

Limit: 100 µAdc Max.

FIGURE 4-43



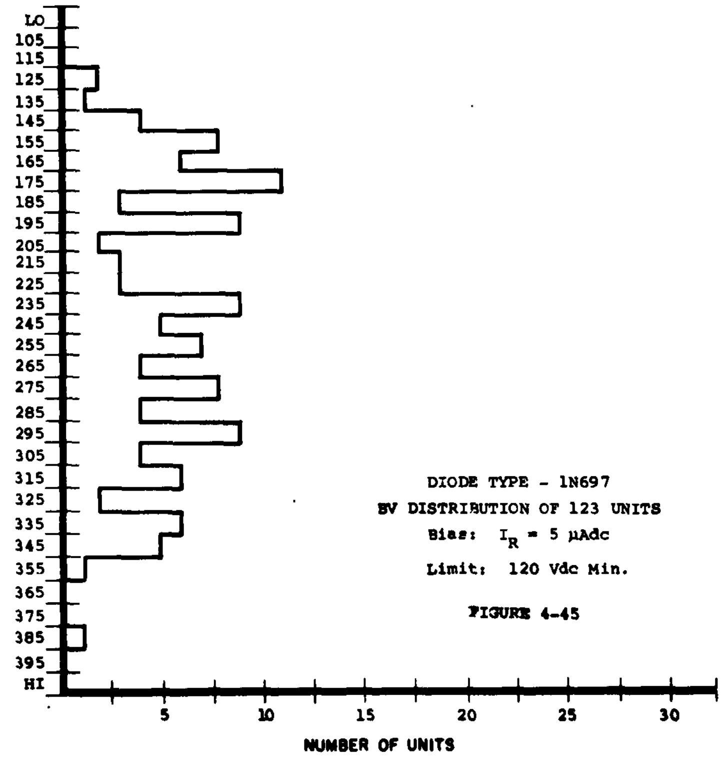
DIODE TYPE - 1N675

V_F DISTRIBUTION OF 121 UNITS

Bias: I_F = 0.4 Adc

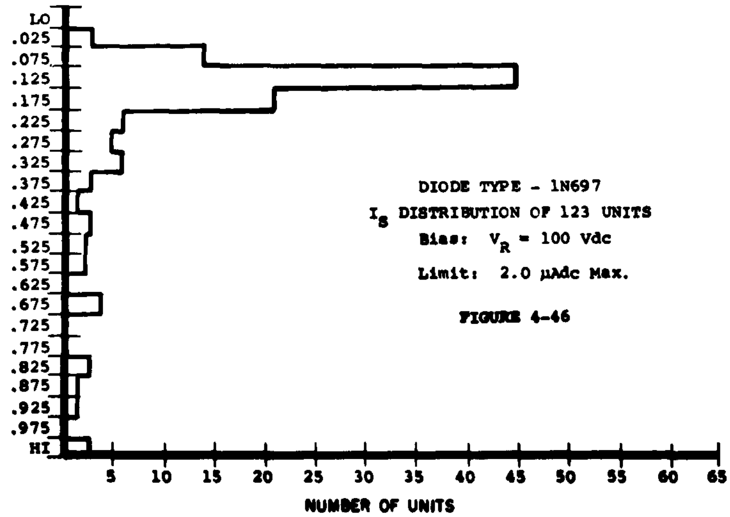
Limit: 1.0 Vdc Max.

FIGURE 4-44



DIODE TYPE - 1N697
BV DISTRIBUTION OF 123 UNITS
Bias: I_R = 5 µAdc
Limit: 120 Vdc Min.

FIGURE 4-45



DIODE TYPE - 1N697
I_S DISTRIBUTION OF 123 UNITS
Bias: V_R = 100 Vdc
Limit: 2.0 µAdc Max.

FIGURE 4-46

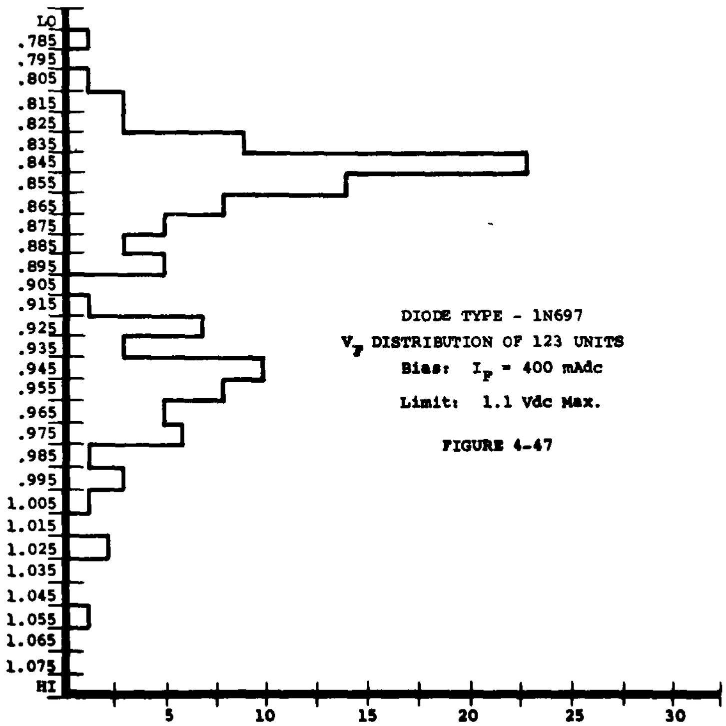


FIGURE 4-47

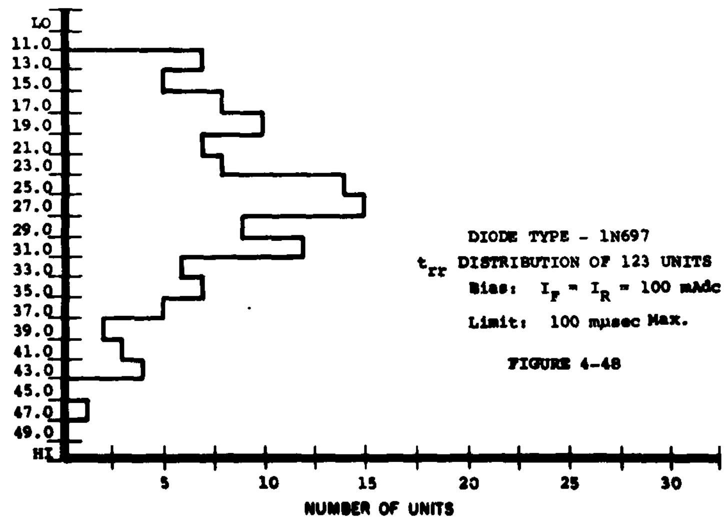
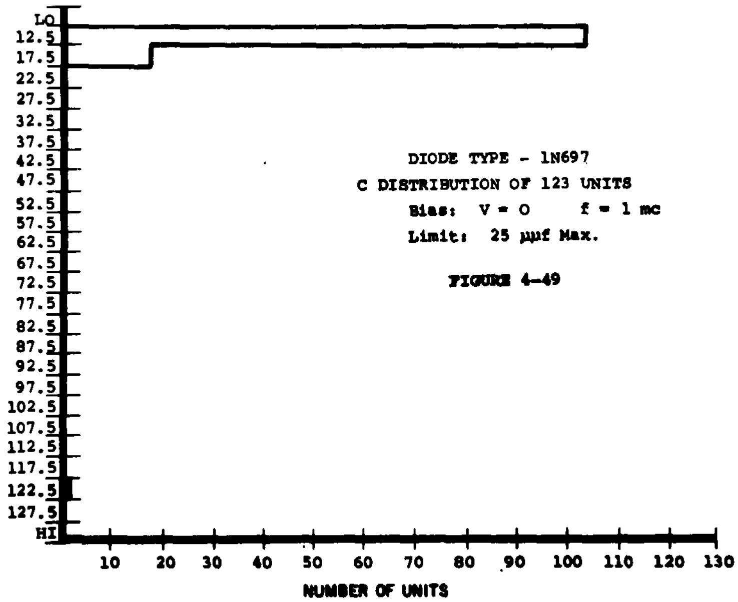
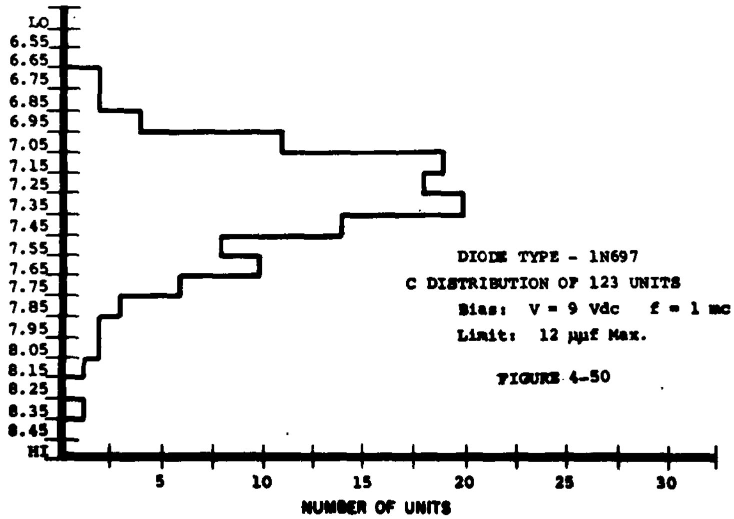


FIGURE 4-48



DIODE TYPE - 1N697
C DISTRIBUTION OF 123 UNITS
Bias: V = 0 f = 1 mc
Limit: 25 μμf Max.

FIGURE 4-49



DIODE TYPE - 1N697
C DISTRIBUTION OF 123 UNITS
Bias: V = 9 Vdc f = 1 mc
Limit: 12 μμf Max.

FIGURE 4-50

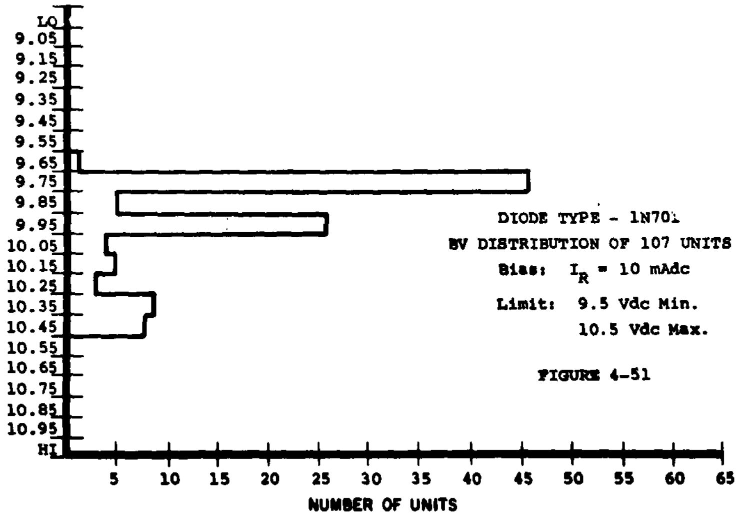


FIGURE 4-51

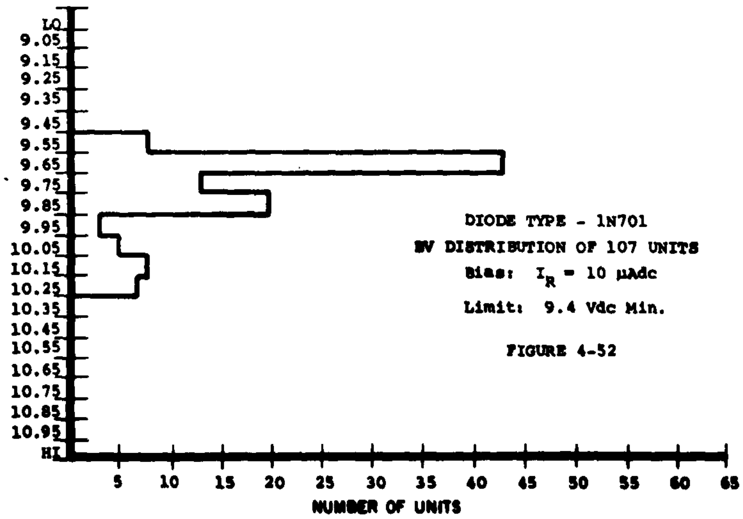


FIGURE 4-52

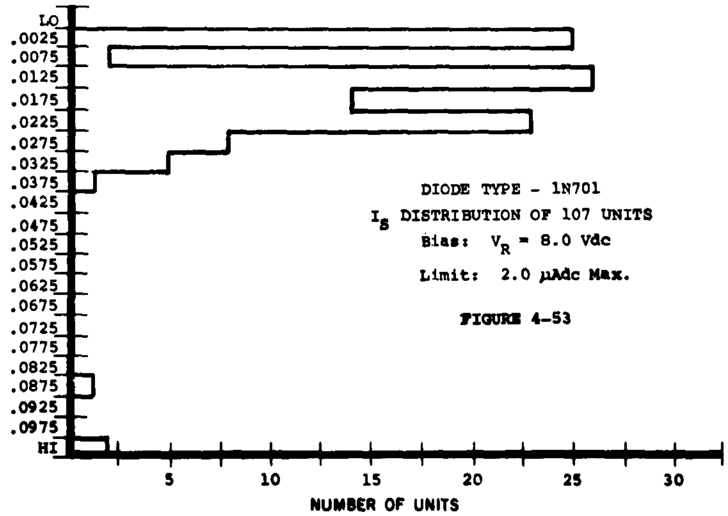


FIGURE 4-53

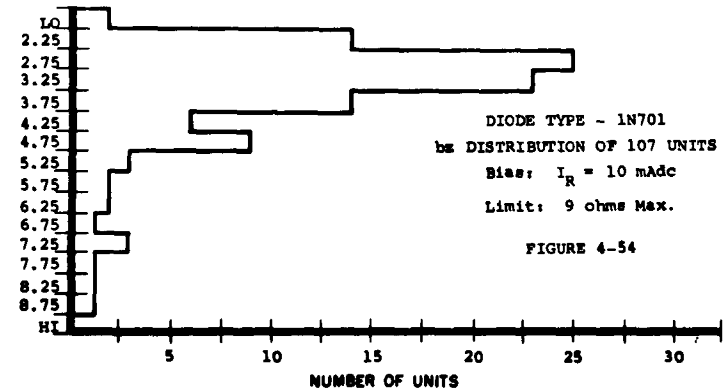


FIGURE 4-54

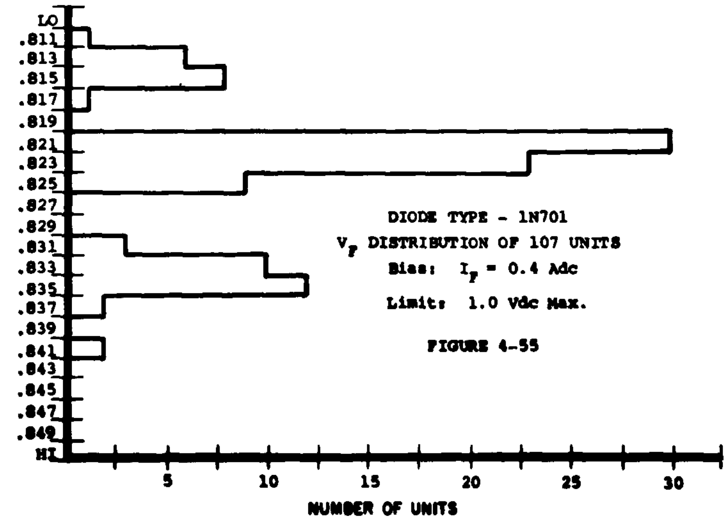


FIGURE 4-55

SUMMARY OF 0.4 WATT DIODE MECHANIZED RUN GROUP B INSPECTION

Lot Quantity - 1,209 Devices

EXAMINATION OR TEST	End Point Tests	Code Used	No. in Sample	No. of Failures	Failures Permitted
MIL-S-19500/150					
Subgroup 1					
Physical Dimensions	None	Mixed	36	0	1
Subgroup 2	I_S				
Forward Surge Current	BV	1N666	52	0	2
Reverse Current	BV	1N675	52	0	2
	bz				
	V_F				
Subgroup 3	I_S				
Temperature Cycling	BV				
Moisture Resistance	BV	1N665	52	0	2
	bz				
	V_F				
Subgroup 4					
Shock	I_S				
	BV				
Constant Acceleration	BV	1N664	52	1	2
Vibration Fatigue	bz	1N667	52	1	2
Vibration Variable Freq.	V_F				
Subgroup 5					
Lead Fatigue	None	Mixed	38	0	1
Subgroup 6					
Salt Atmosphere (Corrosion)	None	Mixed	38	0	1
Subgroup 7					
Thermal Resistance	Θ_{J-A}	1N668	52	0	2
Subgroup 8					
Storage Life	I_S	1N668	52	0	2
	BV				
	BV				
	bz				
	V_F				

FIGURE 4-56 (Part 1)

SUMMARY OF 0.4 WATT DIODE MECHANIZED RUN GROUP B INSPECTION (cont.)

EXAMINATION OR TEST	End Point Tests	Code Used	No. in Sample	No. of Failures	Failures Permitted
MIL-S-19500/149					
Subgroup 2					
High Temperature Operation	BV, V_F, I_S	1N673	38	1	1
Subgroup 3					
Maximum Reverse Current Forward Surge Current	BV, V_F, I_S	1N673	52	2	2
Subgroup 4					
Temperature Cycling Moisture Resistance	BV, V_F, I_S	1N673	38	0	1
Subgroup 5					
Shock Constant Acceleration Vibration Fatigue Vibration Variable Freq.	BV, V_F, I_S	1N673	52	1	2
Subgroup 8					
Thermal Resistance	Θ_{J-A}	1N673	38	0	1
MIL-S-19500/141					
Subgroup 2					
Saturation Current	I_S	1N697	38	0	1
Subgroup 3					
Maximum Reverse Current Forward Surge Current	BV, V_F, I_S	1N697	38	0	1
Subgroup 5					
Shock Constant Acceleration Vibration Fatigue Vibration Variable Freq.	BV, V_F, I_S	1N697	52	2	2
Subgroup 8					
Thermal Resistance	Θ_{J-A}	1N697	22	0	0

FIGURE 4-56 (Part 2)

DIODE MACHINE REFERENCE NUMBERS

PEM CONTRACT DA-36-039-SC-81294

CONTRACT ITEM NO.	MACHINE	WECO DRAWING NUMBER	OPERATING & MAINTENANCE SPEC. NO.
2-2-1	Stud Lead Cleaning	C-281659	21921
2-2-2	Gold Bonding	C-281624	21922
2-2-3	Etching, Oxidizing, Cleaning & Drying	C-281627	21923
2-2-4	Assembling Case to Stud & Welding	C-281664	21924
2-2-5	Lead Straightening & Racking	C-281678	21925
2-2-6	Low Temperature Reverse Current Testing	SID-306396 C-684897	21926
2-2-7	Gold Plating	C-281627 C-281682	21927
2-2-8	Coding	C-281641	21928
2-2-9	Coating	C-281650	21929
2-2-10	Final Electrical Testing	SID-306326 C-281590	21930
2-2-11	Packaging	C-281651	21931

FIGURE 4-57

DIODE MACHINE REFERENCE NUMBERS

PEM CONTRACT DA-36-039-SC-81294

CONTRACT ITEM NO.	MACHINE	WECO DRAWING NUMBER	OPERATING & MAINTENANCE SPEC. NO.
2-2-1	Stud Lead Cleaning	C-281659	21921
2-2-2	Gold Bonding	C-281624	21922
2-2-3	Etching, Oxidizing, Cleaning & Drying	C-281627	21923
2-2-4	Assembling Case to Stud & Welding	C-281664	21924
2-2-5	Lead Straightening & Racking	C-281678	21925
2-2-6	Low Temperature Reverse Current Testing	SID-306396 C-684897	21926
2-2-7	Gold Plating	C-281627 C-281682	21927
2-2-8	Coding	C-281641	21928
2-2-9	Coating	C-281650	21929
2-2-10	Final Electrical Testing	SID-306326 C-281590	21930
2-2-11	Packaging	C-281651	21931

FIGURE 4-57

SECTION 5

MECHANIZED DIODE OPERATIONS

During Phase 1 of the .4 Watt Diode Mechanization Program, 12 operations were mechanized and development of another was started. Only the four operations listed below were to be mechanized initially. Engineering Approach Studies were also required before mechanization of these operations could begin.

1. Wafer Preparation
2. Gold Bonding
3. Etching, Oxidizing, Cleaning and Drying
4. Painting and Coding

Similar studies were also contracted for (1) Assembling Case to Stud and Welding, (2) Final Electrical Testing - 1N673 and (3) Packaging. One year after entering into the Contract, Modification No. 2 added prototype machines for these operations. Then, seven operations were being mechanized.

Contract Modification No. 5, September 29, 1961, increased the number of machines contracted from 7 to 14. Six new mechanized operations were added, and the Painting and Coding operation were divided. In addition, the Painting operation was renamed Coating since a design change now required an unpigmented protective coating for the gold plated diode case.

Twelve of the 14 operations listed in Modification No. 5 are now mechanized. After the Data Producing Test Set is completed in 1963, 13 operations will be mechanized. One of the 13 operations, Wafer Preparation, is no longer listed in the Contract. A commercial machine was provided for this operation. Consequently, it was deleted from the Contract and the special tooling developed for the operation was added to the list of Special Tooling and Test Equipment provided under this Contract.

Development of the fourteenth operation, Wafer Evaluation, was also started. It was discontinued after a survey indicated that present evaluation techniques were adequate. Effort expended on this development is reviewed in Section 6.4.

Each of the following subsections contain a description of the machine provided and a review of its development, operational problems and performance. A narrative on Wafer Preparation is also included in this section even though it is no longer listed as a mechanized operation. Considerable engineering effort was expended evaluating various methods of preparing wafers before purchasing a commercial machine and then developing high volume production tooling for the machine.

SECTION 5.1

STUD LEAD CLEANING

H. A. Griesemer

STUD LEAD CLEANING

I General

The Stud Lead Cleaning Machine cleans the bonding surface of the .4 watt diode stud as it automatically passes through three jets of hot nitrogen separated by two sprays of solvent. Racks are loaded into the load station, intermittently indexed along a track through the cleaning station, and automatically unloaded into the unloading station.

This machine replaces a manual batch-type cleaning process. It transports the stud-leads in the standard material handling racks, maintains lead straightness and provides improved cleaning of the studs. The output of the machine is approximately 2,000 units per hour.

II Description of Machine

The machine is 3 feet square and 5-1/2 feet high. The general arrangement of stations is shown in Figures 5.1-1 and 5.1-2 with the load station on the right, the glass enclosed cleaning compartment in the center, and the hooded unload station containing a protective atmosphere on the left. The instrument and control panel is located at eye level within easy operator reach. Nitrogen gas and 440-volt electric power are supplied to the machine.

The loading station consists of two parallel tracks so designed as to receive standard material handling racks from handling trays. A weighted trolley pushes the racks onto the transfer track as they are required. The vertical arm of the trolley is hinged so that it can be lowered for rack loading.

Two short pivoted arms are provided at the entrance to the transfer track (Figure 5.1-2) for the purpose of holding the tongue of the first rack on the load station 1/16 to 1/8 inch away from the leads in the rack being indexed away from the load station. These arms operate at the start of the first rack indexing and remain in operation until another rack is required on the track. Oscillatory motion of the pivot arms is obtained from the indexing cam lever. A mechanical locking device holds the arms in operating position and works in conjunction with a linkage that senses the need for another rack on the transfer track.

The transfer track consists of two angle sections with a back plate, cutout to receive the rack tongues, mounted on the rear angle. Space for the racks is provided between the face of the front angle and the back plate.

The racks are intermittently moved through the track in 1/4-inch increments by a drive foot having a conical projection which seats in the countersunk cavities centered on the lead holes of the handling racks. The drive foot moves in a rectangular path. At the proper position, a cam on the indexing mechanism lowers the drive foot into the countersunk cavities of the racks. The indexing mechanism is cam operated from a "V" belt driven shaft by a Boston Gear Reducer and Motor #MIB-30-CS. An adjustable pulley provides speed variations from 1,930 to 2,620 indexes per hour.

The cleaning compartment is divided into five sections. The studs receive five alternate sprays of hot nitrogen and solvent beginning with hot nitrogen as they pass through the compartment. Solvent from the tank in the machine base is siphoned through nitrogen operated Spraying Systems Company nozzles #2850. The quantity of solvent sprayed is determined by the rate of nitrogen flow. All used solvent is evaporated and removed by an exhaust system.

Racks reaching the end of the transfer track close a switch which causes the direct current solenoid to push them beyond the retaining springs on the unload station. These retaining springs prevent the weighted rack restraining trolley from returning the racks to the transfer track. To facilitate loading racks into handling trays from the unload station, a preset number of racks are seperated from succeeding racks by the release of a lever on a trailer to the main trolley.

Switches are provided to stop the indexing drive motor when the last rack leaves the load station, when the unload station is full, or when the unload solenoid fails to push a rack off the track.

A gong and signal light indicate when additional racks are required on the load station and when racks must be removed from the unload station. These indicators along with the intermittent monitoring of the pressure gauges, solvent spray, gas flow raters and temperature indicators allow partially unattended operation of the machine.

III Machine Development

A survey of the existing manual batch-type solvent cleaning process indicated that it was unsuitable for use on the mechanized line because of variability in the process, inability to keep leads straight, and its lack of handling units in racks required by subsequent machines. Therefore, the four following cleaning methods were studied:

1. Modify the existing process by manually processing large groups of stud leads in a handling rack fixture, automatically filling and dumping solvent pans, and drying in a hot nitrogen dryer.
2. Clean assemblies in a cascade ultrasonic bath followed by hot nitrogen drying.

3. Clean assemblies by transporting them in racks through three jets of hot nitrogen separated by two sprays of solvent with automatic loading, unloading, and transport through the cleaning chamber.
4. Clean assemblies using method described in Item 3, with the exception that the automatic load and unload features are eliminated.

An evaluation of these processes led to the choice of the fully mechanized method described in Item 3. This choice was based on the lead straightness requirement, decreased process variation, and reduction of material handling by processing units in standard racks. An added advantage over the existing process was the elimination of the highly flammable acetone.

To evaluate and obtain design information for the chosen process, the following cleaning experiment was conducted:

1. A hot nitrogen stream was applied to a stud lead assembly, having a thermocouple welded to its top, until the temperature stabilized.
2. Solvent spray was applied until temperature stabilized again.
3. The water break test was applied to the stud before and after the cleaning cycle.

Results indicated the most effective conditions were a hot nitrogen temperature of 300°F with three dryings and two solvent exposures of 5 seconds each.

During the prove-in phase it became apparent that stud leads in the rack on the transfer track adjacent to the load station could be bent by the tongue of the first rack in the station. To overcome this problem, a rack relief mechanism was added which provided 1/16 to 1/8 inch separation between these racks.

IV Operational Problems

The main problems encountered during prove-in were lead bending by the indexing mechanism and establishment of criteria for final shop trial evaluation. To reduce lead bending, the indexing unit was realigned; a rack positioning spring was installed at the left side of the load station; the track width was increased, and a switch with less activating force was installed at the left end of the track. As a result of these changes the number of bent leads was reduced to less than 1 percent.

The water break test was used to evaluate the effectiveness of the machine's cleaning process. Experimental results indicated that human oil and grease were removed. Cleanness of machine cleaned units was checked further by recleaning them in other solvents, including acetone. Application of these solvents for extended periods did not apparently improve the cleanliness. Machine cleaned units were, however, cleaner than units from the existing process. Because of difficulty in evaluating the water break test on a small area such as the top of the stud lead assembly, a polished piece of 1 inch by 1/4 inch steel was submitted to the same tests with identical results.

Machine cleaned studs were immersed in deionized water and the conductivity measured as a test for a gross build up of ions which might result from the process combination of heat and solvent. Prior experience with this type of test indicated that the results showed no excessive accumulation of ions.

A microscopic examination of stud-lead assemblies before and after cleaning showed that the mechanized process removed white dust-like particles which were not removed by the existing process.

An extensive shop trial was now conducted using the bond strength between the gold preform and stud as an indication of cleaning effectiveness. Approximately 200,000 stud-leads were cleaned by each process, gold bonded, and submitted to an 80,000-g centrifuge test. An analysis of the failures from a sample of 1,100 assembled diodes taken from each group showed 1.39 percent failures from the mechanized process. While this data does not show a significant statistical difference some improvement in the cleaning process is indicated.

V Performance

During the shop trial an output of 2,000 stud-leads per hour was obtained. Since the machine is operating at a maximum capacity of 2,290 units per hour, elimination of manual rack loading by full integration into the mechanized line should increase this figure.

The number of leads bent during indexing has been reduced to less than 1 percent. However, on some racks, the lower portion of a few leads were slightly bent making them difficult to load into the Gold Bonding Machine. This condition has been corrected by readjusting the index timing and rack relief mechanism to provide maximum clearance between the racks on the track and in the load station before indexing starts.

While cleaning about 600,000 stud-leads, the machine operated with a high degree of reliability. The only maintenance required was the adjustment of the spray nozzles and the replacement of two broken springs, a stud, a latch on the indexing mechanism, and the holding springs on the unload station.

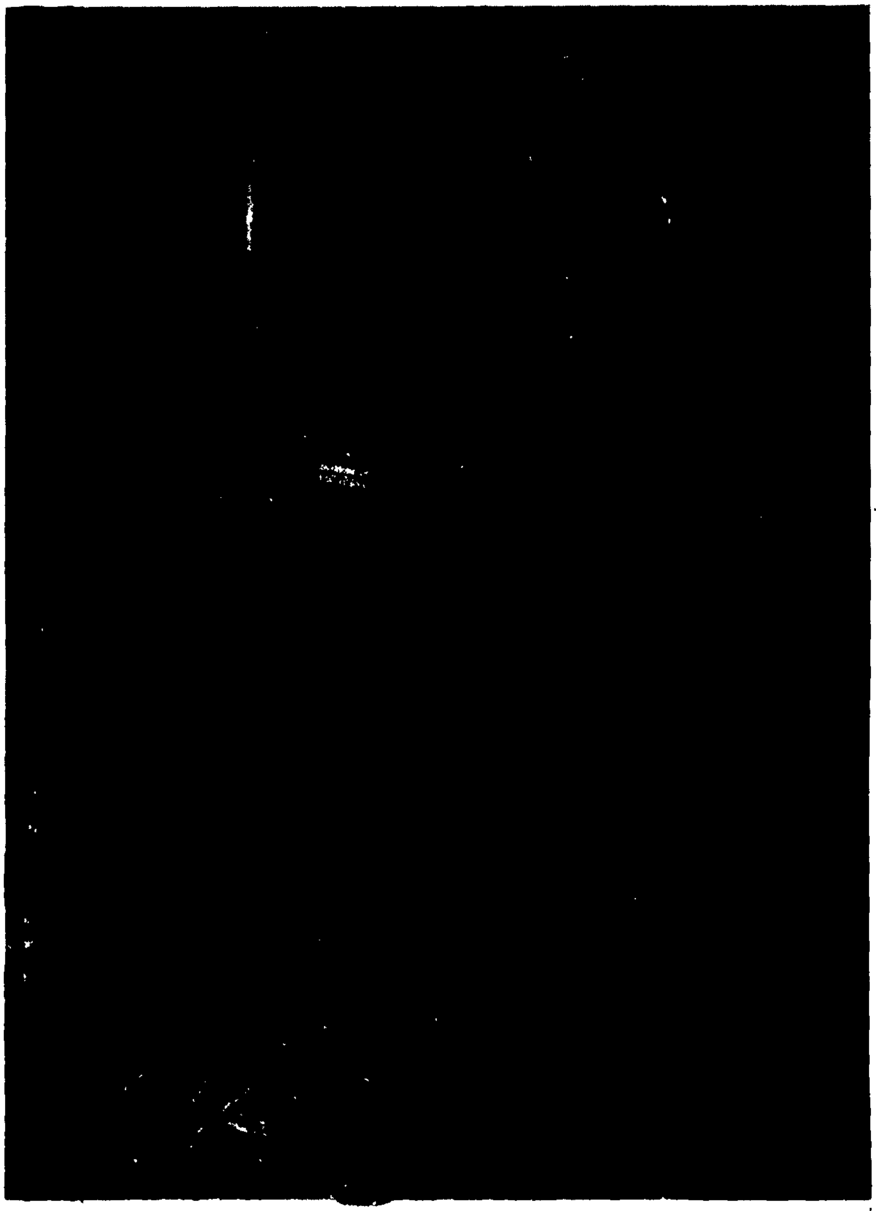
VI Evaluation

The machine cleaning process has proven superior to the existing process as shown by the experimental and shop trial data. The scrubbing action and thermal change of the solvent and hot gas sprays removes both soluble substances and solid particles. Machine operation without major maintenance or adjustment has been possible over an extended period. The machine reliability is such that only partial operator attention is required.

There are, however, several areas where improvements could be effected which will be investigated under Phase 2 of the Contract. Use of a modified indexing mechanism would eliminate the lead bending problem. Any variations in the racks or indexing mechanism can now bend the leads because the drive foot operates immediately adjacent to them. Use of a drive operating against some other portion of the racks would eliminate this problem. Replacement of the existing siphon solvent feed with a gravity type would provide greater flow control and more positive operation. Provision for additional nozzles and greater positioning flexibility would add to the machine's ability to meet new cleaning criteria as well as permit a faster cleaning rate.

VII Conclusion

The original requirements assigned to this machine have been met. Stud-leads are handled in the standard racks; lead straightness is maintained and superior cleaning is performed. Sufficient capacity is available to support the mechanized line. The machine gives every evidence of performing an excellent cleaning operation with good reliability.



STUD LEAD CLEANING MACHINE
FIGURE 5.1-1

OPERATING STATIONS OF STUD LEAD CLEANING MACHINE
FIGURE 5.1-2

SECTION 5.2

GOLD BONDING

J. E. Beroset

GOLD BONDING

I General

The Gold Bonding Machine was built to mechanize the thermocompression bonding of wafers to .4 watt diode studs and internal gold leads. Cleaned stud-lead assemblies in handling racks, pre-oriented wafers in tubular magazines, and .006-inch-diameter gold wire on spools are the inputs to the machine. The studs, wafers, and wires are assembled and subsequently bonded as the 12-station indexing table of the machine rotates. After bonding, the gold-bonded assemblies are replaced in the handling racks for removal from the machine. The tooling area is completely enclosed by a plexiglas dry box to insure cleanliness of the assembled components. The extreme cleanliness of the stud, wafer, and internal lead must be preserved to avoid device contamination and to insure a high strength bond.

The following special features are incorporated on this machine:

1. An automatic lead balling and cut-off station.
2. Thermocompression bonding without gold preforms.
3. Automatic handling of wafers supplied in tubular magazines.
4. Testing and screening of the gold-bonded units before unloading.

The Gold Bonding Machine, which operates at a rate of 1200 per hour, was built for the contemplated high volume Nike Zeus production requirements. An increase of bond reliability was an additional goal, since the human skill required for the mechanized bonding process is significantly less than the skill required for the manual bonding process. The manual bonding, performed on a semiautomatic bonding tool at an average rate of approximately 90 units per hour, requires manual loading and alignment of studs, preforms, wafers, and wires. The alignment is largely dependent upon the operator's skill.

The machine is presently proven-in and installed in the production area. After adding the automatic wafer feeding station, the original production level was attained. Further shop trial is held pending final approval of the design change eliminating the gold preforms.

II Machine Description

The Gold Bonding Machine (Figure 5.2-1), consists of a 12-station Ferguson Intermitter index table and operating stations synchronously driven by a Graham variable speed drive through an endless roller chain. The tooling area is enclosed by a plexiglas dry box with access doors located at key points. The machine, less its auxiliary equipment, is 59 inches deep by 54 inches wide. The overall size of the machine and its associated equipment is 132 inches deep by 108 inches wide, including work space for the operator. Two Lepel induction heating generators, which supply the heat for bonding, are mounted on a stand at the immediate left of the machine. Another Lepel induction heating generator for the gold balling station is mounted on another stand at the rear of the machine. At the right front corner of the machine is a floor-mounted control cabinet and console, 24 inches deep by 36 inches wide.

Stud lead assemblies, wafers, and .006-inch-diameter gold wire are loaded into the machine by the operator before it is started. The machine output is .4 watt diode gold-bonded assemblies in handling racks. The operations of the machine are performed in the following order as the index table containing 12 bonding nests rotates. The plan diagram of the Gold Bonding Machine (Figure 5.2-2) and the tooling plate photograph (Figure 5.2-3) depict the operating station arrangement.

Clean stud lead assemblies loaded in handling racks are intermittently indexed by a solenoid-driven indexing mechanism, from the input side of the rack handling station to a pick-up point. The stud lead assemblies are then lifted out of the rack by a vacuum arm and loaded into the bonding nest. A synchronously driven iris mechanism accurately locates the lead end of the stud lead assembly and guides it into the locating counterbore of the bonding nest.

At the following station a photo-detection system, which senses light reflected from the surface of the stud, detects a properly loaded stud in the bonding nest. When a stud is missing, the absence of reflected light actuates an alarm circuit and stops the machine.

The wafer feeding station (Figure 5.2-4) feeds pre-oriented wafers, one at a time, out of the wafer magazine to a pickup point. A vacuum transfer arm picks up the wafer at the wafer feeding station and loads it onto the stud, which has been loaded into the nest at the first station.

Gold-balled leads are formed from the .006-inch-diameter gold wire by melting the end of the wire in a high intensity, high frequency, induction heating field, and loaded into the bonding nest assembly at the balling station (Figure 5.2-5). The nest assembly jaws are raised to grasp the lead by closing above the ball. The jaws then move down until the gold-balled lead contacts the wafer and applies the bonding pressure while holding the gold-balled lead in alignment with the stud and wafer. A cutoff mechanism cuts the gold wire before the nest indexes to the next station.

The assembled unit is then preheated and bonded at the three following stations. The unit is preheated by a heated nitrogen flow to reduce the thermal shock to the unit as the bonding heat is applied. The bonding heat is produced by the application of a high-frequency induction heating field. Two levels of power are applied for timed intervals at each bonding station, first, to bring the unit up to bonding temperature rapidly and, second, to keep the unit at the bonding temperature. The bonding pressure remains applied throughout the entire preheating and bonding periods.

At the nest opening station, immediately following the bonding stations, the nest assembly jaws are raised slightly and opened. Simultaneously, the internal lead of the bonded assembly is contacted in the nest assembly, and a test circuit, making contact through the grounded stud assembly, determines whether the unit is acceptable, inverted, open, or shorted. A low A-C voltage is applied to the unit and a polarity-sensitive current-measuring circuit determines which half-waves of current are passed by the unit. A logic network then translates this information to categorize the unit into one of the four types. If three consecutive bonded units fail this test, an alarm is sounded and the machine cycle is stopped.

At the following station, the stud unload station, the bonded unit is removed from the nest by a vacuum arm and replaced in the handling rack if the test at the opening station indicated that it was acceptable. If the test at the opening station detected an open unit (no wire), a shorted unit (no wafer), or an inverted unit (inverted wafer); the vacuum is not applied, and the unit is left in the bonding nest.

The purge station, which follows the stud unload station, removes rejected units left in the nest at the stud unload station. A nitrogen flow through the nest ejects the units and a purge tube guides them into a receptacle. The flow of nitrogen through the purge tube is sensed to provide detection of units which are not removed by the nitrogen purge flow. If a rejected assembly remains in the machine, there is no nitrogen flow; an alarm is sounded and the machine is stopped.

The operator is responsible for the following duties: Load wafer magazines into the wafer load station when a magazine is emptied; load and thread wire into balling station; load studs when required; unload bonded units when required; observe machine operation for unusual action; and correct malfunction when unusual action is observed or one of the sensing circuits stops the machine.

Safety features are provided to prevent machine damage or operator injury. Guards are provided over the area under the tooling plate to avoid accidental operator contact with moving components. All moving components on top of the tooling plate and the R-F heating coil leads are covered by a plexiglas dry box. Nest position indicator switches are installed which stop the machine if a bonding nest is in an interference position with the balling and cut-off station.

Alignment of the stud, wafer, and internal gold lead must be closely held in order to achieve an acceptable bonded assembly. Periodic maintenance of the nest assemblies is required to insure proper alignment of the stud, wafer, and gold lead, since the jaws and nests are subject to wear. After jaws or nests are replaced, the nest assemblies must be re-aligned utilizing the nest assembly alignment fixture (Figures 5.2-6 and 5.2-7).

III Manual Bonding

The manual bonding process is performed on a semi-automatic bonder at an average rate of approximately 90 units per hour. The operator performs the following steps: Load stud-lead assembly into heated bonding nest; place first preform on stud; orient wafer for proper polarity and place wafer on first preform; place second preform on wafer; load balled lead, which has been previously formed and cut, into bonding needle; lower bonding needle to a stop; center bonding needle on stud, wafer, and preforms; and initiate automatic bonding cycle. During the automatic bonding cycle, the assembly process is repeated at a duplicate bonding position. After the bonding cycle is completed, the operator raises the bonding needle; removes the bonded unit from the nest and places it in a handling tray. The automatic bonding cycle consists of lowering the bonding needle onto the parts previously loaded into the nest, holding the units under pressure for a pre-determined time, and raising the bonding needle at the end of the cycle. The operator performs the loading operations while observing the work through a microscope. The alignment of stud, wafer, preforms, and internal gold-balled lead depends to a large extent upon the skill and visual acuity of the operator.

IV Machine Development

After machine specifications were formulated, a feasibility study was contracted to Anderson-Nichols & Company, Boston, Massachusetts. As a result of this study and additional feasibility investigation by Western Electric Company engineers, it was determined that .4 watt diodes could be automatically bonded at a rate of 800 per hour. It was proposed to cold form, chemically clean, and anneal silver nail-head leads on the machine. Stud-lead assemblies were to be fed from bulk and loaded into the bonding nests. Wafers were to be fed from bulk, oriented for proper polarity, and fed into the bonding nests. The automatic forming, cleaning, and annealing of the silver nail-head lead comprised more than half of the proposed machine equipment and operations. After investigating a number of alternate methods for preparing or feeding silver nail-head leads, it was decided to utilize gold leads. The gold leads require very slight preparation compared to the extensive annealing and cleaning operations required with the silver lead. A method of forming a ball on the end of a gold wire through the use of high frequency induction heating was devised to provide a lead preparation technique which could be incorporated on an automatic machine. Investigation of various methods of bonding was also undertaken, and thermocompression bonding was chosen. A method of thermocompression bonding was developed, that eliminated the use of preforms. Further development work in this area was undertaken to determine the optimum conditions of pressure, temperature, surface conditions, and time.

During the machine design phase, several problems were encountered. One of these problems was the development of a compact mechanism which would produce the required intermittent motion for the stud load, stud unload, and wafer load stations. A compact, self-contained transfer drive box was the result. A second problem arose in the selection of nest assembly jaws and nests. Since the bonding heat is produced by the application of high frequency induction heating, the portion of the nest assembly in the area of high field intensity must be an electrical and thermal insulating material. The material must also be capable of withstanding high temperatures, must have the capability of being machined to close tolerances, and must have good mechanical strength. The bonding nest also must be of such a design as to incorporate a means of holding the stud, wafer, and wire in accurate alignment and applying bonding pressure during the application of bonding heat.

During construction, a number of problems arose with the bonding nest assemblies. The jaw and nest materials proved to be extremely vulnerable to mechanical shock. The nest assemblies were not rigid enough to maintain the accuracy required for nest assembly alignment. In an attempt to alleviate these problems several improvements were made during the final stages of nest assembly construction, but nest and jaw breakage remained a problem, and accurate nest assembly alignment was extremely difficult to maintain.

V Operational Problems

During machine prove-in, the nest assemblies continued to be a source of trouble and were subsequently redesigned and new nest assemblies built. The new nest assemblies incorporated new jaw and nest materials and had greater rigidity, means for accurately controlling the bonding pressure as well as for easily aligning the jaws and nest. The nest opening station was extensively modified to adapt it for the redesigned nest assembly, and the jaw closing mechanism at the balling station was also modified for the new nest assembly.

Photo-detection of wafers and wires in the nest proved to be extremely critical. A sensing circuit which tests the bonded unit output for shorts (no wafers), opens (no wires), or inverts (inverted wafers), was added which performs the detection of wafers and wires. An additional benefit of this system was realized by the addition of a means of screening out the unacceptable units at the machine output.

The original wafer feeding and orienting station was not used after extensive prove-in effort failed to sufficiently increase the feeding reliability. Wafers were to be vibratory fed from bulk, probed for polarity, and fed to a pick-up point. Inverted wafers were to be returned to the vibratory bowl for subsequent refeeding. Since the wafers fed from the bowl feeder were randomly oriented, the probe and feed mechanism was required to operate at 2,400 per hour (twice the machine rate of 1,200 per hour). Variations in wafer size and shape limited the reliability of the gating and probing mechanism. Partial wafers, wafer chips, and foreign material also caused failures in this area. Since extreme cleanliness of the feeder tracks and gating mechanism was necessary to insure reliable movement of the wafers, it was necessary to disassemble, clean, and reassemble the gating mechanism after each failure to remove silicon particles. In view of these problems, a wafer feeding station was developed, designed, and built which feeds pre-oriented wafers from a tubular magazine.

The rack handling station was revised during prove-in to provide ease of loading, and increased visibility of machine input and output. The revised station also incorporates a rack indexing mechanism having greater reliability than the original design. An iris mechanism was added at the stud load station to increase the reliability of stud loading. It guides the lead end of the stud-lead assembly into the bonding nest.

VI Performance

During the mechanized run, the machine was run approximately 13,000 cycles. Since the redesigned wafer loading station was not installed, an interim manual wafer loading station was employed during the mechanized run. Although the machine was run on a 3-second cycle (rate: 1200 per hour), the net machine rate was less due to manual wafer loading. The average net rate of the Gold Bonding Machine was 560 bonds per hour during the pilot run. The mechanical yield averaged 75 percent, with a peak efficiency reached of 85 percent. The majority of rejects were due to poor wafer location or no wafers; both are attributable to the variables introduced by manual wafer loading. The bond strengths were fully acceptable, with an average failure rate of 11.5 percent at an 80,000-g centrifuge test as opposed to an average of 12 percent for manually bonded units.

Piece part problems arose during the mechanized run. Irregular studs and bent stud leads caused units to stick in the bonding nests, stud-lead loading failures, and unloading failures.

Two improvements were made during the mechanized run which improved the performance of the machine. The nest lowering cam at the balling station was altered to decrease the rate of bonding pressure application, and hence reduce mechanical shock to the wafer. The problem of controlling the .006-inch-diameter gold wire at the balling station was reduced by the addition of an anti-springback pressure device above the balling station guide needle, and a pair of pressure pads which straighten the wire as it is fed off the reel.

The automatic wafer feeding station was completed, installed, and proven-in after completion of the mechanized run. A subsequent shop trial and special evaluation run was completed which resulted in an average net cycle rate of 957 cycles per hour and an average mechanical yield of 91.2 percent.

VII Evaluation

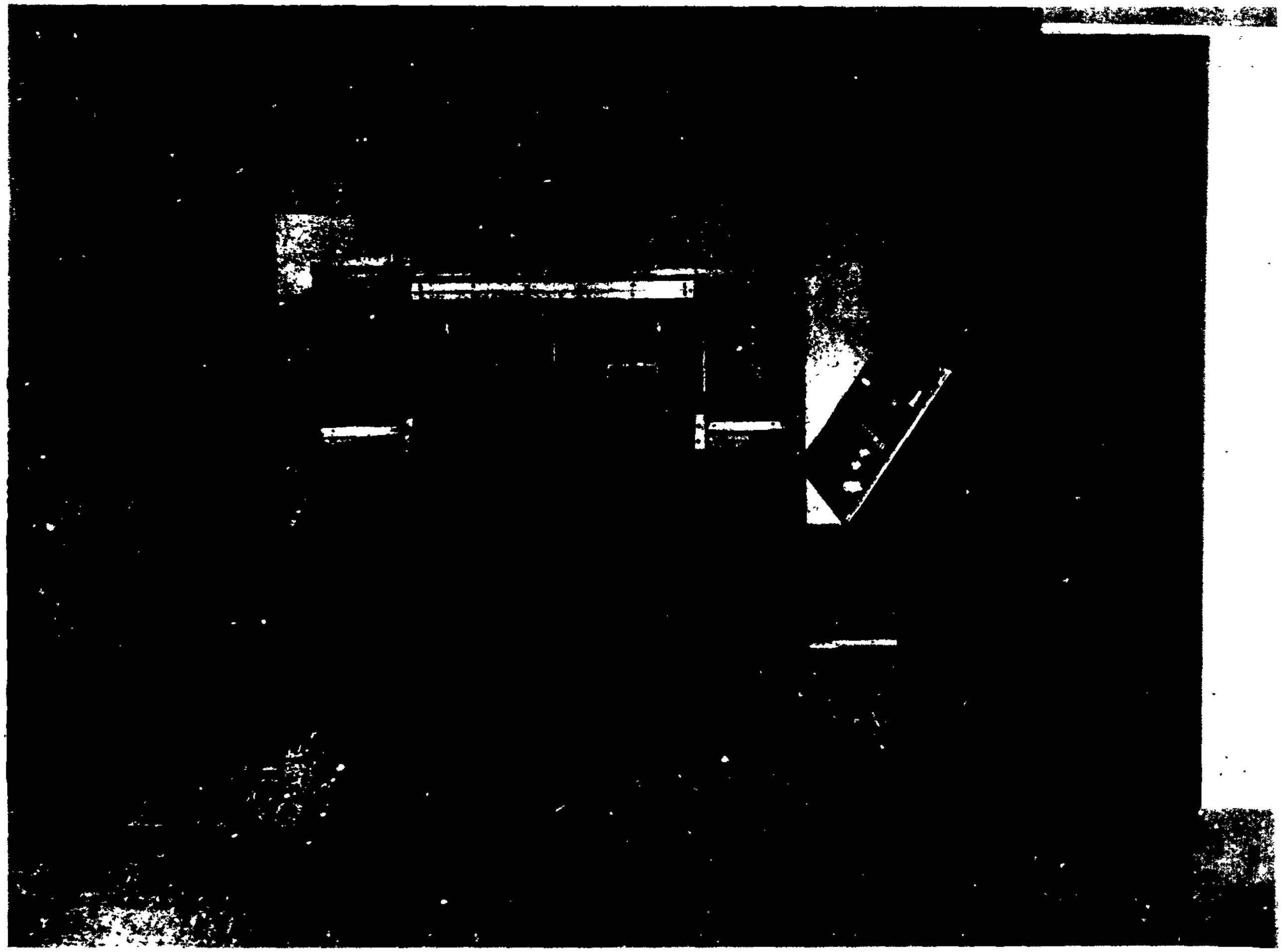
The alignment of stud, wafer, and internal wire of the gold bonded units bonded on the machine has been very good. The wafer feeding and wire feeding stations, both critical areas, are performing with a high degree of reliability. Dimensional instability of the "Teflon" handling racks has decreased the rack handling reliability. Bonding temperatures have proven to be sufficiently repeatable, although temperature measurement and setup are rather laborious. Since the sensing circuits, which detect the presence of a stud at Station 2, the absence of a stud at Station 12, and screen the output of the machine, are operating at a high level of reliability, the operator's duties are limited to periodically filling the machine with studs, wafers, and wire; removing the gold bonded units, and observing the machine operation for unusual action.

VIII Conclusion

During Phase 2 the following machine improvements are proposed to increase reliability and ease of operation:

1. Addition of bonding temperature monitoring system to simplify verification and adjustment of the bonding temperature.
2. Revision of rack handling station to utilize an improved aluminum handling rack.

The wafer feeding concept was revised from bulk feeding and orienting to magazine feeding and handling. A considerable increase in machine reliability and operation flexibility has resulted from this deviation from the original machine specifications. The addition of the testing station, which tests and screens the output of the machine, is an improvement made during machine prove-in which was not outlined in the original machine specifications. These two deviations from the original machine specifications have resulted in a machine with greater operation flexibility and ease of operation than originally provided for.



GOLD BONDING MACHINE
FIGURE 5.2-1

PLAN DIAGRAM OF GOLD BONDING MACHINE

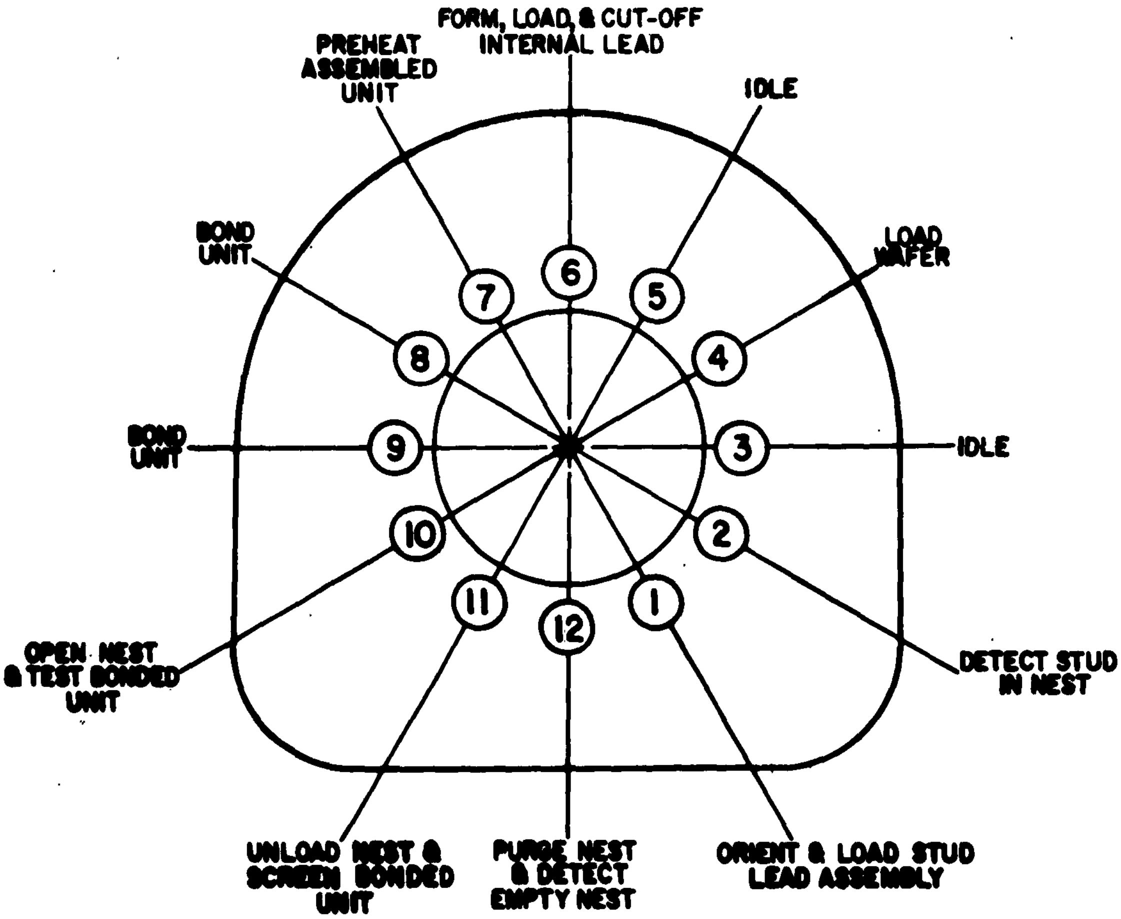
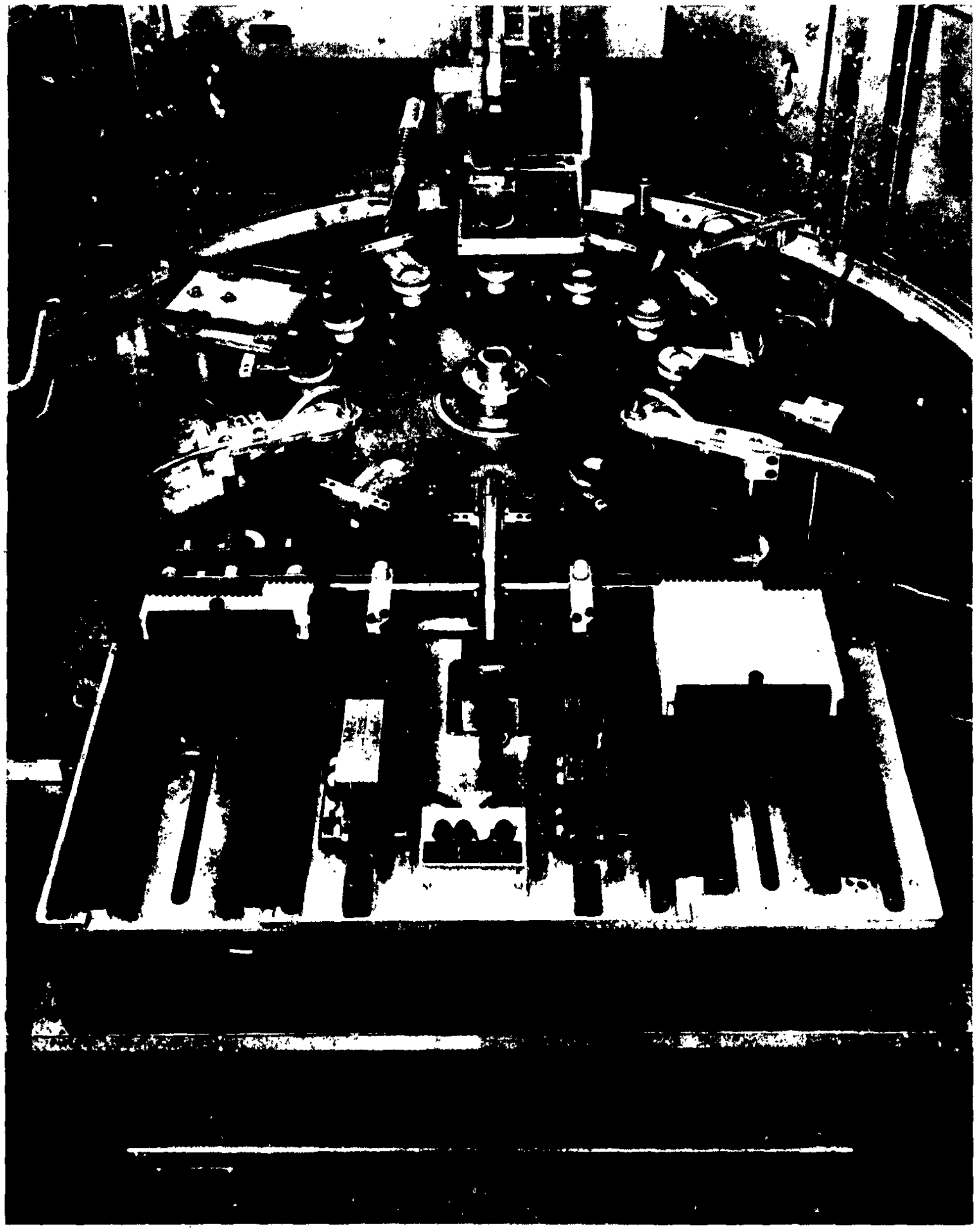


FIGURE 5.2-2

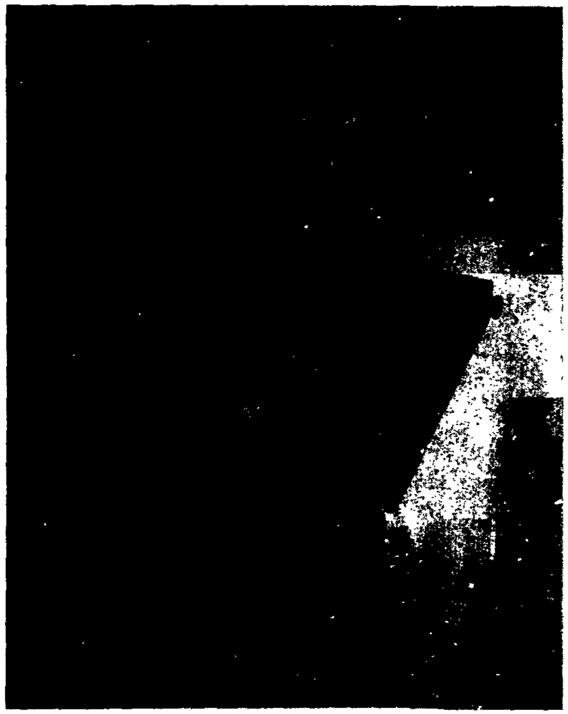


TOOLING PLATE ASSEMBLY OF GOLD BONDING MACHINE
FIGURE 5.2-3

WAFER FEEDING STATION OF GOLD BONDING MACHINE
FIGURE 5.2-4

LEAD BALLING AND CUT-OFF STATION OF GOLD BONDING MACHINE
FIGURE 5.2-5

NEST ASSEMBLY ALIGNMENT FIXTURE OF GOLD BONDING MACHINE IN
JAW ALIGNMENT POSITION
FIGURE 5.2-6



NEST ASSEMBLY ALIGNMENT FIXTURE OF GOLD BONDING MACHINE IN
NEST ALIGNMENT POSITION
FIGURE 5.2-7

SECTION 5.3

ETCHING, OXIDIZING, CLEANING AND DRYING

D. M. Large

ETCHING, OXIDIZING, CLEANING AND DRYING

I General

The Etching, Oxidizing, Cleaning, and Drying Machine mechanizes the following operations on gold bonded subassemblies of .4 watt diodes prior to their encapsulation:

1. Controlled clean up etching of the silicon wafer periphery
2. Coating the etched area with a protective oxide
3. Deionized water rinsing
4. Ultrasonic deionized water rinsing
5. Acetone rinsing
6. Oven drying

In the unmechanized process the gold bonded subassemblies are loaded into circular "Teflon" holders which are inverted and placed into beakers containing the various chemical solutions. Timers indicate when the operator should transfer a holder from one solution to the next. After leaving the last solution, the units are transferred from the circular holders into an aluminum tray for oven drying. Since all operations are controlled by an operator, undesirable variations in process times can occur. Removing the human element from the process would provide a more uniformly etched unit and result in a higher yield. In view of the high volume Nike Zeus production requirements and in order to improve the electrical test yield, a machine was designed to etch 2,880 units per hour. This capacity is considerably more than the contractural requirements. A high capacity, however, is an inherent feature of the batch-type process used on this machine.

The Etching, Oxidizing, Cleaning, and Drying Machine has demonstrated its capability during the mechanized run. A mix of ten codes, totalling 10,000 units, were etched and resulted in a first curve trace yield which was slightly lower than the present manual production line yield. This was attributed to the fact that machine parameters were not yet optimized. An experiment has been designed to optimize the machine settings, and also to make a final evaluation using the new settings. This experiment will be conducted in Phase 2 of this mechanization program.

II Description of Machine

The machine is a batch-type machine of an in-line design. It consists of four main components identified in Figure 5.3-1: a control cabinet (1), a refrigeration system (2), an etching machine (3) and a drying oven (4). The entire installation covers an area approximately 25 feet long and 5 feet wide. Several portions of the machine are approximately 7 feet high. The following service requirements are needed for this machine: a 440-volt, 3-phase, explosion-proof electrical installation, plant air supply, dry air supply, "Prepure" nitrogen supply, deionized water supply, and exhaust systems for corrosive and inflammable fumes.

Gold bonded assemblies are manually prepared for etching at the magazine loading station, a portion of which can be seen on the table top covering the refrigeration unit, (Item 2 in Figure 5.3-1). A magazine loaded with gold bonded subassemblies is then placed on the input key (Item 2, Figure 5.3-3) of the etching machine. The magazine on the key is slid into position on a carriage in the machine after opening a door to the rear of the magazine. Closing the door starts the automatic etching machine cycle. The carriage travels horizontally from left to right. When the carriage reaches a station, the magazine moves down until the units are in the bath and remains down a pre-adjusted time. This sequence repeats itself automatically as the magazine is transported through five stations: etching, oxidizing, deionized water rinse, ultrasonic deionized water rinse, and acetone dip. Processed assemblies are removed at the unload station (Item 1, Figure 5.3-3) by a manual combing technique, using the combs shown in Figure 5.3-4, and placed into an oven for drying prior to electrical testing as shown in Figure 5.3-5.

The fluid handling systems function as follows: In the etching station there are two modes of operation; use and dump, and recirculate. In the use and dump mode of operation, each time a batch of units is processed fresh acid is used. The recirculate mode of operation allows the acid to be reused a prescribed number of times before disposal. Both modes of operation deliver acid to a dip overflow bath which is fed by a gravity feed tank whose liquid level is maintained by a pump. The acid enters a tray from the bottom and flows through a series of holes in three baffel plates and then overflows at the rear of the bath. This flow pattern causes a slight bubbling-type agitation beneath the surface of the liquid while the units are submerged in the bath. Then the units are removed and indexed to the oxidizing station. This station functions in the same manner as the etching station except there are no provisions for recirculating the oxidizing agents.

The next station is the deionized water rinse bath. This station incorporates the same dip overflow concept mentioned previously. The units are lowered into the bath the same as at all other stations in the machine. However, the bath also rises to submerge the magazine, racks and units in continuously flowing deionized water for a prescribed time while a manifold sprays water horizontally to rinse the racks and magazine. After the racks and magazine are thoroughly rinsed, the bath lowers and continues to rinse the units. The units are then removed and indexed to the next station which is the ultrasonic deionized water rinse station. This bath incorporates a standard ultrasonic tank which is supplied with fresh water for each batch processed. Here the units are dipped into the bath and rinsed ultrasonically for a prescribed time after which they are removed and indexed to the acetone station. This station has a tray which is supplied with fresh acetone for each batch processed. The units remain in this bath a prescribed time and are then removed and indexed to the unload station. Details of the mechanized operation are diagrammed in Figure 3.5-6.

The large number of units processed in a single batch made it necessary to incorporate several interlocks into the machine. First, the etchant and oxidizing acid supply tanks must be at a prescribed temperature before a batch of units can be processed. Second, the etchant must be present in the etching station prior to starting the automatic cycle. Third, while processing each batch, the liquid level in all baths is monitored and the machine is interlocked so that, in the event of a malfunction, the operator can not process another batch of units without recognizing the failure. Fourth, an additional safety feature was necessary in the acetone handling system. This system had to be interlocked so that the supply valve to the bath would "close" and the drain valve "open" in the event of a fire thus avoiding the possibility of feeding a fire with acetone.

The following special features have been incorporated in the machine in order to optimize the etching yields and reduce the consumption of acids: (1) The etchant can be disposed of after each cycle or be recirculated. (2) The etchant and oxidizing acids can be refrigerated and held at a constant temperature. (3) All etching machine cycles can be automatically controlled over a wide range by timers.

The corrosive acids being used in the process require that regular preventive maintenance checks be made on the carriage drive cable, acid pumps, acid valves, and refrigeration system. The acid pumps should be lubricated once per week and the acid handling systems should be rinsed periodically.

III Machine Development

During the feasibility phase, existing etching techniques were examined. The first method studied was the present manual approach. From this study a process was established similar to the manual line with the following additional features:

(1) A provision for recirculating the etchant in order to reduce the consumption of acid,

(2) a provision for cooling the etchant and oxidizing acids to provide a closer control of the etching and oxidizing rates,

(3) a controlled atmosphere to prevent contamination,

(4) a system for conveying a batch of units through the various baths with a constant transfer interval between baths, and

(5) an adjustable time cycle for each bath.

The second etching technique studied was the manual stream etching facility used on the 2N559 transistor. This method was not feasible for several reasons: First, it would not provide the accurate controls necessary in dispensing of the solutions required in the process. Second, this technique did not lend itself to recirculating of acids or the application of ultrasonics. Third, the process required only etchant and deionized water whereas the present diode process requires etchant, oxidizing acid, deionized water, ultrasonic deionized water, and acetone. Fourth, the units were processed in a room atmosphere which is not desirable. The third technique studied was a diode stream etching machine used at the Allentown Works of the Western Electric Company. This machine was of a circular design which dispensed chemicals through tubes to one unit at a time. The main objection to this approach was that it did not provide a means of adjusting the process time at each station without proportionally lengthening or shortening all process times.

Other investigations were conducted to aid in design of the machine as follows:

A study was made to determine the best method of applying the etchant to the units. The following methods were tried - stream etching, fountain etching, cascade etching, vapor etching, and dip overflow etching. The dip overflow technique proved to be most practical and was adopted.

A study was also made to determine what material could be used in the construction of the handling racks which would withstand the corrosive characteristics of the acids, the solvent power of acetone, and the elevated drying temperatures necessary in the process. The use of ceramics was investigated. Experimentation, however, showed that ceramics were attacked by the hydrofluoric acid in the etchant. This led to the use of a "Teflon" rack during the etching portion of the cycle and then transferring the etched subassemblies to aluminum racks for drying cycle.

A method of transferring the etched subassemblies from one rack to another had to be developed. After considerable effort was expended designing a mechanized transfer operation, it was decided to replace the transfer to aluminum racks with a simple combing technique. This technique provided a means of manually transferring 720 units at a time from the "Teflon" racks into a pair of combs for drying. The main objective of this approach was to shorten the drying and cooling time by reducing the mass being heated and cooled. Sliding handhole baffles (Item 1, Figure 3.5-3) were then necessary in order to efficiently perform the combing operation in a controlled atmosphere.

The next area studied was drying. The following drying concepts were considered: infrared drying, vacuum drying, continuous conveyor radiant heat drying, and batch-type oven drying with a recirculating nitrogen atmosphere. The batch-type oven drying approach was adopted because of its flexibility.

Another design problem was encountered when attempting to purchase an explosion proof ultrasonic bath. This explosion proof feature was necessary because of the safety problems associated with acetone in the process. Since an explosion proof ultrasonic bath was not commercially available, a specially designed bath with the transducers submerged in transformer oil was fabricated.

The corrosive characteristics of the etchant being used in the machine led to the selection of unplastisized polyvinylchloride as the basic construction material for the etching machine. However, the flexibility of this material was underestimated and caused considerable trouble during assembly of the machine. Supporting aluminum base plates were placed under all mechanisms to eliminate binding and misalignment problems caused by the flexibility of the polyvinylchloride.

IV Operational Problems

"Teflon" tubing was specified as a protective covering over the refrigeration coils submerged in the acids. During construction it was found this would not be practical and another concept which involved coating of these coils with "Penton" K-51 was adopted. After continued use during prove-in, a pin hole in the coating allowed acid to seep through to the coil and caused the loss of a refrigeration unit. Operation of this machine continued throughout Phase 1 without refrigeration while design and construction of a new cooling coil was undertaken. The redesigned cooling coils were soldered on the inside of a copper cylinder. This design provides a smooth surface to which a more reliable coating could be applied. An indicator, which the operator can monitor, was provided to detect a pin hole in the coating. This signal provides ample time to drain the acid and repair the pin hole before any damage occurs.

Minor mechanical problems in shifting and indexing the carriage were overcome during prove-in. The biggest problems during prove-in were due to leaks in the acid handling system. These leaks were caused by foreign particles getting into the pumps and destroying the pump liner, breaking of the pump liners along the moulding parting lines, and faulty installations of the pump liners which caused liners to leak. One series of leaks enabled acid fumes to attack several stations. These stations were disassembled and refinished with acid resistant paint. A splash pan with a drain was installed under the machine to confine any further acid leaks and allow rinsing and disposal of the rinse water.

V Mechanized Run Performance

Several small lots were etched during shop trial to determine the process times prior to making the mechanized run. These results showed the etching time is approximately 50 percent longer than for the manual process. The longer etch time was attributed to two facts: First, larger quantities of acid flow past the units when recirculating the acid thus decreasing localized heat at the unit during etching; second, there is less agitation during etching on the machine than in the manual method.

During the mechanized run a mix of ten codes, totaling approximately 10,000 units, were etched and curve traced. The results of this run are tabulated on the following page.

During the mechanized run a contamination problem was encountered. The contaminant was traced to "Hypalon" valve seats which were being decomposed by the acid. These seats were replaced with "Teflon" to prevent a recurrence of this problem.

VI Evaluation

The mechanical and electrical portion of the machine performed satisfactorily. Difficulties have been experienced in the past with leaking of the acid pumps; however, this problem has been solved. Since the machine is relatively easy to set up and operate, the time required for operator training has been minimized. The etching yield for the pilot run was lower than anticipated; therefore, in Phase 2 of the Contract efforts will be directed toward improving the yield by optimizing the process times.

The change from aluminum to "Teflon" handling racks adds a transfer operation to the mechanized process. This extra transfer is necessary because acid resistant racks are needed in this machine. The "Teflon" racks are also designed to clamp the gold bonded subassemblies in place so they can be inverted while etching. Experience has shown that the clamping feature and the combing technique work well; however,

CURVE TRACE RESULTS DURING MECHANIZED RUN

CODE	NUMBER ETCHED	MECHANIZED CURVE TRACE YIELD AFTER FIRST ETCH COMPARED TO MANUAL YIELD (1)	MAJOR REASONS FOR REJECTS EXPRESSED AS A PERCENTAGE OF THE TOTAL REJECTS
1N664	720	27% Lower	80% Soft Knee(2)
1N665	850	23% Higher	50% Soft Knee
1N666	1,216	7% Higher	50% Soft Knee
1N667	463	16% Lower	81% Soft Knee
1N668	1,032	11% Higher	72% Soft Knee
1N669	1,733	20% Lower	23% Soft Knee 54% Low BV(3)
1N673	785	22% Lower	65% Soft Knee 22% Low BV
1N675	879	8% Lower	61% Soft Knee
1N697	679	10% Lower	27% Soft Knee 40% High Capacitance(4)
1N701	2,000	38% Lower	56% Soft Knee 32% Low BV

(1) Mechanized yields lower than manual yields are attributed to the fact that the mechanized process times are different from the manual process and were not optimized before making the mechanized run. These times will be optimized through a series of experiments during Phase 2 of the Contract.

(2) Soft knees are attributed to improper drying and/or insufficient etching.

(3) BV or breakdown voltage is a function of diffusion prior to etching.

(4) High capacitance is attributed to insufficient etching.

both contribute to lead bending. Since relatively straight leads are required by the Assembling Case to Stud and Welding Machine, refinement of the material handling system will be undertaken during Phase 2.

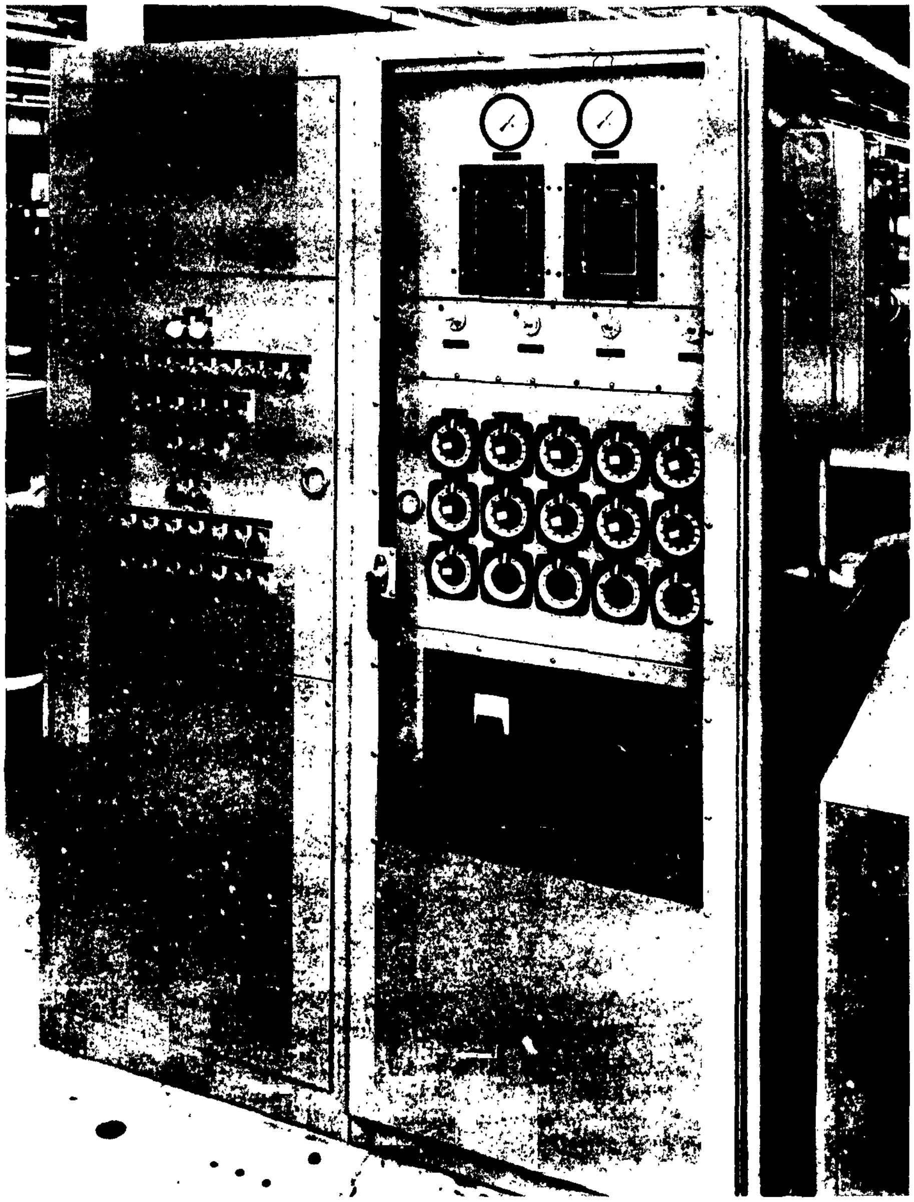
VII Conclusion

All major goals have been realized; however, work in Phase 2 will be necessary in the following areas: The redesigned refrigeration coils must be installed; better lighting should be provided in the unload station; process times must be optimized; and a new method of material handling is needed on the machine in order to eliminate lead bending and to reduce the heating and cooling periods during the oven drying cycle, thus significantly increasing the output.

The Etching, Oxidizing, Cleaning, and Drying Machine has proven to be versatile, for it provides the following features: Adjustable process times; a refrigeration system to control etchant temperature, and a recirculating system which permits re-use of the etchant. The machine is easy to operate. Little setup time is required to adjust process times for the various diode codes; therefore, an output of 2,880 units per hour can be expected at yields in access of the manual process and with improved electrical characteristics.

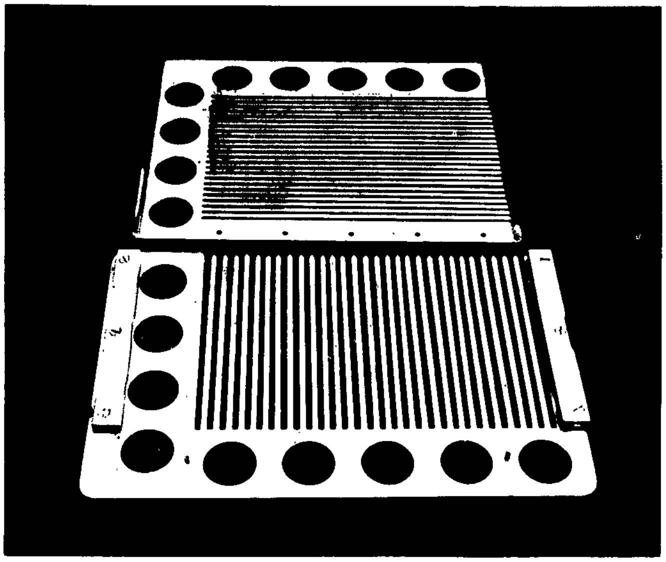
ETCHING OXIDIZING CLEANING AND DRYING MACHINE
FIGURE 5.3-1

ETCHING OXIDIZING CLEANING AND DRYING MACHINE
FIGURE 5.3-1

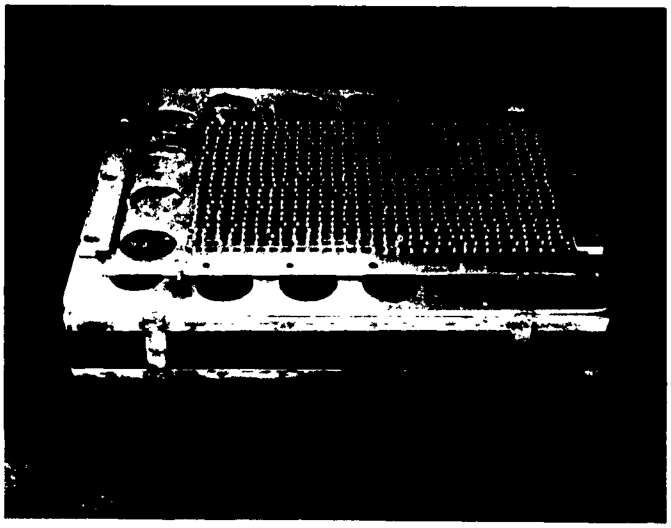


CONTROL CABINET OF ETCHING OXIDIZING CLEANING AND DRYING MACHINE
FIGURE 5.3-2

ETCHING MACHINE AND DRYING OVEN OF ETCHING OXIDIZING
CLEANING AND DRYING MACHINE
FIGURE 5.3-3

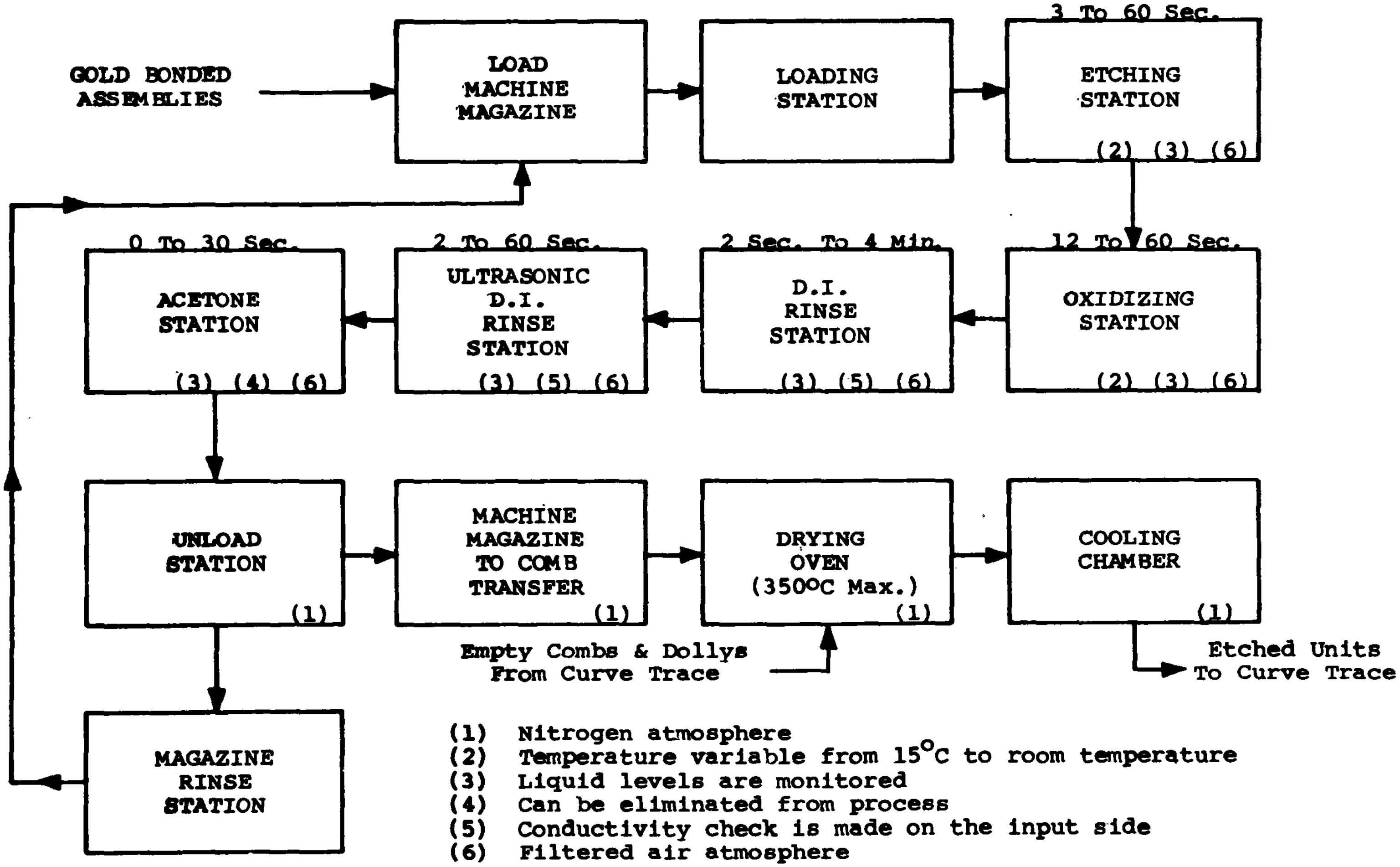


COMBS FOR UNLOADING 720 ETCHED SUBASSEMBLIES
FIGURE 5.3-4



COMBS AND DIODES LOADED IN HANDLING TRAY FOR DRYING
FIGURE 5.3-5

ETCHING, OXIDIZING, CLEANING & DRYING MACHINE
FLOW DIAGRAM



(1) Nitrogen atmosphere
(2) Temperature variable from 15°C to room temperature
(3) Liquid levels are monitored
(4) Can be eliminated from process
(5) Conductivity check is made on the input side
(6) Filtered air atmosphere

FIGURE 5.3-6

SECTION 5.4

ASSEMBLING CASE TO STUD AND WELDING

F. E. Tweed

ASSEMBLING CASE TO STUD AND WELDING

I General

The function of the .4 Watt Diode Assembling Case to Stud and Welding Machine is to thread the .006-inch-diameter internal gold lead of the diode into the tubulation of the tubulated can and perform the closure weld to seal the can to the stud. It is an in-line type of machine with most of the operations being performed while the units remain in the aluminum handling rack.

The machine is presently operable but at a reduced rate of 700 units per hour instead of the designed 1,200. The rate reduction was made necessary due to the lack of reliability at the welder lead loading and unloading stations and due to the addition of a tack welding operation. This situation will be remedied under Phase 2 by redesigning the welding portion of the machine.

II Description of Machine

Figure 5.4-2 is a view of the machine with the protective hoods in place while Figure 5.4-3 shows the top of the machine with the protective hoods removed. It is a self-contained unit having its own frame and cabinetry and is essentially an in-line type of machine. It is 60 inches long, 33 inches wide, and the table height is 37 inches. Figure 5.4-8 is a picture of the aluminum handling rack in which the units are moved through the machine. Racks containing the stud-lead-wafer assemblies with the .006-inch-diameter gold internal lead attached are loaded into the machine at the rack input station (Item 1, Figure 5.4-3). The racks are indexed along the track by means of the rack indexing mechanism

(Item 2, Figure 5.4-3 and Item 1, Figure 5.4-5). When they reach the straightening station (Item 2, Figure 5.4-5) the .006-inch-diameter internal lead is straightened and located. This is accomplished in the following manner: After the indexer has placed the units in the straightening station, a clamp moves in and holds the .020-inch-diameter external lead against the cut-out in the aluminum rack. Then the two straightening jaws move in and capture the internal lead. One straightening jaw is a solid steel block and the other jaw contains four individually spring-loaded rubber fingers. When the jaws have moved in and captured the wire, they then move upward over the entire length of the internal lead. At the top of the stroke, the jaws open and return to the down position. At this time, the clamp on the lower lead is released and the units are indexed over one space. This straightening action is performed four times on each unit before it leaves the straightening station.

The next station is the assembly station (Item 4, Figure 5.4-3). This station is actually the heart of the machine as this is where the internal lead is threaded into the tubulation of the can; the can and stud are brought together and tack welded. This is a highly complex mechanism requiring several intricate motions to be accomplished in a small area with precise timing. The operation of this station is as follows: When the indexer has moved the unit into the correct position, an air cylinder, located under the table, moves the bottom electrode forward, which raises the stud and locates it. The clearing mechanism (Item 1, Figure 5.4-4) then moves in and sweeps the area to insure that the previously assembled and tack welded unit is clear of the assembly area. A split-funnel (Item 2, Figure 5.4-4) then moves together and encloses the internal lead. Meanwhile, the can holder (Item 3, Figure 5.4-4) has moved up to the can-feed-track and picked up a tubulated can assembly from the escapement mechanism (Item 4, Figure 5.4-4), inverted it, and moved down to a dwell position. When the internal lead has been enclosed in the funnel, the can holder moves the can down until the funnel is inserted into the can and is resting against the bottom end of the tubulation. The funnel and the can then move down together, thus inserting the gold lead into the tubulation. The can holder then dwells while the funnel continues to move down until it clears the can, where it opens and moves up slightly. The can holder then moves the can down until it touches the stud. At this point, the upper tack welding electrode moves in and down and tack welds the can to the stud. The upper electrode then moves up and back. The bottom electrode and clearing mechanism are retracted to allow the next unit to be indexed into place.

The tack welded unit is then indexed to the welder load station (Item 5, Figure 5.4-3) where it is removed from the rack, located, and placed between the electrodes of the welding head. This is accomplished in the following manner: The unit is presented to the loading head by means of an air operated mechanism which raises the unit to the correct height and holds it while the loading head moves forward. Positioning of the unit in the loading head is achieved by a magnet which pulls the unit back into three "V" slots. One slot locates the body; one locates the end of the tubulation and another locates the end of the external lead wire. The loading head then removes the unit from the rack and places it between the electrodes in the welding head. These electrodes then begin to close. When the tubulation has been started into the upper electrode cavity and the external bottom lead has been started into the bottom electrode cavity, the electrode closing action dwells while the loading head retracts. As the electrodes continue to close, a vacuum is pulled on the upper electrode through a tube (Item 3, Figure 5.4-6) which pulls the can up into the upper electrode cavity and virtually eliminates crushing of the unit due to misalignment.

This machine has a unique feature in the design of its closure welding electrodes (Items 1 and 2, Figure 5.4-6). These electrodes are discs approximately 2.25 inches in diameter with 48 equally spaced cavities drilled on a 2.000-inch-diameter circle. The welding head itself, (Figure 5.4-6), is an eight station rotary index table which indexes once for each weld. Since each electrode cavity is good for approximately 500 welds and there are eight stations, the electrodes need to be rotated only after a total of 4,000 units have been welded. Rotation of the eight pairs of electrode discs to the next hole position requires only about 5 minutes and this can be done 48 times for a total of 192,000 welds. This reduces the problem of electrode redressing to a point where it is essentially negligible. Redressing of the electrode discs is accomplished by placing them on a surface grinder and removing approximately .005 inches of material from each side. This redressing can be done several times without harming the electrode.

After a unit is loaded in the welding head, the head indexes bringing the unit under the welding station (Item 6, Figure 5.4-3) where the necessary pressure and current are applied to accomplish the closure weld. The welding head then indexes to the unload station (Item 7, Figure 5.4-3) where the electrodes open and the unloading head removes the unit from the electrodes and places it back into an aluminum rack. The aluminum racks are then indexed and ejected into the output station (Item 8, Figure 5.4-3).

This machine has many interlocks and detection stations to protect the machine and operator. These interlocks and detection stations make it possible for the operator to concentrate her observations on the assembly station.

III Machine Development

The previous method of performing this operation consisted of manually threading the internal lead into the tubulation and manually tack welding the can to the stud. After assembling and tack welding the units, they were then transported to the semi-automatic welder (Figure 5.4-1) where they were manually loaded and the closure weld made. This meant that the unit remained in room atmosphere for as long as an hour. The output for the manual threading and tack welding operation is approximately 300 units per operator hour. The semi-automatic welding operation has an hourly output of about 450 units.

Feasibility studies were conducted on two basic machine concepts in addition to the final in-line type of machine. In the first concept, the machine took the form of two tangent rotary index tables. Loading of the stud-wafer-lead assembly, straightening and locating of the internal lead was to be accomplished on a small index table. Case feed, welding and unloading would have been done on a larger index table. The common station at the point of tangency of the two tables would perform the assembly operation. The second concept considered was a single rotary turn table multi-station machine.

Development work was done on an assembly technique which utilized a spinning operation to straighten and locate the internal lead for threading into the tubulation. This idea was abandoned because laboratory tests showed that spin straightening caused undesirable stressing of the thermocompression bond.

The problem of electrode life was originally approached by the proposed incorporation of an electrode redressing station on the machine.

Redressing by grinding (on the machine) was eliminated since it would have contaminated the atmosphere near the units. The idea of redressing by coining electrodes on the machine was also investigated but it was found that redressing in this manner caused the electrode material to work harden and fail. The present method of having a multi-cavity electrode was then formulated.

With this type of machine it was found that several of the motions such as the indexers, the funnel carrier, and the tubulated can holder were similar. Each of these were to be operated in a rectangular motion. Therefore, the basic mechanism for obtaining rectangular motion was developed and used for all of these operations. The indexer shown as Figure 5.4-7 is a view of this mechanism.

The overall concept of an in-line type of machine with a comb straightening technique for straightening the .006-inch-diameter internal gold lead; a split-funnel type of threading technique; and a multi-cavity rotary type of welding head was adopted. However, it should be noted here that this original concept did not include tack welding as part of the assembly operation. With this concept in mind, the machine was designed and constructed.

IV Operational Problems

As soon as prove-in began, it was found that after the units were assembled, they were not rigid enough to allow reliable indexing and loading into the welding head without becoming misaligned or disassembled. It was at this time that the tack welding concept was introduced. The original assembly station was modified to accept the tack welding operation; however, due to the fact that the new motions were being obtained from existing motions through linkages, the modified station presented many space and timing problems which affected the reliable operation of the machine. Although considerable effort was expended, it was apparent that this concept was not the answer to the assembly problem. This station was, therefore, redesigned to include not only the tack welding operation but also a new threading technique.

The original concept for threading was a split funnel arrangement where the funnel came in over the wire and closed prior to moving down. As it moved down, the wire was forced upwards through a tapered section and on into a small confining cylinder to locate and thread the wire into the tubulation. This gave rise to many threading failures due primarily to the fact that many of the gold wires would collapse as they attempted to follow the tapered section of the funnel. Therefore, the reliability of this operation was not sufficient to warrant its use as a production tool.

When the assembly station was redesigned to add improved tack welding equipment, the funnel mechanism was also redesigned to increase its reliability. The new threading concept is also a split funnel arrangement but as this funnel closes, the wire is located into the small threading cylinder immediately by an interlocking "V" section. This eliminated the necessity of forcing the .006-inch-diameter internal lead through a tapered section. This new station proved to be a great improvement.

During the trial of the original assembly station with its added tack welding equipment, many difficulties were experienced in tack welding. It was impossible to obtain consistency in the tack weld even though different electrode materials, power supplies, welding times, welding temperatures, and welding pressures were tried. It was found that the addition of three small projections on the contact area of the can greatly enhanced the reliability of tack welding. This was due to the fact that without the projections, the contact area varied from one assembly to the next. As a result of these variations, unequal current distribution caused the welds to vary. An investigation was undertaken and approximately 2,000 diodes were made with these special cans. Extensive tests showed that this change did not adversely affect the completed diodes. It was later determined, however, that projections were not necessary because the new tack welding concept on the redesigned assembly station proved capable of reliably performing good welds with the regular cans. This was due to the more consistent application of the necessary welding pressure with the new mechanism.

While the redesign and construction of the assembly station was being done, the rest of the machine was being run and checked to find any other sources of trouble. The first such area was found to be the loading of the tack welded units into the welding head. The original concept included a nylon friction plug in the bottom electrode to maintain the unit at the correct height while the electrodes closed. This method was improved upon by replacing these friction plugs with spring loaded plungers (Item 5, Figure 5.4-4) of the correct height which allowed the bottom lead to rest in a concave area in the top of the plunger.

Many assemblies were not entering the upper electrodes completely and consequently they were crushed when the electrodes closed. This was overcome by adding a vacuum system to each upper electrode so that the unit is pulled up into the electrode cavity prior to its closing. This modification has essentially eliminated the crushing problem.

Another problem area involved the indexing mechanism. The original machine concept had three rack indexing mechanisms like the one shown in Figure 5.4-7. These rack indexing stations were designed to index exactly .250 inches with no allowance for adjustment. To index a rack, the index finger had to straddle the bottom lead of the stud lead assembly and engage the counter-sunk holes in the rack. This indexing method did not provide the precise positive index required and thus caused the units to be damaged. Damage occurred when the holes in the racks did not align with the index fingers and were bent when the index fingers moved forward. Also, whenever the index fingers did not seat properly in the counter-sunk holes, they would ride out of the hole instead of indexing and thus damage the unit. The damage could either cause total destruction of the unit or bending of the stud lead wire which would cause malfunctions at succeeding stations. The rack indexing problem was solved by the use of a rack and pawl type of indexer shown as Item 1, Figure 5.4-5. To accommodate this type of indexer, the aluminum handling racks were modified by adding accurately located slots as shown in Figure 5.4-8. This indexing method has proven to be very successful and has eliminated all the problems experienced with the original mechanisms.

Another area that proved to be troublesome was the loading of units into the welding head. Originally the tack welded units were required to index up a ramp to be at the correct height for pickup by the loading head. This method of raising the assembly caused the bottom external leads to be bent and caused occasional jams. A separate raising mechanism was installed to pick the unit from the track and deliver it to the loading head at the correct height. The loading head itself was modified by adding "V" slotted collapsible foot on both the top and bottom. The top foot locates the end of the tubulation and the lower foot locates the bottom lead. The force required to move the unit into these slots is achieved by a magnet which pulls on the body of the unit. The collapsible feet allow the ends of the unit to be located accurately and yet remain in the welding head as the electrodes close until both the lead and tubulation are inserted well into their respective electrodes.

V Machine Performance

The shop trial was performed in steps. While the assembly station was in the process of being redesigned, pre-assembled tack-welded units were run through the welding portion of the machine. This afforded a means of evaluating this portion of the machine as well as training an operator.

During this portion of shop trial approximately 55,000 units were automatically loaded, welded, and unloaded with an average machine yield of 97.2 percent. Many of the failures during this run were attributed to the fact that since the units had been processed over manual equipment, the straightness of the leads was not adequate to insure proper machine operation.

To evaluate the aforementioned experiment using cans with projections to facilitate tack welding, approximately 1,300 units were run through this machine. These units were then processed completely through the line and given the 1,000 storage hour life test. Then the life test date of these units and standard production units were compared. The standard production units experienced 1.51 percent defects and the experimental units experienced 1.05 percent defects. Thus the units welded with the special cans were as good as or better than standard product.

After the assembly station had been redesigned and proven-in, the machine was run in its entirety. The machine yield was 94.3 percent with an efficiency of 85.3 percent. The efficiency in this case was determined by dividing the number of good units by the number of machine cycles. It should be noted that a machine failure does not necessarily constitute a ruined unit. This is because the operator, by close surveillance can anticipate a machine failure and stop it in time to save the unit. The machine yield was determined by dividing the number of good units produced by the number of units started.

The following table shows the performance of the machine during the mechanized pilot run:

Code	Starts	Good	Yield
1N673	485	439	90.5%
1N668	841	720	86.0%
1N665	650	584	89.7%
1N675	691	651	94.3%
1N701	239	218	91.2%
1N669	355	319	90.0%
1N666	990	813	82.0%
1N697	651	531	81.5%
1N664	388	376	97.0%
	5,290	4,651	88.0% (Average)

The major difficulties during the mechanized pilot run were experienced at the threading operation and at the welder load station. The cause for threading failures was attributed to a burr in the funnel. This was found and corrected before the final (1N664) group of units was run. It can, therefore, be concluded that had this defect been corrected earlier, the yields would have been in accordance with that experienced on the 1N664.

Some piece part problems, especially the straightness of the .020-inch external lead, were experienced. In the manual threading operation, the length of the internal lead and the concentricity of the tubulation with respect to the can are not critical since the operator is able to compensate for such inconsistencies. However, with the automatic machine these two items are critical. Since the machine is unable to compensate for such variances, it is important that the internal lead length and tubulation concentricity requirements be maintained so that the necessary accurate locations can be maintained for the threading operation. However, the variations in length of the .006-inch-diameter gold internal lead were much less as they came from the Gold Bonding Machine than those which normally come from the manual bonders.

VI Evaluation

Thus far in the running of this machine, considerable maintenance of the assembly station funnel was required. The internal finish of the funnel is very important to the successful threading operation and a scratch or burr will destroy its effectiveness. Also after running for a period of time, gold deposits left by the sliding of the internal leads can make the funnel unreliable. The funnel is very fragile due to its small size and therefore a malfunction at this point can pause complete destruction of the funnel. This area requires frequent preventive maintenance to insure reliable operation of the machine.

The welder load station is another area that will require operator surveillance. The success of this station depends on straight leads. Without straight leads the removal of the assembly from the rack and its insertion into the welding electrodes is not reliable. Malfunctions of this station have accounted for about 50 percent of the units destroyed.

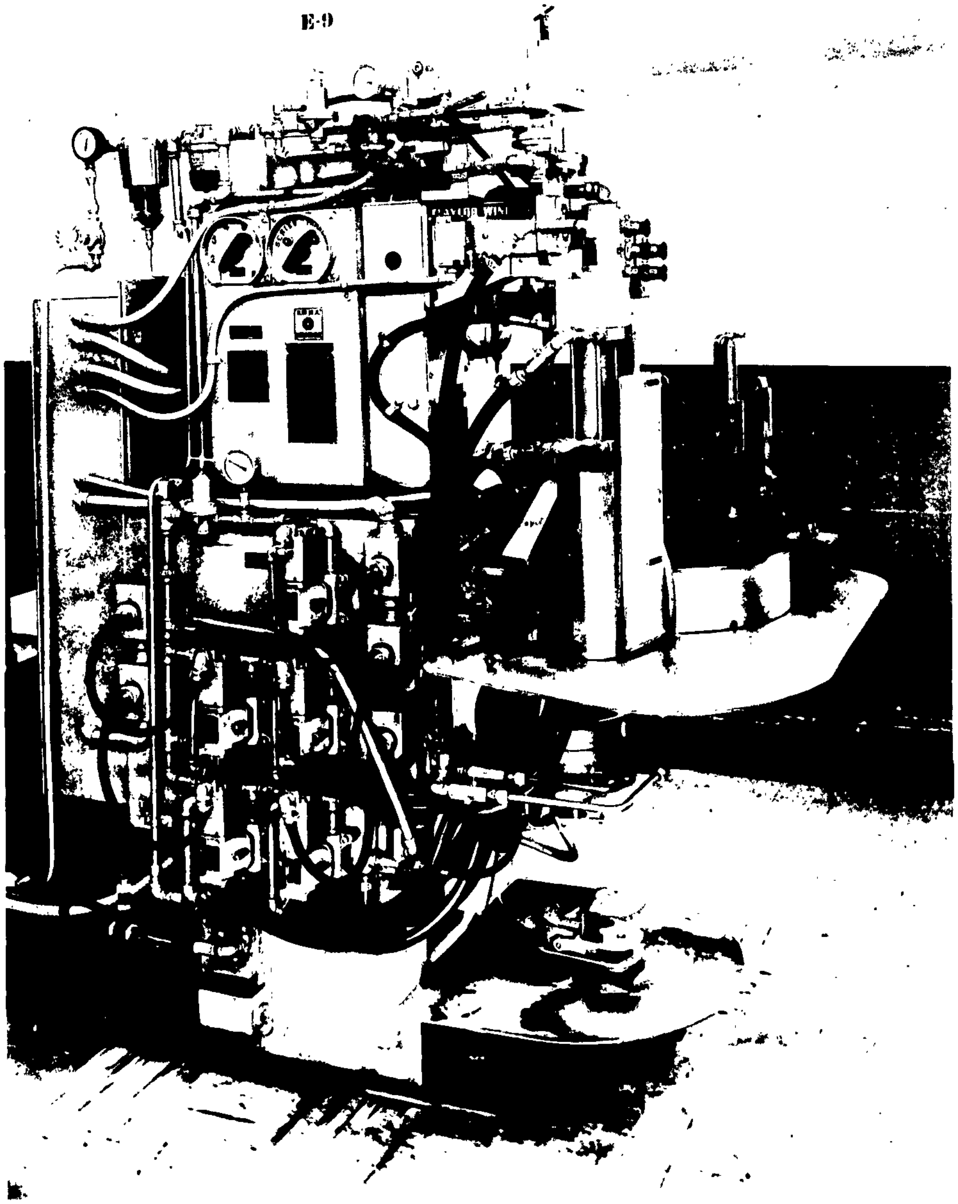
The welder unload station which removes the unit from the electrodes and places it back in the rack has essentially the same problems. Although the unload station accounts for a small percentage of the destroyed units, it does account for approximately 50 percent of the machine malfunctions. Due primarily to these two areas of trouble, and the addition of tack welding, the machine speed has been reduced from the designed speed of 1,200 to 700 per hour.

The control system, drive mechanisms, indexing mechanism, and straightening station have proven to be reliable in their operation and have required no maintenance except the necessary cleaning and lubrication.

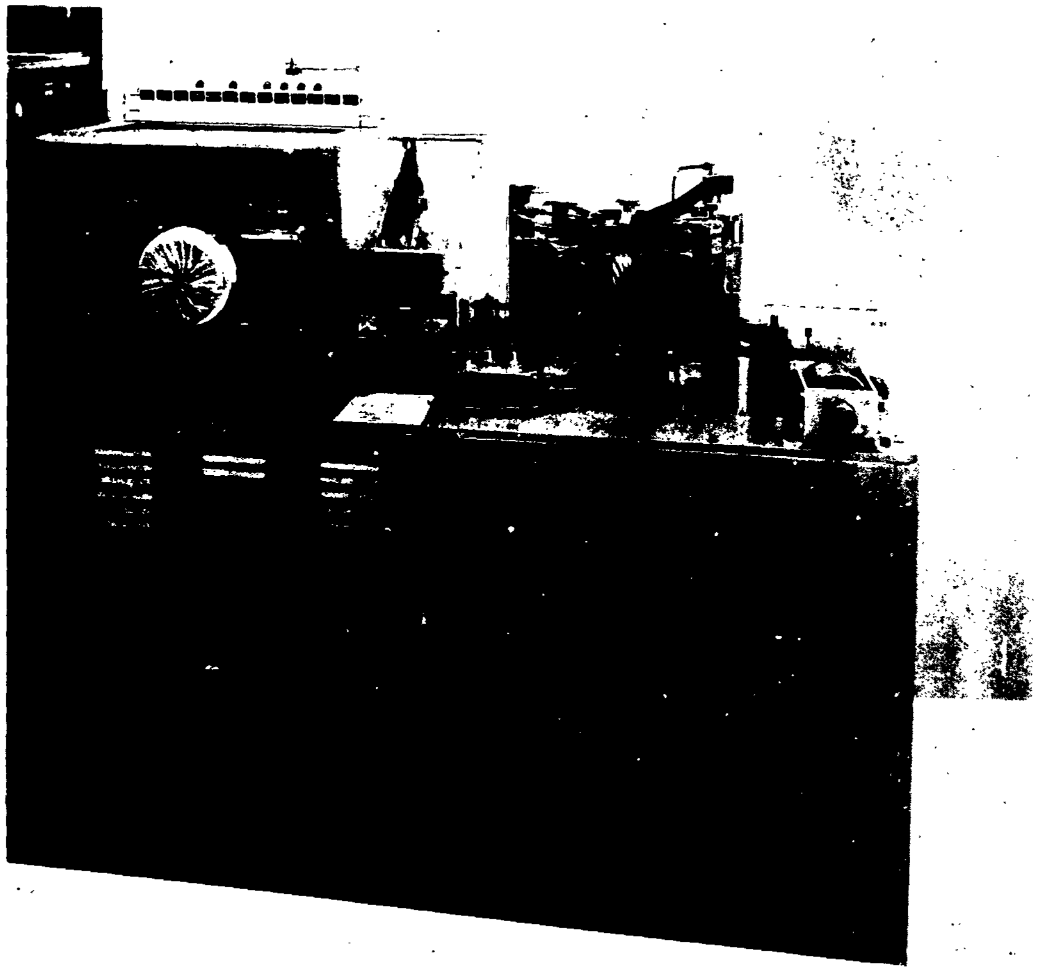
VII Conclusion

The Assembling Case to Stud and Welding Machine has a capacity equivalent to four manual tack welders with nearly three times the capacity of the semi-automatic welder with better protection to the unit by maintaining the units in a controlled atmosphere until they are tack welded.

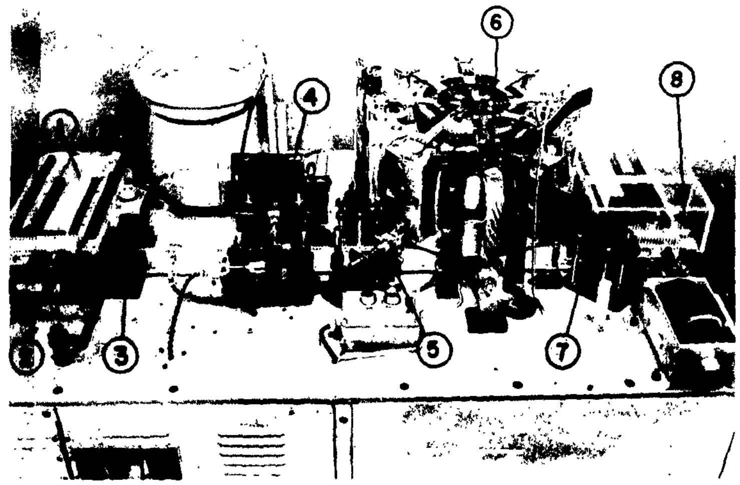
The problems involved with loading and unloading the rotating welding head has required that the machine speed be reduced from the 1,200 units per hour designed output to 700 units per hour. Presently a new concept is being considered which will eliminate the need for the rotary welding head. This will be done by adding electrode material to the top of the handling rack. This will allow the closure weld to be performed without removing the unit from the rack. Although the feature of minimum electrode dressing will be lost with the new concept, ease of electrode replacement and increased machine rate will offset this loss. This new concept will eliminate the problems of removing the unit from the rack, threading it into the electrodes, and then replacing it in the rack. In addition, since the unit will not be removed from the rack, the tack welding operation will no longer be necessary. This will simplify the assembly station. With the new concept it is felt that the machine will be capable of reliable operation at 1,200 units per hour. Feasibility of this new technique will be tested on a bench model prior to its incorporation into the machine.



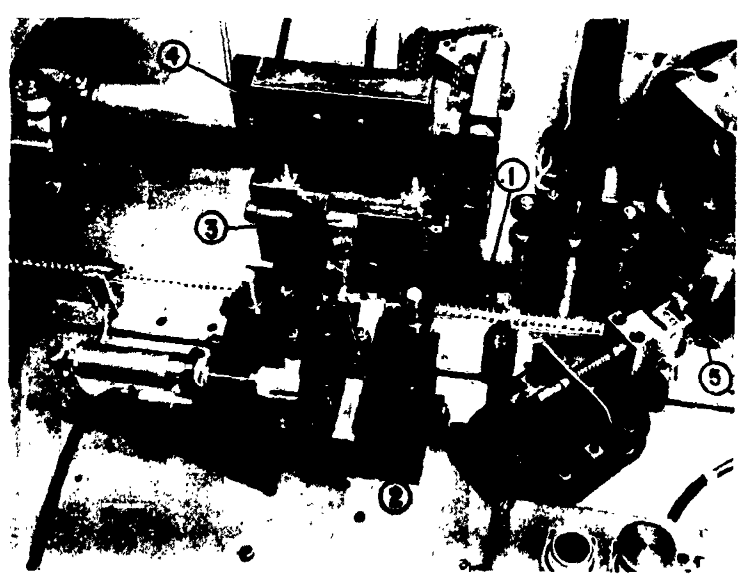
SEMI-AUTOMATIC WELDING MACHINE
FIGURE 5.4-1



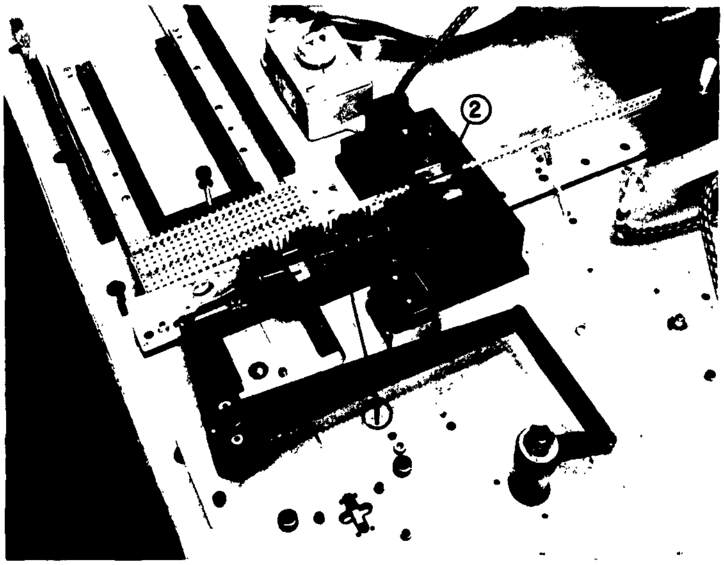
ASSEMBLING CASE TO STUD AND WELDING MACHINE
FIGURE 5.4-2



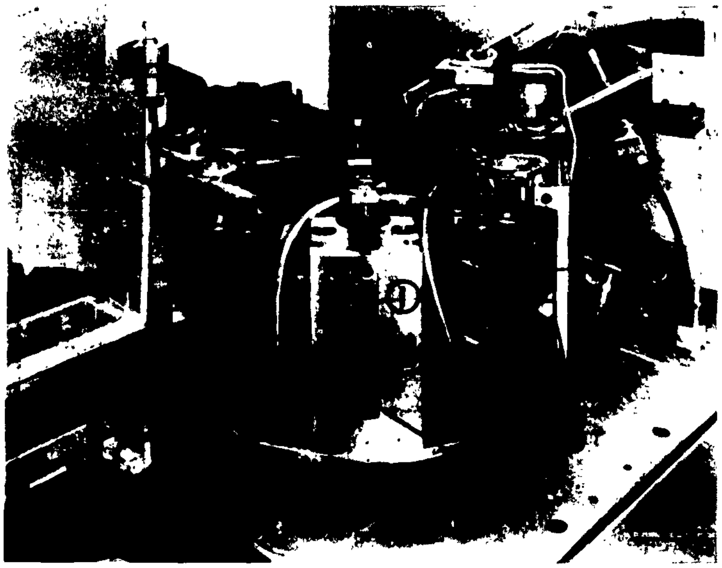
STATIONS OF ASSEMBLING CASE TO STUD AND WELDING MACHINE
FIGURE 5.4-3



ASSEMBLY AND WELDER LOAD STATIONS OF ASSEMBLING CASE TO STUD AND WELDING MACHINE
FIGURE 5.4-4

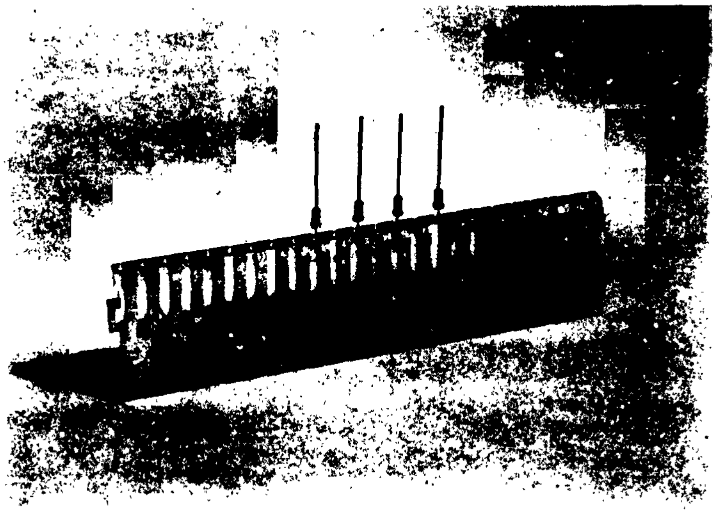


RACK INDEXING AND LEAD STRAIGHTENING STATIONS OF
ASSEMBLING CASE TO STUD AND WELDING MACHINE
FIGURE 5.4-5



WELDING HEAD OF ASSEMBLING CASE TO STUD AND WELDING MACHINE
FIGURE 5.4-6

ORIGINAL INDEXING MECHANISM OF ASSEMBLING CASE TO
STUD AND WELDING MACHINE
FIGURE 5.4-7



ALUMINUM CARRIER USED ON ASSEMBLING CASE TO
STUD AND WELDING MACHINE
FIGURE 5.4-8

SECTION 5.5

LEAD STRAIGHTENING AND RACKING

W. A. Schlemm

LEAD STRAIGHTENING AND RACKING

I General

The process which has been mechanized is the straightening of the .4 watt diode leads and placing the finished units into a rack. Prior to the development of this machine, straightening of the leads was a manual process which was performed only when necessary to improve the appearance of the product. Kinked leads required the use of pliers and the less severely bent leads were finger plied. To facilitate the handling of the diodes on the mechanized equipment, it became necessary to add a straightening process. All diodes are now straightened to the following specifications: The leads must lie within an area described by a 1/16-inch radius whose center is the axis of the diode. In addition to straightening the units, the machine places them into a rack. This machine in conjunction with the other machines and the material handling system produces a product superior in appearance to the normal product.

This machine depicted in Figure 5.5-1 utilizes a commercial lead straightener, manufactured by the Universal Instrument Corporation, Binghamton, New York. The racking and rack handling devices were specially designed for this application.

II Description of the Machine

The machine is constructed on a metal table and occupies a 4-foot by 2-foot floor space. The three separate mechanical systems; namely, roll straightening, racking, and magazine loading and unloading, are mounted on the metal table. The roll straightening portion consists of an input chute, two revolving rollers each with mating specially designed spring loaded floating shoes, and an output chute. A spring loaded pick-off finger, located between the rollers on the revolving roller shaft, takes an unstraightened diode from the input chute and places it between the rollers and the shoes. Since the shoes are relatively stationary and the rollers are revolving, the bent leads are roll straightened as they pass between the rollers and shoes. At the far end of the shoes, the diodes are released into an output chute leading to the second portion of the machine, the racking mechanism.

The racking mechanism consists of a movable carriage which is indexed by a pawl and rack mechanism. The pawl is actuated by an air cylinder on signal from a diode which trips a limit switch while passing through the rollers and shoes. Forty-eight diodes are loaded into a slotted rack which is then manually transferred to the third position of the machine, the magazine loading station.

At this third portion of the machine, the loaded racks are stacked into a metal magazine from the bottom by means of an air cylinder actuated elevator and a retaining latch to support the previously stacked racks. At the empty rack dispensing station, the retaining latch is powered to release a rack onto a platform where it is readily available to the operator.

The operator duties start with her loading a magazine full of empty racks onto the station at her right and then loading an empty magazine onto the station at her left. Into this magazine she places two empty racks and a wooden block. These are necessary to constrain the straightened diodes in the first loaded rack during transportation of the filled magazine and during the unloading into the following machine. The operator then turns "on" the machine and presses the two buttons at the load station, thus releasing an empty rack at the dispensing station. She places this rack on the movable carriage and pushes it forward to a stop position. This automatically starts the straightening rollers. After 48 diodes are fed, one at a time, into the input chute, the machine shuts off automatically. The operator then transfers the filled rack to the load station, pushes it into the stop, and presses two adjoining buttons which trigger the mechanisms to load the filled rack into the magazine and release an empty rack from the other magazine. She repeats the cycle until the magazine is filled.

The dual buttons are a safety feature since they are spaced so widely apart that both hands are occupied while the magazine loading mechanism is in operation. Another safety switch, installed at the straightening mechanism, turns the rollers "off" when the straightening head is raised to remove a jammed unit or to clean the rollers. Relatively little maintenance is required other than cleaning and oiling. The straightening rollers and shoes normally need replacing only after a minimum of 2,000,000 diodes are straightened. Should the body of a diode get between the rollers and shoes, either or both could be damaged, and then replacement would also be necessary.

III Machine Development

The feasibility study of this machine consisted of investigating different methods of lead straightening. Commercial die-type straightening equipment, which straightened one lead at a time, proved to be slow and cumbersome, although its capability to straighten a severely bent or kinked lead was desirable. Die straightening of both leads simultaneously and aligning them to the axis of the can was investigated. This method was rejected because excessive glass breakage could not be eliminated.

Four thousand diodes were sent to Universal Instruments Corporation to be straightened on their commercial roll straightener. After favorable results were obtained, we purchased one of their units to conduct tests to find out whether any damage was incurred during straightening. Diodes which had passed the alcohol leak test were obtained from the production line. These units were straightened and then subjected to the alcohol test again. The object of the alcohol leak test was to determine if glass seal damage resulted from straightening. The results of these tests were inconclusive since detrimental glass cracks could occur without causing the seal to leak.

The alcohol test was replaced by a visual inspection of the unit before and after straightening. The inspection criteria adopted were the same ones used to inspect the .4 watt diode case. Figure 4.5-2 tabulates the results of 17 runs. It lists the lot sizes, the severity of lead bends, and the number of times the diodes were straightened. Note that on Runs 2, 3, and 10, the leads were straightened two to five times. After each straightening, the leads were bent within the bending range indicated. During this evaluation 1,496 diodes were used; of these, 250 were restraightened the number of times indicated. A total of 1,996 straightening operations were performed and 7 defective units were noted; therefore, a 99.65 percent yield was realized. With the mechanized line and better control over handling of units in this line, the leads will be less severely bent than some of those used in this test; therefore, the yield should be even higher. Thus the roller-type straightening was accepted as the basic technique for the machine.

During design, automatic feeding and automatic magazine loading of the filled racks were considered. Since this level of mechanization was not necessary to provide the needed capacity, these considerations were dismissed. Design and construction of the magazine loading and unloading system was done at Western Electric in Laureldale; whereas, the design and construction of the straightening and racking mechanism was done by Universal Instruments Corporation. No construction problems were encountered, but during mechanical prove-in a solenoid, used to actuate the racking mechanism, proved to be troublesome and was replaced by a double acting air cylinder.

IV Operational Problems

During prove-in, the difficulty encountered in laying the straightened diodes into the slotted racks was overcome by fastening a 10-inch-long horseshoe magnet on the carriage, in the center of the rack. Also, an "open loop" control system had to be replaced by a "closed loop" system so that the indexing speed would be independent of the straightening speed. After this change, an increase in the production rate was realized. The machine performed at expected rates. The straightening and racking speed is set at 4,200 units per hour. Magazine loading and unloading rates are a function of the operator's dexterity.

During shop trial run the following piece part problem was prevalent. The diodes presented to this machine were more severely bent than those which will be presented when the mechanized line is in use. Also, the units were not oriented. These two conditions were alleviated by pre-straightening (finger plying) and orienting the units manually. No problem in operator training was encountered.

V Machine Performance

No particular program was scheduled as a shop trial run for this machine, but it was used to provide straightened and racked diodes to the Final Electrical Testing Machine. Approximately 5,000 diodes were straightened and racked. A machine efficiency of 99.5 percent was realized during this run. This efficiency was based on a number of sample inspections.

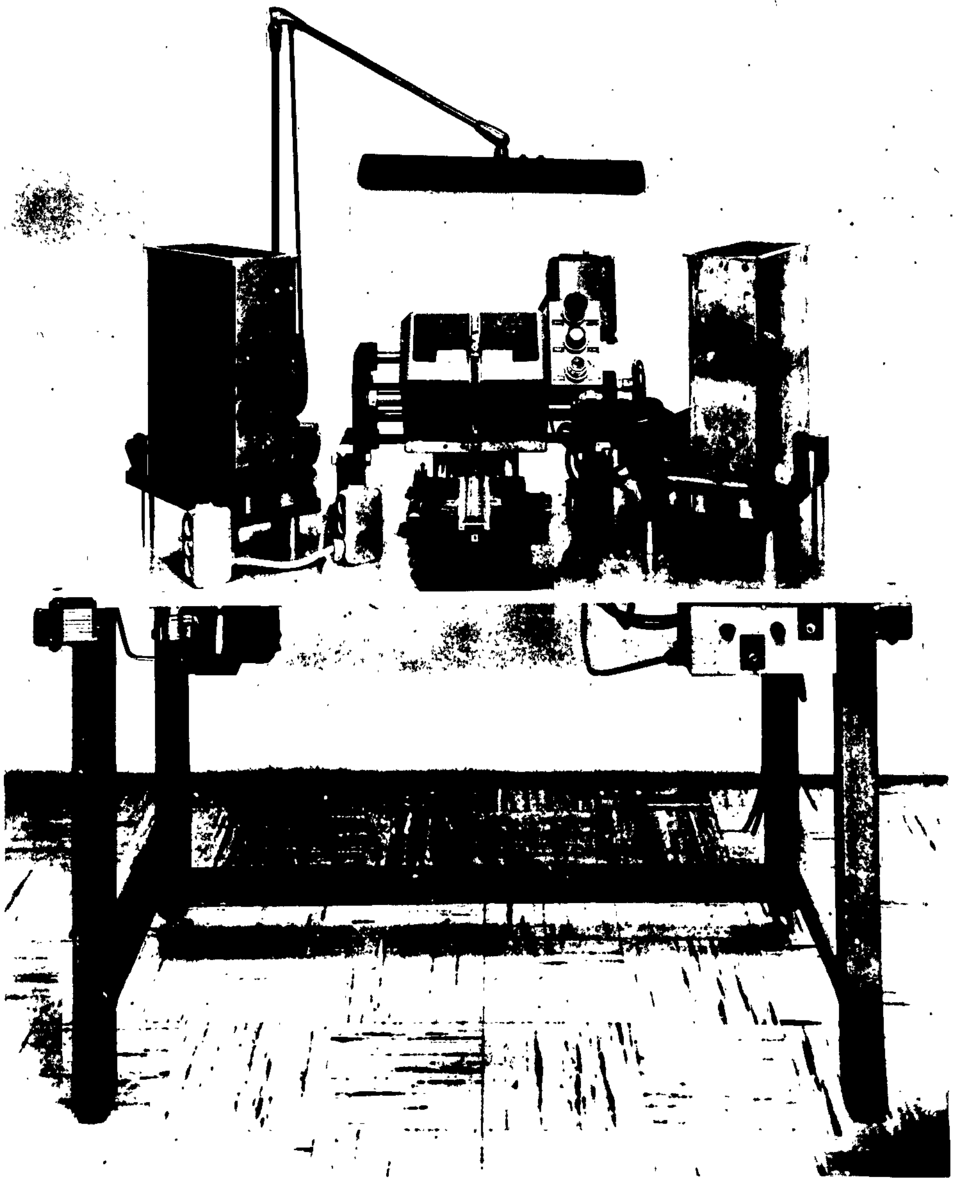
Minor maintenance, which was required, included adjusting of flow control valves to "smooth out" the rack indexing and adjusting straightener shoe pressure to produce maximum straightness. An estimated hourly output of 1,000 was realized during this run although an hourly output of 1,800 was maintained for a short period. In regular production use, however, the predicted rate of the machine is 2,500 per hour.

VI Evaluation

This machine straightens 100 percent of the diodes to the specifications desired, and racks the units at a 98 percent reliability. The 2 percent racking failure is due to two causes: First, if a diode is not presented to the shoes and rollers properly, it will not drop to the racking mechanism reliably. This type of faulty feeding is presently caused by overly bent leads. Secondly, the lack of symmetry of the .4 watt diode does not lend itself to completely reliable handling. The machine is easily operated after a few minutes training.

VII Conclusion

The goal of mechanizing the lead straightening operation has been gained since the machine will straighten the leads to the specifications desired without damaging the diodes during straightening. An experienced operator performing at 100 percent efficiency will be capable of processing 2,500 diodes per hour.



LEAD STRAIGHTENING AND RACKING MACHINE
FIGURE 5.5-1

RESULTS OF .4 WATT DIODE LEAD STRAIGHTENING EXPERIMENT

LOT NO.	LOT SIZE	BEND RANGE	STRAIGHT-ENING SPEED	AFTER STRAIGHTENING		NO. OF TIMES STRAIGHT-ENED	% CRACKED
				GOOD UNITS	CRACKED UNITS		
1	97	1/2"	1,800/hr.	97	0	1	0
2	100	Random	1,800/hr.	100	0	3	0
3	100	Random	1,800/hr.	99	1	2	1
4	50	1"	1,800/hr.	50	0	1	0
5	51	1/2"	1,800/hr.	49	2	1	4
6	48	1/4"	1,800/hr.	47	1	1	2
7	100	1/4"	1,800/hr.	100	0	1	0
8	100	1/2"	1,800/hr.	98	2	1	2
9	100	1"	1,800/hr.	100	0	1	0
10	50	Random	1,800/hr.	50	0	5	0
11	100	1/4"	3,600/hr.	100	0	1	0
12	100	1/2"	3,600/hr.	100	0	1	0
13	100	1"	3,600/hr.	100	0	1	0
14	100	1/4"	2,700/hr.	100	0	1	0
15	100	1/2"	2,700/hr.	99	1	1	1
16	100	1"	2,700/hr.	100	0	1	0
17	100	Random	3,600/hr.	100	0	1	0

FIGURE 5.5-2

SECTION 5.6

LOW TEMPERATURE REVERSE CURRENT TESTING

H. A. Griesemer

LOW TEMPERATURE REVERSE CURRENT TESTING

I General

The Low Temperature Reverse Current Testing Machine monitors the reverse current as diodes are cooled from ambient to a specified low temperature. Diodes failing between the specified temperature limits but good at the low temperature are thereby detected.

Two developments enabled the achievement of a practical output and reliability. First, a rapid method of cooling the diodes was devised which consisted of placing a fixture in a cold chamber constantly held below the specified low temperature. Second, a means of measuring the actual junction temperature was developed so that the reverse current test could be stopped when the diodes reached the low temperature.

II Description of Machine

The machine is made up of a test set, contact fixture, hooded loading area, and environmental test chamber (Figures 5.6-1 and 5.6-2). Two standard material handling racks, containing 48 diodes, are placed in a frame which is inserted in the contact fixture where electrical contact is made with the leads of each diode. Continuity of each of the 48 circuits is automatically checked and the circuits immediately switched to reverse current monitoring. The fixture is then pushed into the cold chamber through a small work entrance in the side of the chamber. The cold chamber temperature is held 10 to 20°C. below the specified low test temperature to insure a rapid cooling rate; however, the reverse current test is stopped automatically when the specified low temperature, as measured by a temperature sensing diode circuit, is reached. Rejected diodes are indicated by the numbered lights on the display panel which are turned off. The rejects are removed by the operator after the fixture is withdrawn from the cold chamber. The entire loading area is enclosed in a hood which is supplied with a dry air atmosphere. A frame holding stand and two tray holding stands are provided in the loading area to facilitate the loading and unloading operation.

The frames holding the diode racks are so numbered that each diode can be identified with its numbered light on the display panel. One of the two frames provided can be unloaded and loaded while the other is in the cold chamber.

The lower half of the contact fixture acts as a wiring trough and locates the frame under the electrical contacts contained in the upper half. Common contacts in the form of a slotted strip are provided for the upper leads and individual spring loaded contacts for the lower leads. The wires are run from the contacts through slots to the base and hence to a plug-in connection on the test set chassis. There is sufficient cable slack provided in the test set cabinet to allow movement of the fixture. Four pins operating in ball bushings maintain the position of the fixture halves while a connecting toggle linkage provides the force to compress the contact springs, to lock the two halves together in operating position, and to hold the upper half in loading position with the aid of ball spring plungers.

Dry air is blown directly over the contacts and other critical fixture areas from four tubes on each of two manifolds in order to prevent the condensation of moisture. A flow valve and flow-rater control the dry air flow.

A .4 watt temperature sensing diode, calibrated for its forward voltage vs. temperature characteristic, is permanently mounted in the right hand air flow opening of the fixture. This diode and associated circuitry indicates the diode junction temperature on a panel meter and stops the test when the specified low temperature is reached. The sensing diode is returned to room temperature after each cycle by a controlled stream of dry air warmed while passing over an electric heating coil.

Cooling is accomplished by a standard compressor operated Tenny Engineering Company Environmental Test Chamber Model TMUF-120240 modified with a 11-3/4 inch by 2-3/4 inch work entrance in its left side. Its operating range is from 116 to -80°C. The exterior of the work entrance is closed by a horizontally hinged door which seals against a magnetic refrigerator door gasket. When the contact fixture is in its "out" position, the exterior door is held open and the interior is sealed by a silicone sponge rubber and plastic sandwich fastened to the rear of the fixture. Automatic defrosting is accomplished by two separate temperature control systems and a timer which switches to defrost at preset times. Dry air bled into the cold chamber prevents the formation of frost on the cooling coils.

The test set components are housed in the cabinets on both sides of the work area. Separate continuity check and reverse current monitoring circuits are provided for each diode. Panel adjustments allow the selection of the required voltage and maximum reverse current ranges for various diode codes. The test circuits indicating an accept or reject decision basically utilize a Weston Sensitrol Meter Relay with a 5 microampere movement. Reverse current limits greater than 5 microamperes are obtained with circuitry consisting of appropriate shunt resistors and the meter relays for the 0.2 microampere limit. A reed switch on the contact fixture prevents the application of test voltage unless the frame is in place.

III Machine Development

The unmechanized method of making this test consisted of manually placing 50 diodes on a test fixture located in a dry ice box at the low temperature and manually switching the diodes, one at a time, into a test circuit which indicates the reverse current on a meter at the rate of 550 units per hour.

Consultation with interested parties and the diode specifications definitely established the need for test equipment that would monitor the reverse current and at the same time meet the 850 diodes per hour minimum requirements of the mechanized line.

The above requirements indicated the need for testing more than one diode at a time and hence multiple test circuits. A study, which took into account the desirability of testing units in standard handling racks showed that a maximum of 48 separate circuits was physically and economically feasible. However, the required output could still not be met using the existing methods of cooling. Therefore, the following experiments were conducted in order to determine the best method of obtaining the needed cooling rates:

For these studies a thermocouple was welded to the top of the stud of an encapsulated .4 watt diode.

1. The thermocouple-diode was placed in a standard material handling rack. A hose was connected to a bottle of liquid carbon dioxide at 850 psi. Carbon dioxide gas was directed onto the test diode from various distances. Cooling of the diode was accomplished in from 2 to 30 seconds. The faster cooling rates were estimated to be too rapid for the test set to properly monitor the reverse current; and the slower rates, obtained at greater

nozzle distances, required excessive amounts of carbon dioxide.

2. A stream of carbon dioxide gas was directed into the intake of a blower whose outlet was directed onto the diode from a distance of 1/2 inch. Cooling times of from 30 seconds to 2 minutes were achieved, but again excessive amounts of carbon dioxide were required.

3. The diode, in a rack, was placed in various types of mechanical refrigerators. Again the cooling time from ambient to the specified low temperature was measured. While exposed to the direct flow of fan circulated air, the diode cooled in 30 to 60 seconds. Lowering the temperature within the refrigerator decreased the cooling time.

4. Experiment three, above, was repeated in a mechanical refrigerator without fan circulated air. This experiment indicated that cooling could be accomplished in from 45 to 60 seconds, but that a temperature lower than required for testing would have to be held in the refrigerator.

5. Cooling the diode and rack in a commercial, liquid carbon dioxide cold box, required 4 minutes.

6. One end of a 3/16-inch-diameter copper rod 5 inches long was covered with dry ice while the other end was held against the case of the diode. Initial trials showed promise; however, a heavy insulating coating of frost quickly lowered the cooling efficiency.

In addition, the effect of opening the door on refrigerator ambient was determined. With the cold chamber temperature at the specified limit, opening the door of a chest-type refrigerator for 45 seconds raised the temperature 14°C and required 8 minutes recovery time while the temperature of an upright model increased 24°C and required 10 minutes recovery time.

Fixture design information was obtained from an experimental fixture which indicated an acceptable leakage current of 1.0×10^{-9} amperes between adjacent diodes in standard racks at both ambient and low temperatures. At the same time, experimental work was conducted to determine the best test set circuit design particularly for the low, 0.2 microampere, reverse current range. A number of circuits were subjected to stability and reliability tests before a Sensitrol meter relay cathode follower operated circuit was selected for this range.

Based on information gained from these experiments, the following design specifications were established:

1. Cooling was to be accomplished in a mechanical refrigerator having a constantly operating fan and a small work entrance in the side; hence, eliminating the cost and supply problems of liquid carbon dioxide and wide variations in box temperature.
2. Frost formation on the refrigerator coils was to be prevented by bleeding dry air into the chamber.
3. The contact fixture and work area were to be hooded in a protective atmosphere of dry air.
4. Electrical contact was to be made in a fixture receiving two standard racks (48 diodes) and capable of moving in and out of the work entrance so that monitoring could begin before cooling. Automatic loading, unloading, and removal of rejected units was not to be included so that

the work entrance could be as small as possible.

5. Diode temperature was to be measured by a thermocouple welded to the top of an encapsulated stud. Readout from the thermocouple was to stop the test at the specified low temperature and was to be indicated on the display panel.

6. The test set was to monitor the reverse current of 48 diodes simultaneously, check circuit continuity at the start of each cycle, provide necessary voltage and current ranges, and indicate diode failure by switching "off" its light on the display panel.

During the design phase, the problem of measuring test temperature continued to receive attention since the proposed method left some doubt as to the actual junction temperature. For this reason, the forward voltage versus temperature characteristics of a 1N673 diode were investigated by means of the test circuit shown in Figure 5.6-3. The test results, plotted in Figure 5.6-4, indicate a linear relationship with practical repeatability over a period of time for a given diode. Therefore, since this relationship is a direct indication of junction temperature, a circuit using a temperature sensing diode was incorporated.

The design of doors that would effectively seal the work entrance and at the same time allow rapid insertion and removal of the contact fixture presented difficulties. After consideration, a magnetic refrigerator door gasket was used to seal the outside horizontal door, and a silicone sponge rubber and plastic sandwich, mounted on the fixture, was used to seal the inside.

IV Operational Problems

During prove-in, formation of excessive condensation on the fixture required the installation of two dry air manifolds having eight outlet tubes directed at vital areas of the fixture. The direct flow effectively eliminated the condensation problem. Unheated dry air directed at the sensing diode did not raise its temperature to room ambient quickly enough between cycles. Therefore, a heating coil was installed in the air line.

Additional frame loading clearance between the upper and lower fixture halves was provided by modifying the toggle linkage and installing two ball spring plungers which lock the fixture in loading position.

The following changes to the test set circuitry were found necessary during prove-in:

1. A new transformer was added to increase the intensity of the indicating lights.
2. The continuity checking circuit was redesigned to obtain positive resetting of the "Sensitrol" relays after the continuity check.
3. A light was added on the control panel to indicate the start of the test cycle.
4. A remote voltage control network was designed and installed to provide a voltage control for the operator.
5. The coils of the "Sensitrol" relays had a tendency to burn out. A circuit to limit the maximum coil voltage was designed and installed. In addition, certain relays had a tendency to operate unreliably. Indications are that either repair or replacement of troublesome relays will eliminate this condition. To be certain that poor

lead contact was not contributing to this problem, stronger individual contact springs were installed and the slots of the common contacts extended.

Validity of test results obtained on the test set was established through the use of an experimental test set consisting of a liquid carbon dioxide cold chamber, a Kiethley Model 410 Microammeter, a Griebach Voltmeter and a Sorenson & Co. Model 560-BB Mobatron Power Supply or Hewlett-Packard Variable Supply.

Out of a total of 15,520 diodes (Codes: 1N673 and 1N697) tested on the test set, a sample of 294 was selected at random from the diodes which tested good. On the laboratory apparatus, two of these diodes or 0.7 percent of the total sample tested bad. All rejected diodes (122) were, likewise, retested. Of these, 94 tested bad and 28 good. An evaluation of this data indicated that the test set was rejecting practically all diodes not meeting the low temperature test requirements. However, 23 percent of the diodes rejected later, tested good. Further testing of these units indicated an inherent instability which made their initial rejection desirable. No diodes were lost by mechanical failure.

Little operator training was required to establish an average output of 1,600 units per hour during shop trial and mechanized runs. With the test set in daily use an output of 2,000 units per hour is expected.

Maintenance during daily use has been confined to the test set relays and two refrigerator line leaks caused by broken compressor mounts.

V Evaluation

The test set has been operating on a regular basis since October 18, 1962, with brief shutdowns for modifications. Other than the difficulties experienced with the test set relays or contacts, the refrigerator lines and the compressor mounts, no particular problems have arisen. The accuracy of the test results has been good. The layout of the work area has provided a smooth flowing sequence of operations with no particularly fatiguing or difficult tasks to lower operator efficiency.

The cooling process has proven capable of providing the required diode cooling rate of from 30 to 60 seconds. No excessive buildup of ice on the refrigeration coils has occurred; and the redesigned dry air system has prevented formation of condensation on the contact fixture.

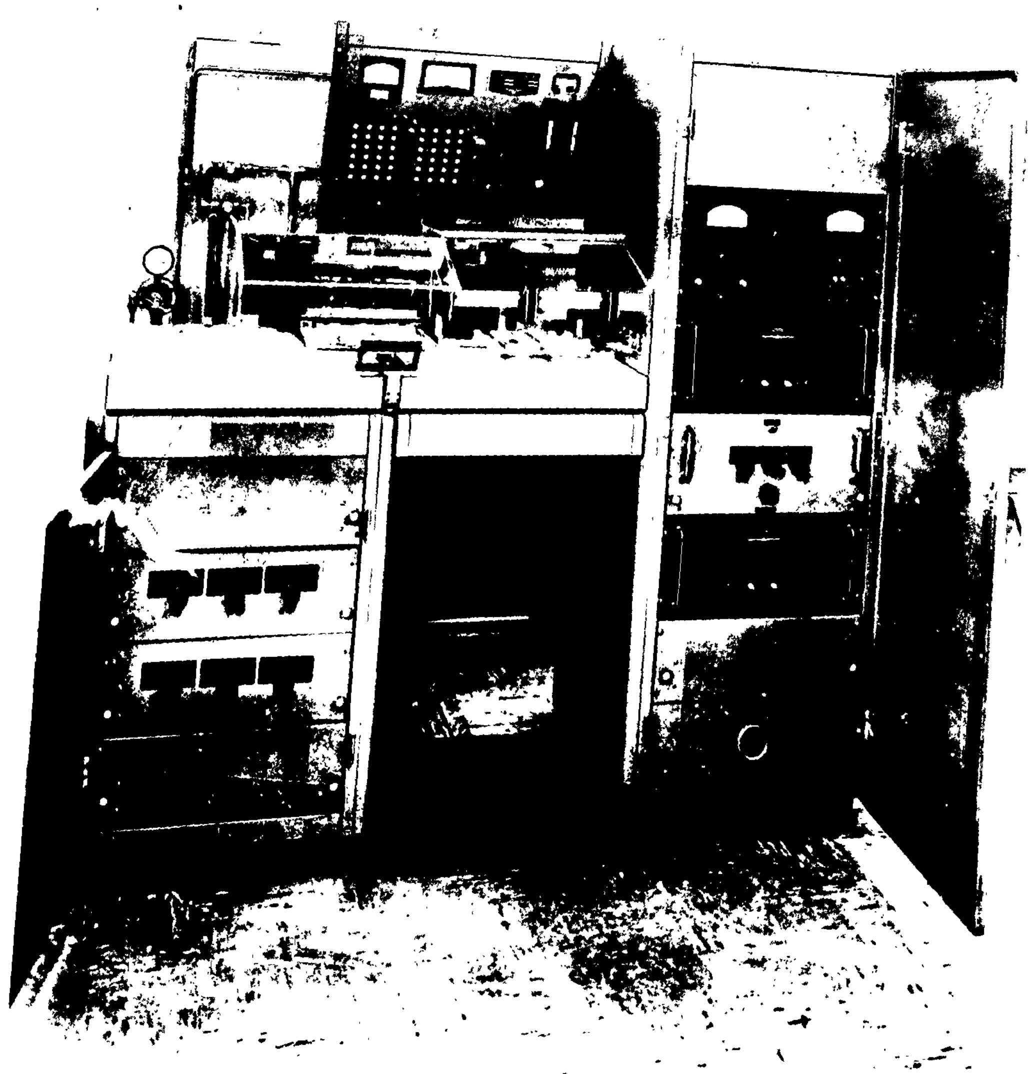
The sensing diode system for measuring the test temperature has been completely effective in providing needed readout information and dispelling doubts as to the actual junction temperature.

The 1,600 to 2,000-unit-per-hour output of the test set is well above the predicted output of 1,200 units per hour and the manual unmonitored test set output of 550 units per hour.

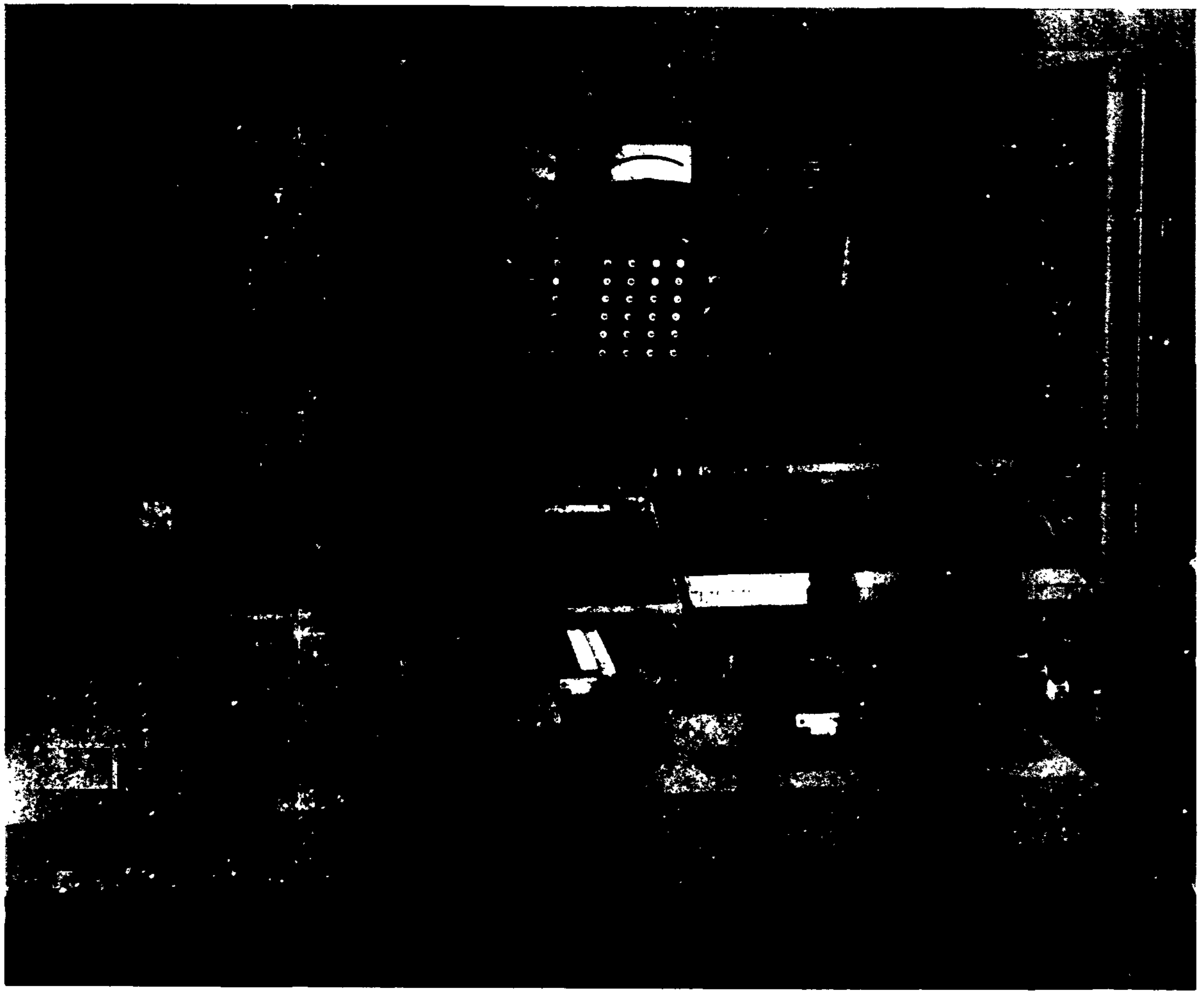
Experience gained during shop trial and the mechanized pilot run has indicated certain improvements for future consideration. A second set of lights, indicating good and rejected units, located immediately adjacent to the frame in the work area would facilitate removal of rejected diodes. Greater separation of the contact fixture halves in loading position would allow testing of diodes with more allowable lead bend without the possibility of catching the leads in the contacts. Experience has shown that a slightly larger refrigerator work entrance could probably be used without affecting operations. This would allow greater latitude in contact fixture design.

VI Conclusion

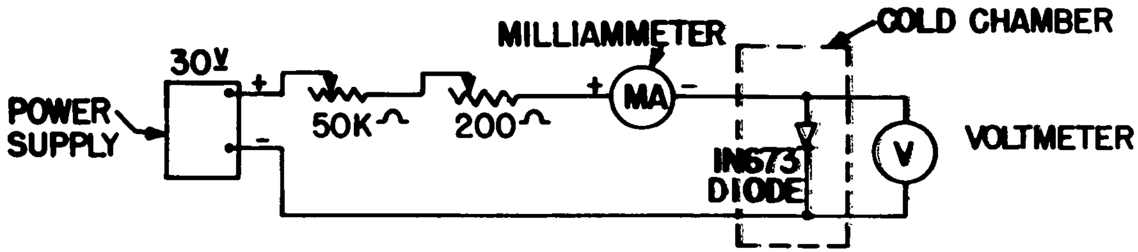
The low temperature reverse current test set has proven capable of meeting the assigned requirements of monitoring the reverse current over the specified temperature range and at the same time providing an output which will meet the needs of the mechanized line. Use of the circuit continuity check and actual junction temperature measurement assure a high degree of confidence in the test results. These items along with the rapid diode cooling process offer a significant advance over the original methods employed. Operation of the test set for several months has shown its ability to work successfully on the mechanized line.



LOW TEMPERATURE REVERSE CURRENT TESTING MACHINE
FIGURE 5.6-1



HOODED LOADING AREA OF LOW TEMPERATURE
REVERSE CURRENT TESTING MACHINE
FIGURE 5.6-2



TEST CIRCUIT
FORWARD VOLTAGE VS TEMPERATURE

FIGURE 5.6-3

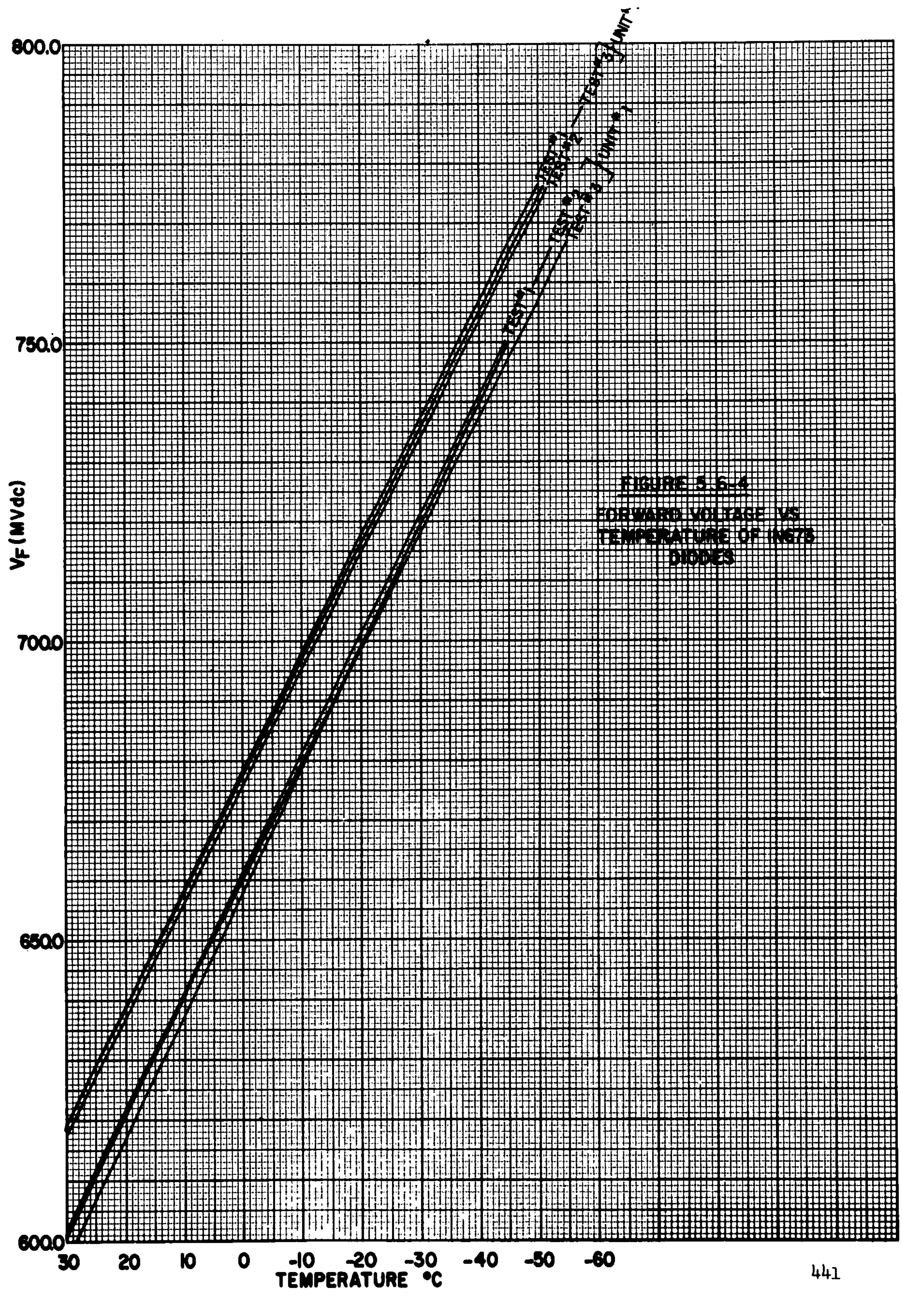


FIGURE 5.6-4
FORWARD VOLTAGE VS TEMPERATURE OF IN678 DIODES

SECTION 5.7

GOLD PLATING

H. C. Grunewald

GOLD PLATING

I General

The Gold Plating operation consists of a method of cleaning .4 watt diodes in preparation for gold plating, and then applying a proprietary electroless "Atomex" gold plate to the cleaned assemblies. This process is accomplished by one operator who manually moves a plating fixture, loaded with up to 720 diodes, in and out of a series of cleaning, rinsing, and plating tanks and finally into a forced air dryer. Several fixtures may be processed at one time at a capacity level of 2,500 diodes per hour compared to the former Shop level of 1,600 per hour. Although the fixtures are manually moved from one tank to another, they are mechanically agitated within the cleaning and plating tanks.

A superior gold plate is achieved because each diode is subjected to the same cleaning and plating conditions. Spacing of the diodes in the handling fixture make this possible. In the former plating operation the diodes were handled in bulk. Lead straightness could not be maintained and plating was not uniform since a certain amount of shielding occurred.

II Description of the System

The Plating System is composed of one material handling bench (Item 2, Figure 5.7-2); seven cleaning, rinsing, and plating tanks (Figure 5.7-3) housed in two ventilated, hooded PVC (polyvinylchloride) sinks (Item 1, Figure 5.7-1); and one forced-air dryer (Item 1, Figure 5.7-2) located at one end of the sinks. Two auxiliary water heaters attached to the backs of the sinks provide the hot rinsing water used in the plating process. One heater provides hot deionized water. It is a 30-kilowatt heater and is made of passivated, grade 316 stainless steel. The other one is an 18-kilowatt heater and is copper sheathed and provides tap water. Both heaters have relatively high watt densities, approximately 50 watts per square inch, to give rapid heat transfer to the water, and both heaters are relatively small in size, being 6 to 8 inches in diameter and approximately 4 feet in length with storage capacities of 2.96 gallons. The temperature in the three tanks which are used for cleaning and plating are thermostatically controlled within $\pm 3^{\circ}C$. The temperatures of the hot deionized and tap water rinses are thermostatically controlled at the output of the heaters. After the controls are set at the desired levels, the operator turns the panel controls "on" and then manually processes the loaded handling fixtures through the various tanks per the process layout and the instructions shown at each station of the system.

The material handling system is composed of a handling tray, a "Penton" clad plating fixture and 30 handling racks, (Item 4, Figure 5.7-2). After receiving the unplated diodes at the transfer station, they are quickly transferred from the handling tray (Item 5, Figure 5.7-2) to the plating fixture (Item 6, Figure 5.7-2), by means of a transfer fixture (Item 3, Figure 5.7-2). The diodes are then processed through the seven tanks which are shown in sequence from right to left on the sketch in Figure 5.7-3. Mechanical agitation within the baths is provided by an arbor and cam arrangement shown as Item 2 in Figure 5.7-1.

Operating conditions for the tanks and the dryer are tabulated on the next page. After processing a loaded plating fixture through the eight stations, the racks and diodes are returned to the handling tray

OPERATING CONDITIONS OF STATIONS

Process Step No.	Tank No.	Operation	Medium	Quantity	Temp. (C^{o})	Time (Min.)
1	1	Clean	"Enthone", Q510-8	1 lb-3 oz/3.2 gal DI Water	85-90	5
2	4	Rinse	Running Tap Water	1/4 gpm	55-65	5
3	2	Pickle	HCL 1:1 Aqueous Solution	10 lbs/1.6 gal DI Water	room	3/4
4	3	Rinse	Running Tap Water	1/4 gpm	room	2
5	5	Gold Plate	"Atomex"	480 CC/3.2 gal DI Water	90-95	15
6	6	Rinse	Running DI Water	1/4 gpm	room	2
7	7	Rinse	Running DI Water	1/4 gpm	90-95	1
8	-	Dry	Bendix Dryer	as required	140	10

for delivery to the next mechanized operation.

The "Enthone" cleaner and hydrochloric acid should be replaced after 20,000 diodes have been processed; and the "Atomex" should be replaced after 10,000 diodes have been plated. Thus, at full capacity of 2,500 units per hour it will be necessary to replace the two cleaning solutions once each 8-hour shift and the " Atomex" Gold Plating solution two times per 8-hour shift.

III Development of the System

After it was decided that an "Atomex" Gold Plating operation was to be added to the mechanized line as a replacement for Painting in the former Painting and Coding operation, a feasibility study was made in conjunction with Bell Telephone Laboratory personnel to determine if "Enthone" cleaner, an alkaline material, had any deleterious effect on the glass-to-metal seal of the .4 watt diode. The results of these tests showed that the "Enthone" cleaner did not attack the glass seal to an objectionable degree. Therefore, a decision was made to substitute "Enthone" for the more hazardous and costly trichlorethylene and acetone which was originally specified for the Shop process.

To provide a plating fixture that would be light in weight and still be strong enough to withstand the clamping pressures needed to securely hold the 720 racked diodes, grade 6061-T6 aluminum was used for its construction. Since the fixture would be subjected to corrosive fumes at temperatures near 100°C, it was necessary to provide the aluminum with an inert surface. This was accomplished by cladding the fixture with a chemically inert thermoplastic material known by the trade name of "Penton".

The three tanks containing the "Enthone", hydrochloric acid, and

"Atomex" solutions required a means for heating these solutions up to 95°C. It was felt that immersion heaters would take up too much room in the tanks and also be subject to corrosion from continued usage. Therefore, an insulated dead air chamber was provided around the sides and bottom of the tanks, and strip heaters were mounted within these chambers. This has proven to be an efficient installation and has resulted in satisfactory temperature control.

The problem of furnishing a continuous flow of hot water at 1/4 gallon per minute for the rinsing tanks was solved economically by utilizing commercially available electric circulation heaters.

IV Operation Problems

During prove-in, it was shown that solution temperature control within ±3°C could not be achieved unless the thermistor probes and lead wires were hermetically sealed from moisture and fumes, and unless the lead extensions were electrically shielded.

As a safety precaution, it was decided to modify the PVC sink tops by providing two auxiliary drains, one for each sink, for any accidental overflow from the tanks or any excessive spillage during routine operational activities.

Further, it became evident during prove-in that a full hour was required to make the system operative because at least 50 minutes are required to heat the "Enthone" and "Atomex" solutions to the 95°C required for the process. Therefore, since there was excess capacity at the hot deionized water circulator, it was decided to provide hot instead of cold deionized water to the referenced tanks by extending a pipe line from the heater to the tanks. Thus, initial heat up time was significantly reduced.

V Performance

As detailed below, five different lots composed of varying quantities of .4 watt diodes from 10 different codes were processed through the Gold Plating System at a 99.8 percent yield during the mechanized run.

Lot No.	Code	Quantity of Diodes
1	1N675	534
	1N667	126
2	1N664	121
	1N701	60
	1N668	336
3	1N673	354
	1N665	350
4	1N666	416
	1N697	181
5	1N669	273
	1N701	108
	TOTAL	2,859

VI Evaluation

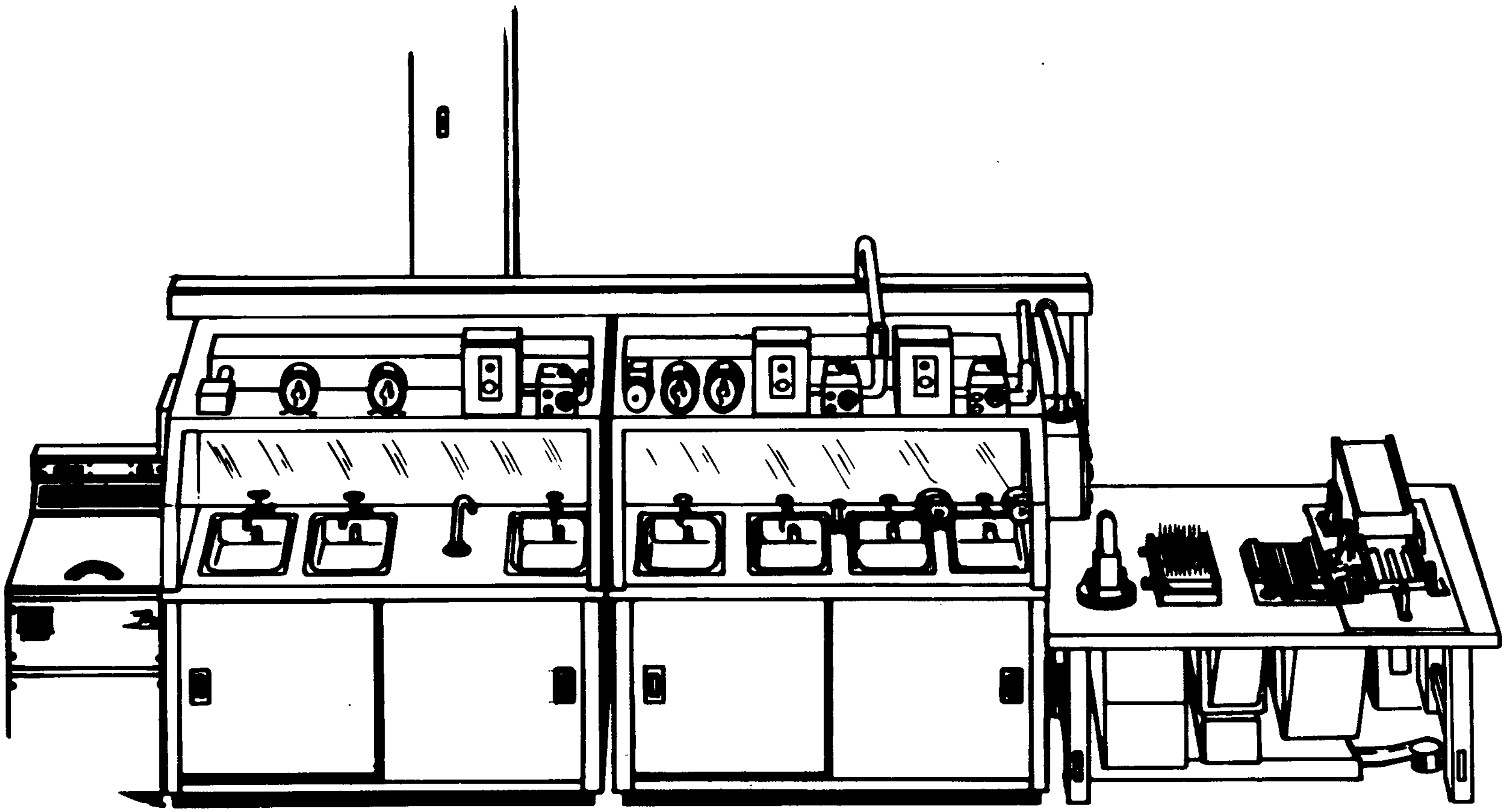
As a result of the development of a Gold Plating System for the Mechanized Diode Production Line, a more economical and less hazardous cleaning method has been substituted for the acetone and trichlorethylene routines originally used in the earlier Shop method. The hourly output has risen from 1,600 to 2,500 with an accompanying improvement in the quality of the gold plate, which is evidenced by a consistent, high luster, light color and a uniform adhering deposition. The better quality gold plate is the result of exposing the diodes to the plating solution in such a way that not more than 25 square inches of surface can be plated in each gallon of "Atomex" solution. It is felt that this represents the optimum condition for successful plating.

VII Conclusion

The Gold Plating System provided for the Mechanized Diode Production Line produces a satisfactory gold plate on .4 watt diodes at a rate of 2,500 diodes per hour. If required, the capacity of this system can be doubled by adding a second plating tank. Space has already been reserved for such a contingency.

HOODED PVC SINKS AND CONTROLS OF GOLD PLATING SYSTEM
FIGURE 5.7-1

LOADING AND DRYING STATIONS OF GOLD PLATING SYSTEM
FIGURE 5.7-2



OVERALL GOLD PLATING SYSTEM
FIGURE 5.7-3

SECTION 5.8

CODING

D. M. Large

CODING

I General

The Coding Machine was built to mechanize the application of code marking to the body of the .4 watt diodes and the racking of coded diodes for oven drying and subsequent Coating. Prior to the use of this machine, the diodes were individually fed into a coding mechanism and loaded into racks manually. Since the feeding and racking are now performed automatically, operator productivity and the consistency of coding are increased. The machine is capable of coding all .4 watt diode codes at the rate of approximately 1500 units per hour with only a type change required to switch from code to code.

II Description of the Machine

The Coding Machine (Figure 5.8-1) consists of two commercial machines integrated by specially designed mechanisms. Its overall dimensions are approximately 6 feet long by 3 feet wide by 6 feet high. The coding mechanism is a Markem Model 146-A Coding Machine. The racking mechanism is a Conforming Matrix Model TL-1 Tray Loader. It was necessary to design and build an automatic feeding mechanism for the coding mechanism since the output of the previous machine is in "Teflon" racks and straight units are imperative for reliable operation of this and succeeding machines. The coding and feeding mechanisms are synchronized and driven by an electric motor. The rack indexing mechanism is air powered with the velocity controlled by a hydraulic check. The coding and racking mechanisms are synchronized by a cam on the coding mechanism, which starts the index, and by a detent on the racking mechanism, which engages a slot in the rack to stop the index.

Empty aluminum racks, which hold 48 diodes, are pushed out of a magazine on the left end of machine and are indexed under the coding mechanism where coded diodes are automatically loaded into the racks. The loaded racks are then re-stacked in a magazine on the right end of the machine. While cycling automatically, the coding mechanism stops when the end of a rack reaches the racking station; it restarts when the next rack is properly positioned under the racking station.

Before starting the machine, the operator places an empty tray and a magazine in the output stations, a magazine loaded with empty racks in the input station, and 30"Teflon"racks containing units to be coded in the dispensing station. Then the operator manually dispenses the diodes into the machine, one rack at a time, by removing a rack from the dispensing station and placing the units into a comb at the loading station. Withdrawing the rack simultaneously loads 24 diodes. The units automatically drop into slots of a conveyor chain which carries them to a short vertical section of track above the code wheel. They are then dropped into slots in the code wheel which indexes them to the coding station. At the coding station the unit is rotated by a rubber segment which rolls the printing onto the circumference of the unit. After coding, the units are indexed to a vertical track and dropped down the track into slots of a handling rack at the racking station. Two decelerating and leveling gates control the diode during the free fall down the vertical track. A riffle at the bottom of the track and a magnet under the racking station prevent bouncing and assure reliable racking. The operator periodically inspects the quality of the coding as the racked units pass an inspection station. The units are then loaded into a magazine which the operator places in an oven for drying.

Proper guards and covers are installed to insure the safety of the operator. A photo-electric sensing cell stops the machine if the coded diodes fail to load into the Conforming Matrix rack at the racking station thus preventing damage to the coded unit.

III Machine Development

The process of coding prior to mechanization was to apply colored bands over the painted body of the .4 watt diode. This type of coding was to be used on the mechanized equipment but a process change to alpha-numeric coding on a gold plated diode body required a different coding concept. The methods of coding which were investigated are pressure-sensitive vinyl labels, spraying thru a mask, and photo-etching. After considerable study, the conventional offset printing technique was chosen. A commercial mechanism, capable of applying this type of code, was purchased to be used in the mechanized process.

No major problems were encountered during design or construction.

IV Operational Problems

During prove-in the problems of accurate alignment of the diodes prior to coding, of transferring the diodes from the coding station into the handling racks, and of timing between coding and racking mechanisms were encountered.

The alignment was improved by adding wire locating devices at the point where the diodes enter the coding wheels and at the coding station. Later the wire locators were replaced by magnetic locators to obtain more reliability and closer alignment.

Transferring the diodes from the coding wheel to the racking station was more troublesome than anticipated. Due to the construction of the Markem coding mechanism, it is necessary to drop the coded diodes approximately 6 inches down a straight vertical track to the handling racks. The erratic falling and the bouncing of the diodes as they hit the handling rack caused the diodes to jam in the vertical track rather than drop into the slots in the rack. To eliminate the erratic falling, two gates were added to the vertical track. Now as a diode falls, it contacts the first gate which levels and decelerates it. The weight of the diode, plus its downward motion, cause the gate to open dropping the diode onto the second gate which functions the same as the first.

To eliminate bouncing at the racking station, a magnet was installed under this station. The addition of the gates improved the control of the diodes during free fall; however, the bouncing was not decreased sufficiently for reliable racking. The vertical track was redesigned to provide better alignment and to provide a small riffle in the lower section immediately above the handling rack. This riffle markedly decelerated the falling diode before striking the aluminum handling rack and thus minimized bouncing.

The third major problem encountered was that of timing the coding and the racking mechanisms. The original concept was for the handling racks to move continuously at a constant speed as they passed under the output track of the coding mechanism; thus by adjusting the air pressure the correct rack speed could be obtained. Since the diodes can not be stacked in the vertical track and since two or more diodes can not be loaded into one slot of the handling rack, it is an absolute necessity that the handling racks move at the correct speed to prevent units from jamming as they enter the slots in the handling rack.

Fluctuating air pressure made it impossible to maintain the correct constant speed. The need for a synchronized intermittant rack feed was now realized. An intermittant drive, actuated by a cam on the drive shaft of the coding mechanism and de-actuated by a detent on the handling rack, was designed and installed on the rack handling mechanism. A photo-electric sensing system was also installed to sense units that fail to enter the handling racks. This system stops the machine when a diode fails to rack, thus preventing damage to the coded diodes.

With the three major problems virtually solved, shop trial began. Minor problems affecting machine operation were encountered and overcome during shop trial, and the need for straight leads has been emphasized in order to prevent jamming of the feeding mechanism and the vertical transfer track. A more reliable photo-electric sensing system was purchased and installed during shop trial to detect jam-ups more consistently.

The shop trial revealed that a means of inspecting the coded diodes was needed; therefore, shop trial was temporarily stopped until an inspection station could be added. It was necessary to disassemble the machine and cut away sections of the side and base plates to provide this station. While the machine was disassembled, several temporary parts, added during prove-in, were removed and replaced with permanent parts. The machine was reassembled and shop trial was completed with no further problems encountered.

During shop trial approximately 15,000 diodes were coded by the machine. The quality of coding was as good as, or better than, that of the manually fed machine; the reason being more consistent loading and location of the diodes.

V Mechanized Run Performance

During the mechanized run, the machine was cycled at its maximum rate of 3600 cycles per hour. It operated satisfactorily. However, only 1500 units per hour were coded while processing the 10 contract codes.

This rate does not represent the actual capability of the machine, for lot sizes were very small, ranging from 60 to 534 units. So, frequent code changes were required.

Approximately 5 minutes were required for one code changeover. This included transferring pre-set chase blocks on the coding mechanism, identifying each magazine of coded units, and transferring the loaded magazine from the machine to the drying oven. In addition, an empty magazine was placed over the track unload station and a full magazine, over track load station. The ease of the load and unload operations plus the nearness of the drying oven contributed to the short downtime during the code changeovers.

These changeovers average less than 15 minutes per hour. An excessively long dwell period of the coding mechanism decreased the output of the machine more than the frequent code changeovers. During this dwell period a full rack is placed into the output magazine. This dwell produced one favorable condition. It gave the operator an opportunity to inspect the code markings more carefully.

VI Evaluation and Conclusion

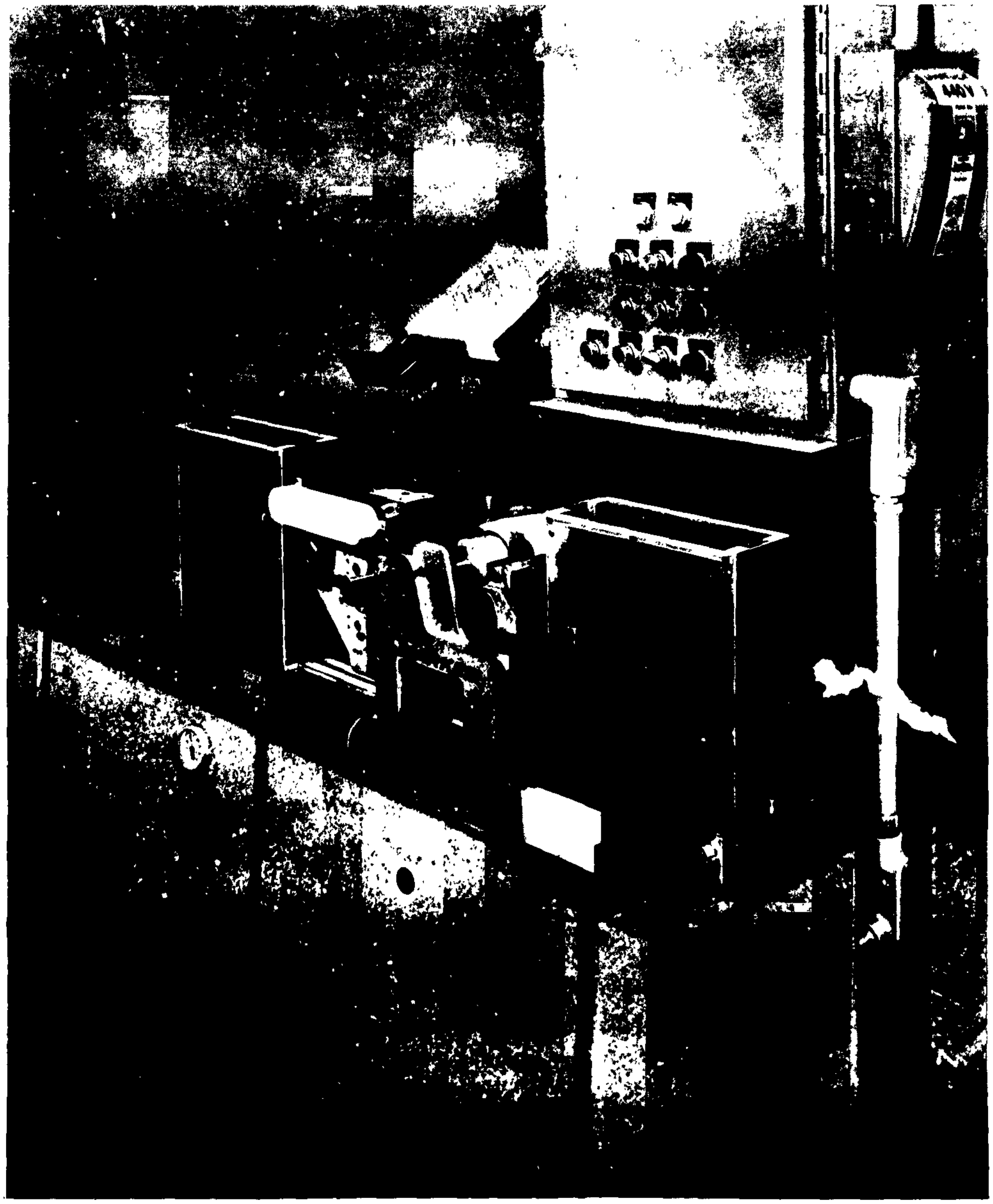
A mixture of the 10 contract codes was submitted to final inspection. All units passed the Group A, Subgroup 2 Inspection of Mil Spec. 19500/150. The code markings applied by the Coding Machine were superior to those produced in the manual operation. This superiority results because the diode feeding mechanism is synchronized with the coding mechanism; every time the code segment is inked, a diode is coded. On the manual operation, the code segment may be inked one or more times between successive codings, since feeding of the diodes is dependent on the discretion and dexterity of the operator.

The mechanical quality of the machine coded diodes is also superior to those coded manually. The possibility of lead misalignment is minimized in the mechanized operation since the operator is not required to handle each diode individually as in the manual operation.

Two significant conclusions can be drawn from the mechanized run performance:

1. Code changeover is accomplished efficiently.
2. The output can be increased by decreasing the dwell period of the coding mechanism.

Phase 2 will be devoted to reducing the time required to automatically transfer racks into and out of the magazines. In this way the dwell of the coding mechanism will be shortened. Then, a significant increase in the output will be realized. An output of 2,000 to 2,500 units per hour should be attainable since the maximum speed of the machine is 3600 cycles per hour.



DIODE CODING MACHINE
FIGURE 5.8-1

SECTION 5.9

COATING

D. M. Large

COATING

I General

The mechanized Coating operation applies a clear silicone varnish to the body of .4 watt diodes. The Coating Machine receives racks, loaded with diodes, in a magazine after code markings are dried. The racks are automatically unloaded from the magazine, processed through the coating station and loaded into another magazine. The units are then placed into an oven for drying.

The manual process diagrammed in Figure 5.9-2 involves manual loading, spraying, and unloading into bulk prior to testing. Manual handling of these units, especially in bulk form, contributes to bending of the lead. Since straight leads are imperative in the mechanized operations that follow coating, a high speed machine was purchased to automatically perform the Coating operation. This machine makes the Coating operation compatible with the output of the previous machine and the input of the following machine. The machine is extremely flexible in that it can coat a wide range of axial leaded components with any sprayable coating with a minimum of setup required.

II Description of the Machine

The Coating Machine (Figure 5.9-1) consists of a commercial Conforming Matrix Model HD-3 Spray Coater (1), a Conforming Matrix Model ML-1 Magazine Loader (2), Conforming Matrix magazines and racks (3), and a special design magazine unloader (4). The overall dimensions of the machine are approximately 1-1/2 feet deep by 5 feet high by 7 feet long. The services required are 110-volt, 60-cycle power (explosion proof); an

80-pounds-per-square-inch air supply, and an 800-cubic-feet-per-minute exhaust system. The machine operates as follows:

A magazine loaded with racks containing diodes to be coated is placed in the unloading station. At this station the racks are unloaded from the magazine, one at a time, and placed into the track by a mechanism which is synchronized with a continuous feed chain. This chain has lugs which engages the rear of a rack immediately after it is placed into the track, and cause the rack to be pushed along the track, a distance equal to the length of the rack. From this point on, the rack is moved by the motion imparted to it by each succeeding rack. When a rack carrying the diodes approaches the spraying area, the diodes pass under two masking films which are slowly fed from separate reels. After masking the racks and diode leads to prevent them from being sprayed, the units are fed into a spinning station. At this point a switch senses the presence of a rack in the spray station and automatically turns on two sensitive pressure regulated spray guns which spray the units while being spun (Figure 5.9-3). When the rack leaves the station, the spray is automatically turned off to avoid spraying the ends of the racks. Then the racks are pushed into the loading station where they are automatically loaded into a magazine. The operator duties are simple and confined mostly to material handling and machine surveillance.

III Machine Development

During the feasibility phase integration of the Coding and the Coating operations on the same machine was considered. However, since a quick drying ink could not be obtained for coding, the length of time for drying after coding limited the machine capacity to such an extent that one machine was not practical. The decision to separate the Coding, Drying and Coating operations made it feasible to purchase commercial equipment to perform these operations. An investigation was made which led to the purchase of a Markem coding machine and Conforming Matrix racking machine which were integrated and used to apply the code markings; a batch type oven for drying after coding and coating; and a Conforming Matrix spray machine for applying the protective coating. The purchase of a commercial machine for coating minimized the prove-in effort required although two minor problems became apparent at this time. The first problem involved safety requirements. Several solenoid valves in the machine were not explosion proof and had to be replaced. Second, a method of disposing of the used masking film after the spraying operation was desirable. A film chopping device was designed and installed. During prove-in of this film disposal unit, partially dried varnish on the film caused sticking in the guides which directed the film to a rotary chopping blade. In view of the problem, prove-in of the film disposal unit was discontinued. The film is now disposed of by feeding it directly into two containers placed in front and back of the machine.

IV Operational Problems

The machine functioned well during the shop trial until the bottom of the handling racks began to wear. This wear was caused by the stacking pressure of the racks in the magazine of the loading station bearing on the bottom rack as it was withdrawn from the magazine. In addition to rack wear, this condition overloaded the clutch and the Zeromax drive and resulted in torn belts and irregular rack feeding. As an interim measure, so shop trial could continue, a more powerful Zeromax drive was installed; loading friction was also reduced by changing the section of track in the magazine from steel to "Teflon" and by loading the magazines to half their capacity. After designing and installing a track loading mechanism which removed the stacking pressure from the rack being loaded, the loading problems were overcome. This mechanism releases one rack from the magazine for track loading without having the other racks in the magazine bear on it.

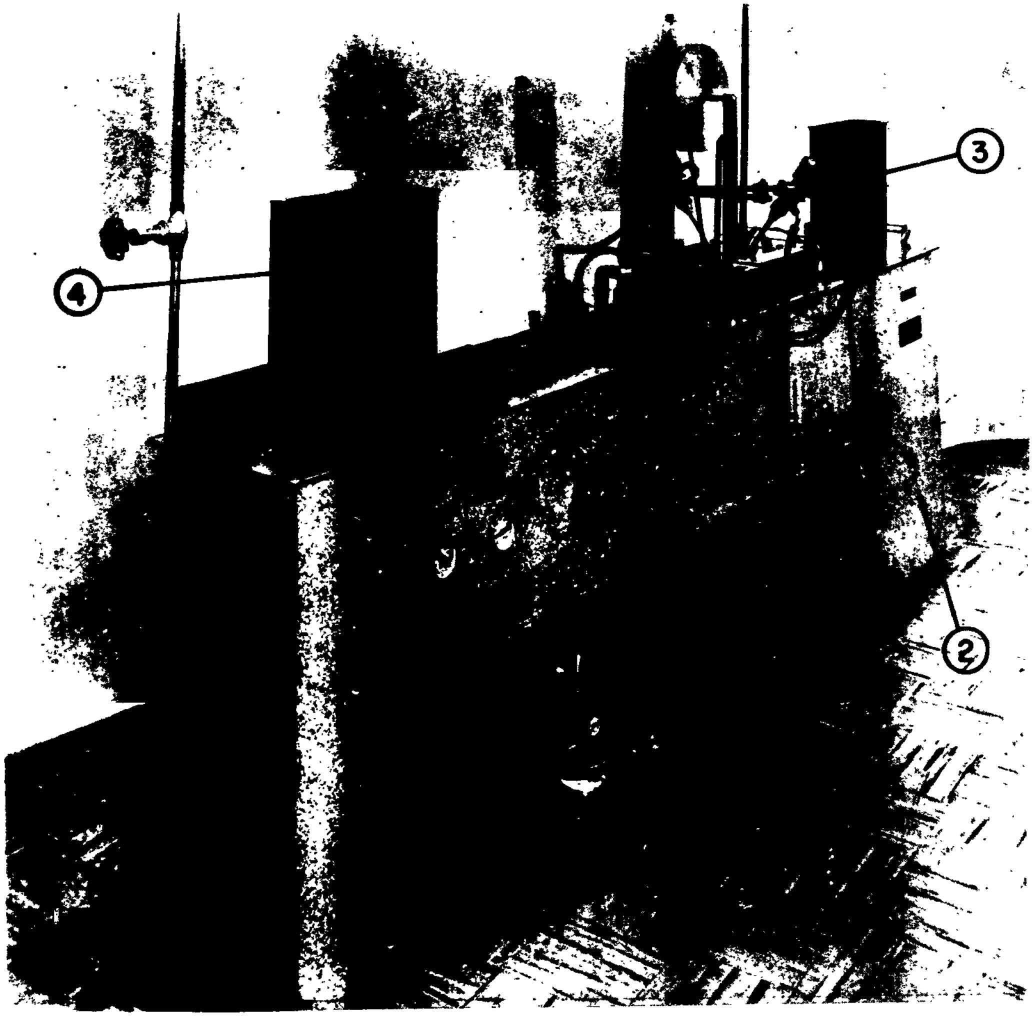
V Evaluation

During shop trial 250,000 diodes were successfully coated which passed environmental tests, and during the mechanized run 9 codes totaling 2500 units were varnished in one hour with a 100 percent machine yield. A maximum output of only 8000 per hour has been realized, although the gross hourly output of the machine is 18,000 units. This lower output is attributed to the fact that the machine has not been operated continuously for longer periods of time.

The quality of the Coating done by this machine has been good and only minor maintenance and setup have been required. The minor problems which occurred are in the material handling and masking equipment. Phase 2 work will include an investigation to determine whether improvements in these areas are feasible.

VI Conclusion

This machine has met all its original objectives and is quite flexible in that it can coat a wide range of axial leaded components with any sprayable protective coating. Although this machine is operating satisfactorily, improvements can be made in material handling and masking. Therefore, these areas will be studied during Phase 2 and Phase 2 work will include a study of these areas minor improvements that are feasible will be made.



COATING MACHINE
FIGURE 5.9-1

MANUAL COATING PROCESS

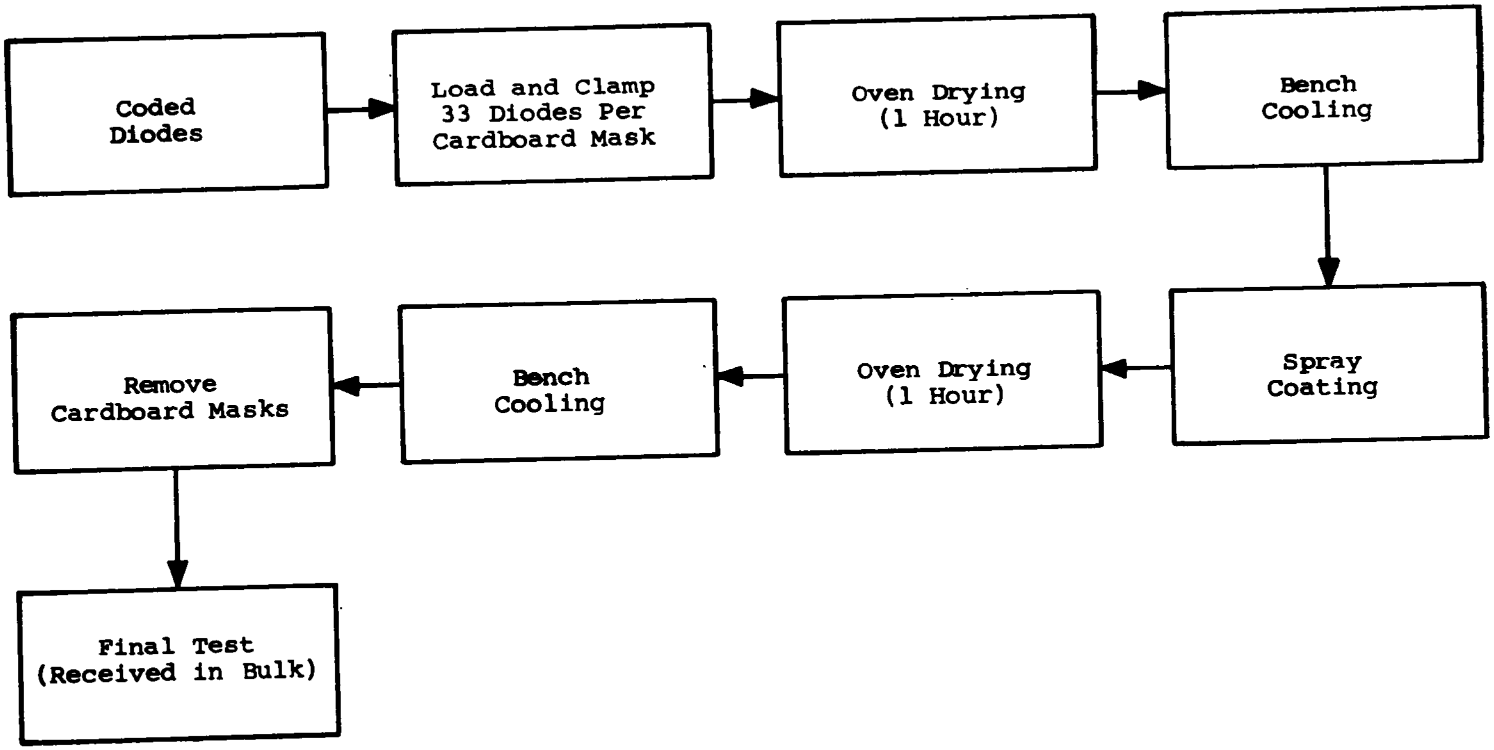


FIGURE 5.9-2

COATING STATION OF THE COATING MACHINE

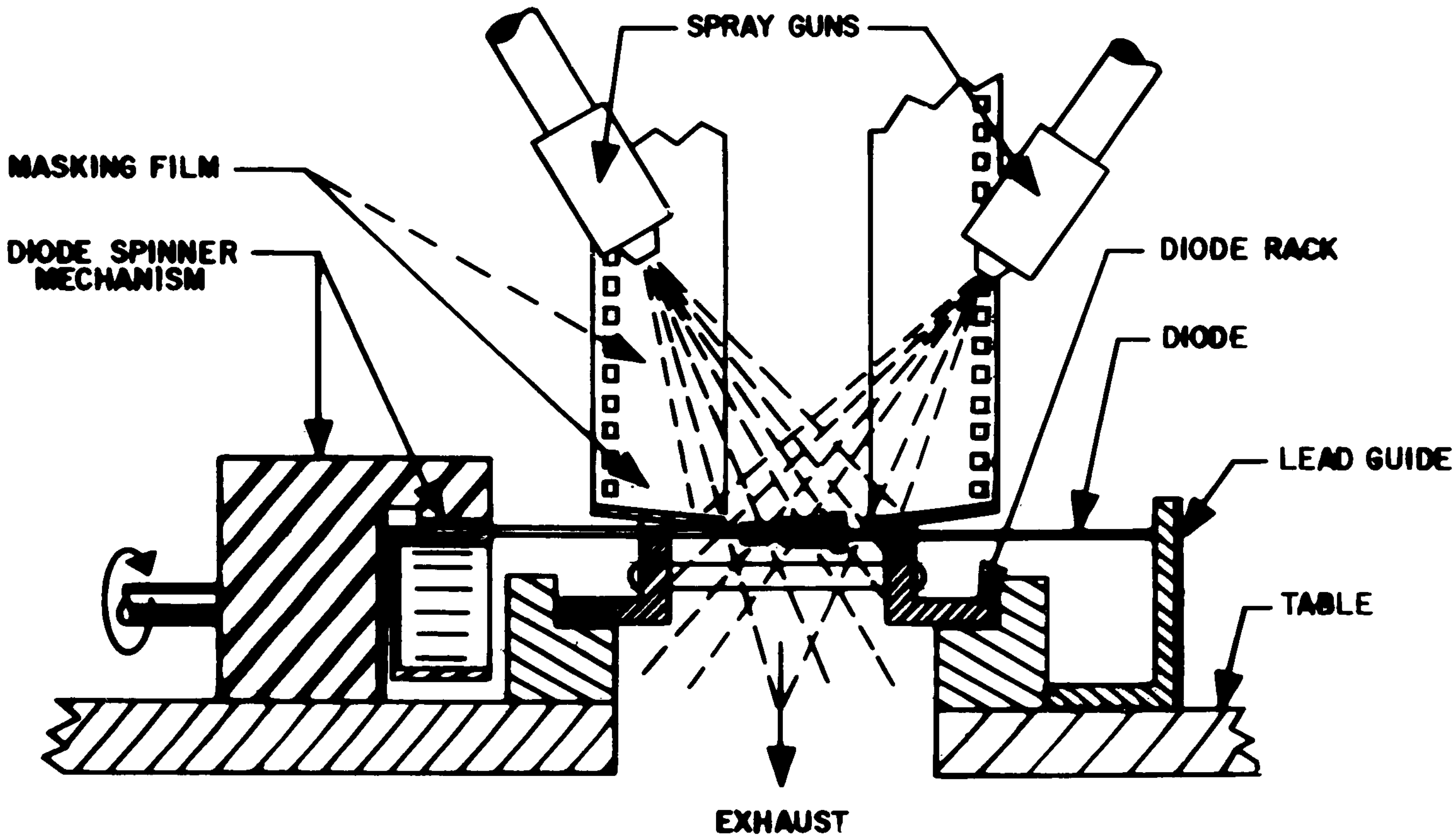


FIGURE 5.9-3

SECTION 5.10

FINAL ELECTRICAL TESTING

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FINAL ELECTRICAL TESTING

I General

The Final Electrical Testing Machine was designed to test .4 watt diodes automatically for all parameters on a go no-go basis. Diodes are fed into the machine in racks and magazines as received from the prior Coating operation. The diodes are then removed from the racks, inserted into test clamps on a conveyor, successively indexed to the various test stations, and segregated according to test results. The diodes which are accepted on all parameters are placed into a bin or into output racks, depending on subsequent process requirements.

The testing machine operates automatically at 1800 tested diodes per hour and replaces manual testing for each parameter using up to three separate test sets. In addition, a more uniform quality level is achieved by the elimination of operator errors.

The machine is designed to test six parameters;

1. Breakdown voltage (BV)
2. Saturation current (I_S)
3. Slope resistance (bz)
4. Reverse recovery time (t_{rr})
5. Capacitance (C)
6. Forward voltage (V_F)

These tests are normally performed in the above order. The sequence can be changed, however, by a simple rearrangement of connectors inside the test cabinet. Although not all of these parameters are tested on all diode codes, the programming is provided by means of a single code selector switch which selects the various tests with their biases and limits required for the specific code under test. The program has been designed to test the following .4 watt diode codes: 1N664 through 1N669, 1N673, 1N675, 1N697, and 1N701. Bias conditions and test limits provided for these codes are shown on Figure 5.10-6.

Inprovement in the versatility of the machine is planned by a modification which will provide a manual loading position. This will also provide an inspection point at which the operator can check for improperly loaded racks during the automatic rack loading mode of operation.

II Description of the Machine

The machine (Figure 5.10-1) consists of two main sections: the mechanical handling system and the electronic testing system. Both are mechanically and electrically connected and interlocked. All controls for operating the machine are located on the control panel shown in Figure 5.10-2 except the main power switch and the main air valve. The switches for optional bypassing of selected test parameters are located on the front of the individual modules. All moving parts are covered or shielded. Routine maintenance requires only lubricating, replacement of worn components, and cleaning as required. The machine occupies a floor space of 4 by 9 feet and is 6-1/2 feet high; the weight is approximately 4000 pounds.

The mechanical part consists essentially of two sections: the rack handling systems and the diode handling system. The input rack handling system takes the loaded racks out of the magazine, and moves them into the indexing track as shown in Figure 5.10-3. The diodes are transferred into the test clamps as the racks pass the loading plunger. The unloaded racks are automatically removed from the indexing track and stored in a magazine for empty racks.

The diode handling system consists of a loading plunger and a horizontal indexing conveyor. The loading plunger takes the diodes out of the rack and inserts them into the test clamps. The clamps are mounted by means of carriers to the horizontal indexing conveyor. This conveyor carries the diodes through the testing stations. Rejected diodes are removed as the conveyor leaves the station of the test failed. This is accomplished by opening the test clamps and dropping the diodes into reject bins.

Accepted diodes are unloaded at the end of the conveyor by setting a selector switch for bin unloading or racking. In the bin unloading mode, accepted diodes are removed in the same manner as the rejects. In the racking mode, the diodes are guided through a chute which leads them into a split funnel at the output rack loading station. The split funnel guides the diodes into the output racks when it is closed. In the funnel open position, ' . racked diode is indexed away from rack loading chute.

The output rack loading station (Figure 5.10-4) transfers empty output racks from a storage track to the loading point. From there, fully loaded output racks are indexed into another storage track. The racks are only indexed if a diode passes the last test station indicating it is accepted on all parameters. This arrangement assures fully loaded output racks.

The electrical tests are made at nine individual stations to which the diodes are carried by means of the carrier mounted test clamps. All tests are made simultaneously, i.e. contact is made to a carrier containing a diode at each testing station. The contact to the diode itself is only made once, at insertion of the diode into the test clamps. The connections to the test modules are made through contact buttons on top of the test clamps, slide contact springs and shielded test leads. The presently used test sequence is:

1. Test for proper 4-point contact
2. BV_1 - reverse breakdown voltage at low currents
3. BV_2 - minimum reverse breakdown voltage at higher currents
4. BV_3 - maximum reverse breakdown at the same currents as BV_2
5. I_S - reverse saturation current at specific bias
6. bz - slope resistance
7. t_{rr} - reverse recovery time(for switching diodes only)
8. C - capacitance (for switching diodes only)
9. V_F - forward voltage drop at 400 MA current

The basic function of these modules is as follows:

1. BV_1 Module - This module checks the minimum breakdown voltage of voltage regulator diodes at low currents. The bias currents used are .005, .010 and 1.0 milliamperes depending upon the code being tested. The constant current supplies used have a voltage compliance to 500 volts.
2. BV_2 Module - This module checks the minimum breakdown voltage of regulator diodes at high currents and rectifier diodes at low currents. Two constant current supplies are utilized in this module. A high current transistorized constant current supply with an output to 20 milliamperes and a voltage compliance to 32 volts is used for the lower voltage codes. A vacuum tube constant current supply with outputs from .010 to 1.0 milliamperes and a voltage compliance to 1,200 volts is used for the higher breakdown units.

3. BV_3 Module - This module is very similar in operation to the BV_2 module except that a check is made of the maximum breakdown voltage rather than the minimum breakdown voltage. The output capabilities of the two constant current supplies in this module are the same as the BV_2 module.
4. I_R Module - This module checks the saturation current limit of all diodes. A programmable constant voltage supply is used to set up the appropriate bias voltages. A voltage sensing circuit is utilized in this module to determine that a bias voltage is being applied to a unit during the test. The reason for this precaution is that if a failure occurred in the bias voltage supply of this module, all units would pass as good product.
5. bz Module - This module checks for a maximum slope impedance of regulator diodes in the breakdown region. A 1,000 cycle constant current signal whose amplitude is 10 percent of the D-C bias current is applied to the unit under test. The resulting A-C voltage across the unit is sensed for a maximum value. The D-C bias conditions in this test are the same as those used in the BV_2 and BV_3 modules for the regulator diodes and similar constant current supplies are utilized.
6. C Module - This module checks the capacitance of the 1N697 switching diode. A 100-kilocycle signal is applied to the unit under test and a readout resistor in series with the unit under test. The A-C signal voltage across the readout resistor will be proportional to the capacitance of the unit under test. The readout voltage is

sensed for a maximum value.

7. t_{rr} Module - This module checks for the maximum reverse recovery time of the 1N697 switching diode. A charged transmission line whose length corresponds to the specification limit of the diode under test is used in conjunction with a mercury relay as a pulse generator. Pulses equal in width to the specified limit are then applied to the unit under test. If the unit recovers during the length of time the pulse is being applied to it, the voltage across the diode will attain the turn-off voltage of the charged line. The 90 percent point of the voltage across the unit is sensed by a peak detecting circuit to determine whether the unit has recovered within the specified limit.

8. V_F Module - This module checks the resulting voltage drop across the diode under test when a D-C constant current is applied to the diode in the forward direction. A 4-point measurement is made in this test to insure that voltage drops due to contact resistance and long lead lengths are not measured as part of the forward drop of the unit under test. The bias current to the unit is supplied by one set of contacts and the voltage of the diode under test is sensed on another independent set of contacts. These contacts are located at the diode under test. The resultant voltage drop of the diode is sensed for a maximum value.

Operator duties on the machine are:

(a) Changing magazines

(b) Observing proper mechanical operation

(c) Removing tested product

III General Development

The basic requirements for the feasibility study and development of the Final Electrical Testing Machine for .4 watt diodes were as follows:

1. Minimum hourly output of 1,200
2. Modular design of the test circuitry
3. Each module contains its own reference standard
4. Self-checking of test conditions and test limits at predetermined intervals
5. Counters
6. Bypass possibility for each parameter
7. Master programming and machine control panel
8. Stopping of machine in case of any electrical malfunction

During the feasibility phase several commercial test sets were investigated but none were adaptable to the above requirements and the accuracy required by the various diode specifications. Another factor to be considered was the need for a diode handling system that was compatible with the remainder of the mechanized production line. Excessive changes to commercial test sets would have been necessary to be satisfactory for our requirements. For these reasons the machine was built in our shop at Laureldale.

Mechanical Development

During the development of the machine it was decided that the diodes would be delivered to the machine in magazines containing up to 40 racks, each rack being loaded with a maximum of 48 diodes. The racks had to be passed through the loading station of the machine and stored in an identical magazine as used on the input of the full magazines.

The diodes had to be removed from the rack and placed into test carriers for testing at up to 9 testing stations. In order to avoid memory circuits an arrangement was selected by which the diodes would be removed from the test clamp immediately after the failure at any test station. Since each station tests only one parameter, segregation at each station on a go no-go basis was included to provide preliminary data of the failure distribution of the lot being tested. To prevent out of specification diodes from being carried to the accept bin or racks, in case of a failure in the circuitry, the reject mechanisms was selected which requires an accept signal to let the diode pass to the next stations. Absence of this accept signal results in rejection of the diode during the next carrier index. By placing the reject operation in the indexing part of the machine cycle, it was possible to increase the output of the machine from 1,200 to 1,800 tested diodes per hour. A horizontal conveyor-type indexing mechanism was selected to permit simultaneous testing of all stations since this was essential to obtain a high volume output.

Electronic Development

The largest part of the electronic development on the test set revolved around the Capacitance and Reverse Recovery Time tests. The concept developed for making the Capacitance test was to make a reactive-type measurement on the unit under test. In this arrangement a 100-kilocycle constant voltage signal is applied to the unit under test with a readout resistor inserted in series with the unit. The current through the readout resistor with the resulting voltage across the resistor is a direct measurement of the capacitance of the unit under test. This voltage is applied to an A-C amplifier with a voltage doubler on the output of the amplifier. The resulting voltage on the output of the voltage doubler is detected by a transistorized voltage comparator to make the necessary go no-go decision. An attempt had been made to use a transistorized differential amplifier-detector system instead of the straight A-C amplifier-detector system. In this scheme a signal proportional to a reference capacitance would be fed into one side of the differential amplifier. The signal, representative of the unknown capacitance, would be fed into the other differential input of the amplifier. With proper phasing of the inputs, an output indication could be obtained indicating whether the unknown capacitance would be higher or lower than the reference capacitance. This approach was abandoned after it was determined that phasing problems existed within the amplifier.

The reverse recovery test scheme developed is that of using charged coaxial cables to generate a pulse whose width is equal to the reverse recovery time specification of the unit under test. A peak catching circuit composed of a diode-capacitor combination is inserted across the unit under test to sense the peak voltage attained by the unit. If the unit completely recovers during the time the reverse pulse is applied to it, the voltage across the unit will rise to half the charging voltage of the charged cable. A transistorized multivibrator is used to operate a mercury wetted contact relay to charge and discharge the pulse generating cables. The multivibrator operates at 150 cycles. An output pulse rate of 300 cycles is obtained by connecting equal lengths of cable (cut to the specification limit of the diode under test) to the normally open and to the normally closed side of the pulse relay. This arrangement gives a pulse each time the operating arm of the relay contacts one of the charged lines resulting in a doubling of the output pulses of the pulse relay.

Mechanical Design

The mechanical design followed the basic concept outlined in the machine development section of this report. Air cylinders with flow controls were used wherever a smooth motion with controllable speed was desirable. Interlocking of motions was used to assure proper cycling and to avoid interference of moving parts. Limit switches and a multiple-cam timer accomplished this interlocking. Ease of operation and minimum maintenance were emphasized throughout the design.

Electronic Design

Conventional semiconductor testing techniques were utilized in the design of the electrical portion of the test set. The breakdown voltage tests were made using constant current supplies dependent on the characteristics of pentode tubes. These supplies had a voltage compliance up to 1000 volts where necessary. Care was exercised in bringing the constant current supplied into the test circuitry from a shorted output condition to insure that no damage to the unit under test would result. In all tests where an open unit or a poorly contacted unit would result in a go decision, continuity detection circuitry was used. Failure of a unit to pass the continuity check would result in rejection of the unit at that test position.

In the forward voltage test a 4-contact connection is made to the unit under test. The bias current is brought to the unit through one set of contacts while the voltage drop of the unit is sensed on the other set of contacts. This method eliminates any potential drops due to contact resistance or lead lengths in the current carrying wiring.

A transistorized chopper-amplifier detector circuit is used in most tests to sense and compare the voltage or current of the unit under test. Using this circuit, go no-go discrimination of the order of .25

percent is achieved.

An automatic self-check feature is incorporated in the test set portion of the machine. A 24-hour timer can be adjusted for any self-check interval between 15 minutes and 24 hours. At the end of the timing period all test modules are automatically checked for proper operation of critical circuitry. If any test module is outside design specification limits, the mechanical drive is stopped and a maintenance light will indicate which module is not operating properly.

Bias conditions and test limits are programmed automatically from a single code selector switch mounted on the main control panel. All relays that require repeated operations are of the mercury wetted contact type to insure high reliability in operation.

Construction

During mechanical and electrical construction no major difficulties were encountered. The output rack handling station, which is also used on the Gold Bonding Machine, proved unsatisfactory and was, therefore, redesigned. The redesigned version was incorporated on the Final Electrical Testing Machine since, at this time, construction on the original mechanism had just started. The electronic test modules were completely built and checked out before assembling into the test cabinets.

IV Operational Problems

Mechanical Prove-In

During the prove-in the following changes were required to assure proper operation:

a. A rack lowering mechanism was added to lower the loaded racks from a magazine to the loading platform. The weight of the stacked racks caused too much wear on the racks since too much force was required to peel off the bottom rack. This lowering mechanism, which is air cylinder operated, lowers the whole stack of racks inside the magazines and then lifts all the racks except the one on the bottom approximately 3/16 inch for clearance. Thus ease of peel off and reduced wear was obtained.

b. The step indexing, originally performed by a solenoid operated ratchet, had to be changed to air cylinder operation because the fast pull of the solenoid caused diodes to jump out of the slots of the handling racks.

c. A positioning pin was added on the test clamp loading position to prevent bending of leads due to varying position of the carriers due to tolerances and stiffness of the chain driven conveyor.

d. The test clamps were redesigned and new ones were made since it was discovered that the original spring contacts wore too rapidly and a reliable contact was jeopardized. Also, the clamp opening time was increased to allow the diode more time to drop out of the clamps at the reject stations.

e. For flexibility in the use of the Testing Machine, a selector switch was added so that the mode of unloading of accepted diodes can be chosen, either into a bin or into output racks. Originally only rack unloading was anticipated.

Electrical Prove-In

In the original design of the BV_1 Module, a voltage divider network and cathode follower circuit fed the voltage from the unit under test to a D-C voltage comparator. The cathode follower and voltage comparator showed signs of drift over short periods of time. This circuitry was replaced by a chopper-amplifier detector system and the problems of short term drift were overcome.

The self-check circuitry was changed in the breakdown-voltage modules. The original intent was to pass the bias current of the unit under test through a precision resistor. The resulting voltage would then be detected for a go no-go decision to check the voltage comparator's operation. This checking arrangement was eliminated since the requirements for stability of the bias currents were many times more stringent for self-checking than for normal testing. A self-check reference voltage from a temperature compensated reference diode is now being used for the self-check circuit. The presence of a bias current is now detected at the time of test as discussed under the Electronic Design section. The noise generated by some of the diode codes under test became a problem in the Slope Impedance test. This was due to the low level 1000-cycle signal being used for the test on some codes. The signal level was increased to 10 percent of the D-C bias applied with some consequent change of readout resistors necessary.

One problem encountered in the testing of breakdown voltages of diodes which was not a fault of the equipment but rather a fault of the units being tested and the time interval of the test. Some units would exhibit a rapid degradation in their breakdown voltages approximately 100 to 350 milliseconds after bias is applied. The unit would breakdown at an initial voltage and instead of maintaining that voltage under constant bias would degrade to a lower voltage which in some cases was 200 volts below the initial breakdown. It had been determined originally to make the breakdown voltage test 250 milliseconds after bias is applied. The decision time was moved out to 400 milliseconds where these erratic units could be rejected if the final breakdown voltage stabilized below the specified limit. This problem was evident primarily on the higher voltage codes.

The first test station on the machine was used to determine whether the diode in the carrier had contact with all four contacts on the carrier. If any one contact was not made to the diode in the carrier the unit was rejected at that position. These rejected units would be reloaded into the machine to be tested.

Shop Trial and Maintenance

Shop trial and operator training were carried out without complications since operator duties are more or less confined to observation of the machine and loading as well as unloading of magazines and bins. Setup for the various diode codes is achieved by merely turning the code selector switch to the code to be tested.

Maintenance requirements are of a general nature consisting of routine cleaning and lubricating. It is important that only clean and straight racks are used for this machine to avoid sticking of racks in the handling mechanisms and to assure proper indexing at the test clamp loading station. During the shop trial period it proved difficult to keep the new output rack handling mechanism working properly, so the operating solenoids and dampers were replaced by an air cylinder with flow controls.

V Performance

To obtain correlation data on the performance of the Final Electrical Testing Machine, various lots of .4 watt diodes were tested. The results of the machine were verified on manual test sets by retesting previously marked diodes. The following procedure was followed to prove the accuracy and repeatability of the Final Electrical Testing Machine:

1. Individual test modules were checked out and calibrated using precision resistors. The lower and upper limits were adjusted for the required points of decision.
2. The same procedure was repeated after the machine was completed by placing the resistors across the test contacts.
3. Tests on all limit points for each code were repeated about 50 times to verify the repeatability of the test circuitry.
4. Selected diodes with test values as close to the limits of the specification as possible were used and the decision of the test set observed. The results were rechecked and verified on laboratory test equipment.
5. The same diodes were identified and, in random order, automatically fed into the test set. The resulting segregation into the various categories was observed and the accuracy of the decision confirmed. Figure 5.10-5 tabulates machine test decisions for a group of 1N673 diodes which was selected at random and retested in five consecutive runs. The machine failed to make the same decision 3 times out of 120.

   The explanation for the three inconsistent decisions of this test run is:

Diode No. 88   (Run No. 1)

BV = 457 Volt (sharp breakdown)

I_S = 0.21 µA

V_F = 0.91 Volt

Since this acceptable diode was rejected on forward voltage (V_F) only on the first run and accepted on all the following runs, it is assumed that a dirt spot on one of the leads created a high resistance contact at the first insertion into the test clamp but was cleaned up before being tested the next time.

Diode No. 141   (Run Nos. 2 and 4)

BV = 425 Volt (soft breakdown)

I_S = 2.56 µA

V_F = 0.91 Volt

The high saturation current (I_S), the soft breakdown and the relative closeness of the breakdown voltage (BV) to the 420-volt limit creates a marginal case on breakdown voltage for the test set. As a result, the diode could be rejected at BV and thus not reach the I_S testing station.

Accuracy of the various test modules varies from one diode type to the next. By referring to points of decision in Figure 5.10-6, the accuracy of a given module on any contract code can be determined. For example on the 1N666 code, which has a nominal breakdown voltage of 15 volts, the points of decision on BV_1 are as follows:

1. All diodes with $BV_1 < 14.09$ volts are rejected.
2. All diodes with $BV_1 > 14.10$ volts are accepted.
3. Diodes with $14.09 \leq BV_1 < 14.10$ volts are rejected or accepted.

Item 3, above, indicates that the BV_1 test module can not repeatedly discriminate in the range of 14.09 and 14.10 volts. This is a maximum error of 0.01 volt or 0.1 percent. Hence, this test module may reject diodes which are within 0.1 percent of the specified test limit.

In like manner, on the reverse current test of the 1N666, the specified maximum reverse current is 0.9 microamperes.

1. All diodes with $I_S > 0.895$ µA are rejected.
2. All diodes with $I_S < 0.890$ µA are accepted.
3. Diodes with $0.890 < I_S < 0.895$ µA are rejected or accepted.

These points of decision indicate that the test set can not repeatedly discriminate in the range of 0.890 and 0,895 microamperes, a 0.5 percent error or a range of 0.005 microampere.

6. The result of pilot run lots, and subsequent production lots, were checked 100 percent at first and then on a sampling basis to recheck the performance. These spot checks will be continued for several months until the long term reliability and repeatability of the equipment is verified. Approximately 40,000 diodes were tested on the machine and the results verified as indicated.

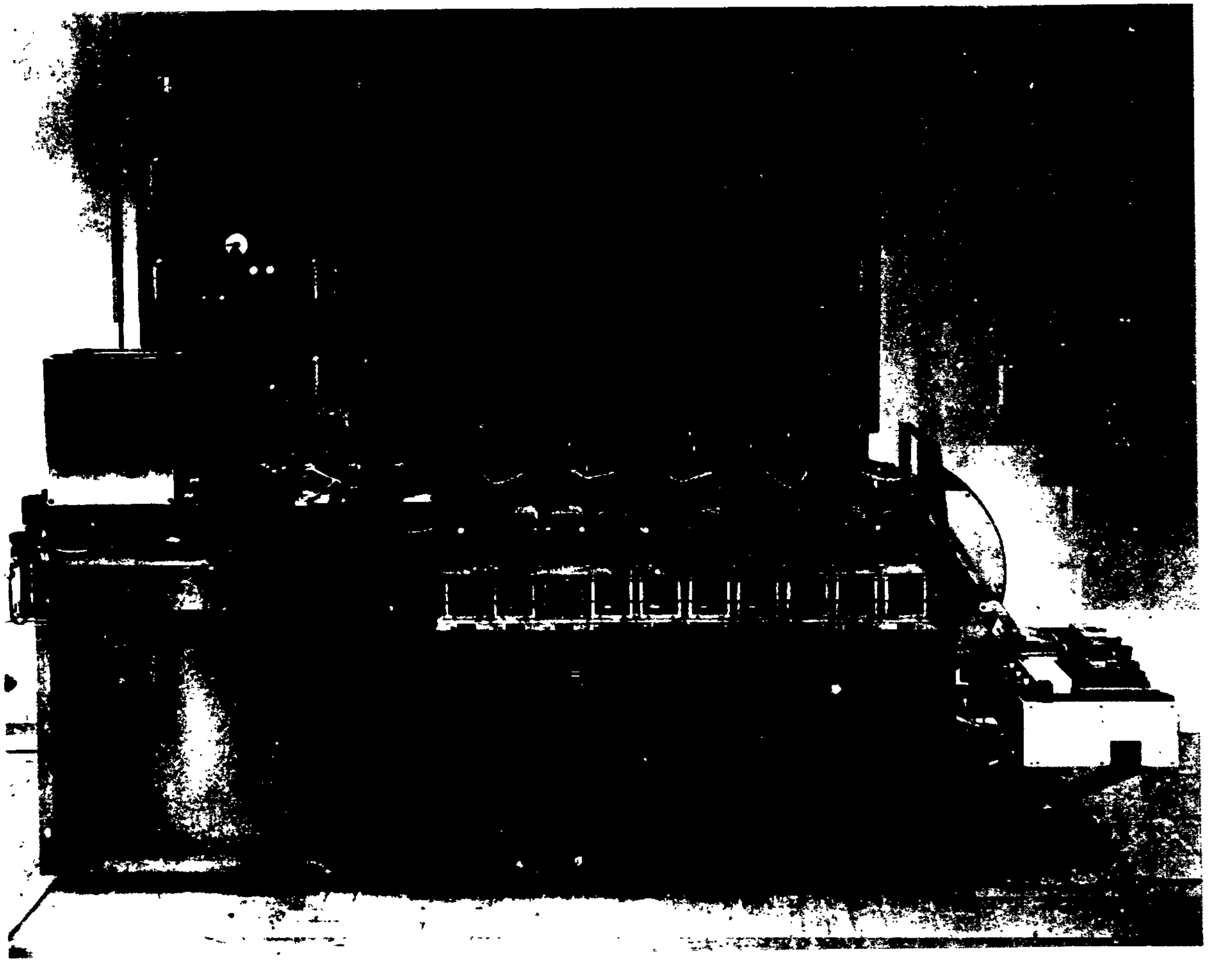
VI Evaluation

The Final Electrical Testing Machine for .4 watt diodes performs reliably within its tolerance range. The requirements for proper operation are mainly straight, clean, and uniform loading racks and straightened diode leads. Operator attention is required to correct minor difficulties mostly due to bent leads or damaged racks. One repeated cause of trouble is the misalignment of diodes in the loading rack which causes a jam up on the loading plunger. This condition should be improved during Phase 2 by moving the magazines to the left in order to give the operator a means of aligning the diodes in the loading racks before they enter the indexing track. Removal of damaged racks and loading of single racks without the use of magazines could also be conveniently accomplished by this change.

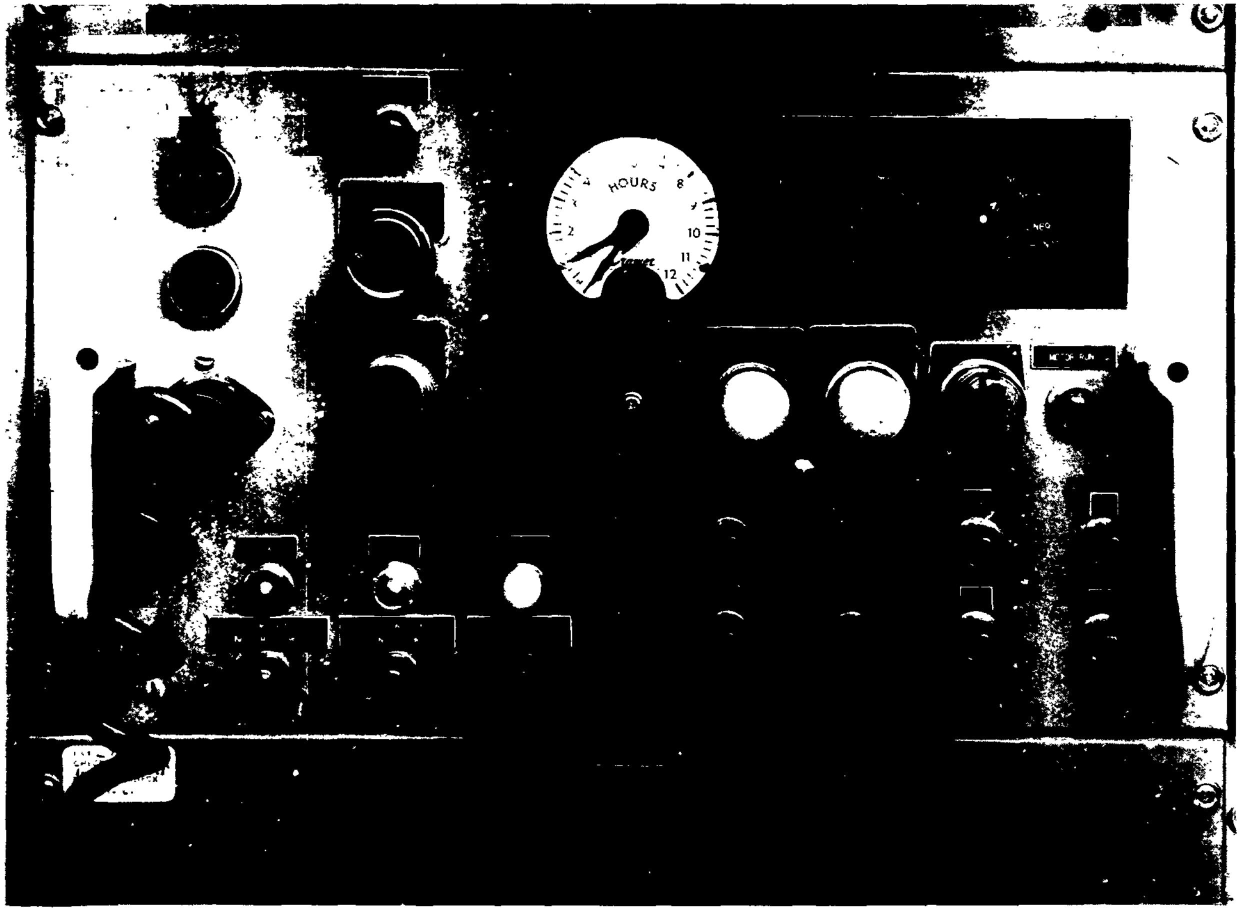
The output rate of 1,800 diodes tested compares favorably with the approximate 350-units-per-hour output averaged on the manual test sets.

VII Conclusion

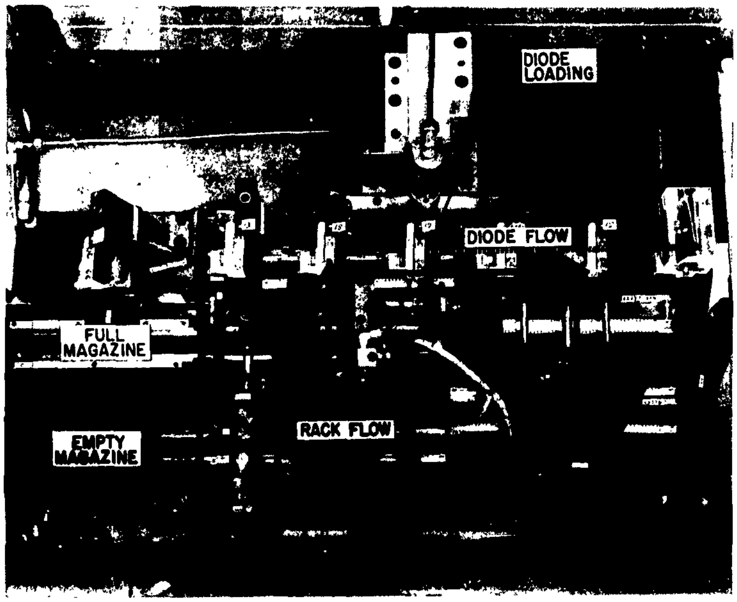
The objective of designing and constructing a testing machine for .4 watt diodes, capable of testing reliably at high production rate, was accomplished. Changes during Phase 2 of this Contract will increase the versatility and reduce potential downtime due to wear.



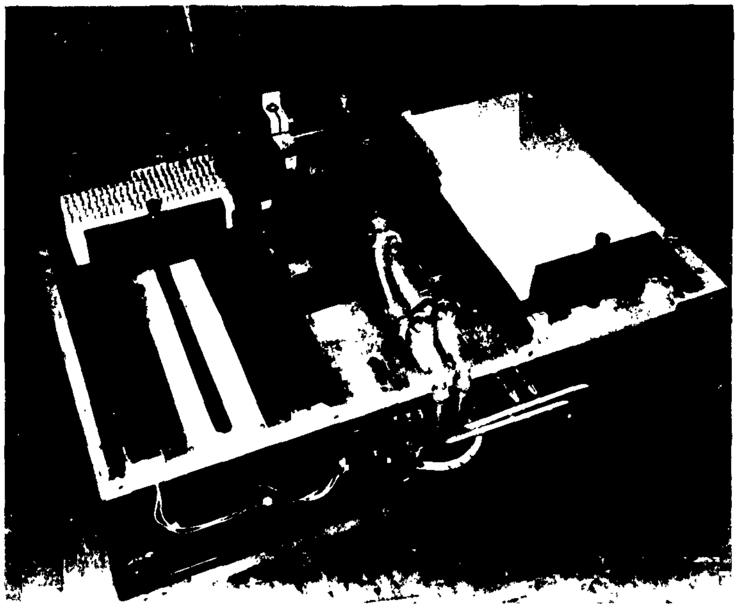
FINAL ELECTRICAL TESTING MACHINE
FIGURE 5.10-1



CONTROL PANEL OF FINAL ELECTRICAL TESTING MACHINE
FIGURE 5.10-2



INPUT RACK HANDLING SYSTEM OF FINAL ELECTRICAL TESTING MACHINE
FIGURE 5.10-3



UNLOAD STATION OF FINAL ELECTRICAL TESTING MACHINE
FIGURE 5.10-4

REPEATABILITY OF FINAL ELECTRICAL TESTING MACHINE

(Diode Type - 1N673)

Diode No.	Run No. 1	2	3	4	5
29	BV	BV	BV	BV	BV
48	V_F	V_F	V_F	V_F	V_F
50	V_F	V_F	V_F	V_F	V_F
76	V_F	V_F	V_F	V_F	V_F
78	V_F	V_F	V_F	V_F	V_F
79	V_F	V_F	V_F	V_F	V_F
80	A	A	A	A	A
81	A	A	A	A	A
82	A	A	A	A	A
83	A	A	A	A	A
84	A	A	A	A	A
85	A	A	A	A	A
86	A	A	A	A	A
88	V_F	A	A	A	A
104	BV	BV	BV	BV	BV
106	BV	BV	BV	BV	BV
108	A	A	A	A	A
110	BV	BV	BV	BV	BV
112	A	A	A	A	A
115	V_F	V_F	V_F	V_F	V_F
140	I_S	I_S	I_S	I_S	I_S
141	I_S	BV	I_S	BV	I_S
142	I_S	I_S	I_S	I_S	I_S
143	I_S	I_S	I_S	I_S	I_S

BV - Indicates breakdown voltage failure

I_S - Indicates saturation current failure

V_F - Indicates forward voltage failure

A - Indicates device passed all tests

FIGURE 5.10-5

POINTS OF DECISION OF FINAL ELECTRICAL TESTING MACHINE AND .4 WATT DIODE TEST LIMITS

PARAMETERS	1N664	1N665	1N666	1N667	1N668	1N669	1N673	1N675	1N697	1N701
Nominal BV Vdc	8.2	12	15	18	22	27	350	6.2	120	10
BV1 Vdc Min.	7.64	11.26	14.10	16.90	20.60	25.10	-	5.83	128.5	9.45
At ... mAdc	.010	.010	.010	.010	.010	.010	-	1.0	.005	.010
Points of (GO	7.64	11.29	14.10	16.93	20.66	25.22	-	5.86	130.5	9.46
Decision (NO-GO	7.62	11.25	14.09	16.91	20.64	25.20	-	5.85	129.4	9.45
BV2 Vdc Min.	7.84	11.46	14.27	17.19	21.01	25.73	420	5.93	-	9.55
At ... mAdc	10	10	5	5	5	5	.010	20	-	10
Points of (GO	7.85	11.47	14.28	17.21	20.98	25.72	421.6	5.94	-	9.532
Decision (NO-GO	7.83	11.46	14.27	17.20	20.97	25.70	419.9	5.92	-	9.527
BV3 Vdc Max.	8.56	12.54	15.72	18.81	22.99	28.27	900	6.47	900	10.45
At ... mAdc	10	10	5	5	5	5	.010	20	.010	10
Points of (GO	8.53	12.51	15.65	18.80	22.95	28.27	889	6.47	889	10.46
Decision (NO-GO	8.56	12.54	15.68	18.82	22.99	28.31	899	6.48	899	10.47
I_S µAdc	1.8	.9	.9	.9	.9	.9	1.8	90	1.8	1.8
At ... Vdc	6.5	9.5	12.0	14.5	17.5	21.5	320	4.5	100	8.0
Points of (GO	1.795	.890	.890	.890	.890	.890	1.795	90.0	1.795	1.795
Decision (NO-GO	1.800	.895	.895	.895	.895	.895	1.800	90.9	1.800	1.800
bz Ohms Max.	6.6	9.5	22.8	24.7	28.6	33.2	-	2.85	-	8.55
At ... mAdc	10	10	5	5	5	5	-	20	-	10
Points of (GO	6.5	9.4	22.6	24.6	28.3	32.6	-	2.80	-	8.40
Decision (NO-GO	6.6	9.5	22.7	24.7	28.4	33.7	-	2.90	-	8.50
C µµf Max.	-	-	-	-	-	-	-	-	24.0	-
At ... Vdc	-	-	-	-	-	-	-	-	0.0	-
Points of (GO	-	-	-	-	-	-	-	-	23.2	-
Decision (NO-GO	-	-	-	-	-	-	-	-	24.4	-
t_{rr} mµsec Max.	-	-	-	-	-	-	-	-	95	-
At ... mAdc	-	-	-	-	-	-	-	-	100	-
Points of (GO	-	-	-	-	-	-	-	-	93	-
Decision (NO-GO	-	-	-	-	-	-	-	-	97	-
V_F Vdc Max.	.98	.98	.98	.98	.98	.98	.98	.98	1.08	.98
At ... mAdc	400	400	400	400	400	400	400	400	400	400
Points of (GO	.980	.980	.980	.980	.980	.980	.980	.980	1.080	.980
Decision (NO-GO	.981	.981	.981	.981	.981	.981	.981	.981	1.081	.981

FIGURE 5.10-6

SECTION 5.11

PACKAGING

F. E. Tweed

PACKAGING

I General

The .4 Watt Diode Packaging Machine simultaneously inserts the leads of 24 diodes into a styrofoam block. The styrofoam block is then stamped with the appropriate code and loaded into either an aluminum storage tray or directly into a cardboard box. The machine is operated pneumatically and is sequential in design with an operating range of from 6,000 to 20,000 units per hour.

The basic package is the styrofoam block. However, for final shipment these blocks will be placed into either of two other packs. In the case of large shipments, the machine will automatically place the blocks into a cardboard box designed to hold 500 diodes. For small shipments, the individual styrofoam blocks will be placed into a protective sleeve. These two types of containers are shown in Figure 5.11-4.

II Description of Machine

Figure 5.11-1 is a view of the entire machine. Its overall dimensions are 60 inches long by 31 inches wide and 38-1/2 inches high. It is operated pneumatically and requires approximately 10 cubic feet per minute of air at 80 pounds per square inch. The air is supplied externally through the main cut-off value (Item 2, Figure 5.11-1) and is regulated, filtered and lubricated by means of a Regulator Filter Lubricator (RFL unit) within the machine (Item 1, Figure 5.11-1). The control panel is located on the front of the machine as shown by Item 5, Figure 5.11-1 and all electrical and mechanical systems are enclosed within the machine cabinetry. In addition, there is a storage area within the machine for styrofoam blocks or other machine items (Item 4, Figure 5.11-1).

The Packaging Machine is essentially an elevator mechanism in which the units are removed from the input handling racks and inserted into the styrofoam blocks. Within the elevator there is a set of clamps which locate and hold the body of each diode and a set of movable combs which capture the leads and move down until they are within 1/16 inch of the ends of the leads. These combs locate the ends of the leads so that they are initially inserted into the styrofoam at the proper point and also guide the wire leads during the insertion operation. The elevator is serviced by four stations whose functions are to load and unload the elevator. The following is a description of each of these four stations, its functions and controls.

Diode Input Station (Item 1, Figure 5.11-2)

Handling racks filled with diodes to be packaged are fed from this station into the machine. The capacity of this station is 45 racks and the necessary force required to move them into the pusher is achieved by a weighted cable. When the elevator is ready to accept a rack of units, a rotary type air cylinder operates a gear and rack mechanism which pushes the handling rack into position in the elevator. This station has controls which will ring a warning bell and light the appropriate warning light on the control panel when only 15 racks remain, and will shut the machine "off" when the last rack enters the elevator.

Rack Output Station (Item 2, Figure 5.11-2)

This station receives the empty handling racks from the elevator after the diodes have been removed. It also has a capacity of 45 racks. The necessary force to keep the racks upright is provided by a weighted cable. This station has a divider which will separate the first 30 racks (the capacity of one handling tray) for ease of unloading. When 30 racks are in this output station, a warning bell will sound and the appropriate light on the control panel will be lighted. When this station is full, it will shut off the machine.

Styrofoam Block Input Station (Item 3, Figure 5.11-2)

At this station the empty styrofoam blocks are fed into the machine. The necessary force required to move the blocks into the pusher is provided by a weighted cable. The styrofoam block is moved into the elevator by means of a gear and rack mechanism operated by a rotary air cylinder. As the styrofoam block enters the elevator it meets and pushes the empty handling rack out into the rack output station. The capacity of this station is 45 styrofoam blocks. When only 15 blocks remain in the station, a warning bell will sound and the appropriate light on the control panel will be lighted. When the last block enters the pusher, the machine will stop.

Output Station (Item 6, Figure 5.11-2)

This station is where the styrofoam blocks containing diodes will be placed either into a box as in Figure 5.11-2 or into a aluminum tray as in Figure 5.11-3. This station also prints "WE" and the code numbers of the diodes being packaged on the styrofoam block. The incoming handling rack from the rack input station meets the styrofoam blocks and pushes it out of the elevator and in front of the pusher-printer (Item 6, Figure 5.11-2). An air cylinder moves the printer forward and pushes the loaded block into either the box or the aluminum tray. Printing is done while the block is being pushed. If the units are being placed in a box, the machine will automatically be shut off when the box is full (21 blocks). If they are being placed in an aluminum tray a light on the control panel will be lighted when 40 blocks are in the tray and the machine will stop when the tray is full (42 blocks).

The operator has relatively few duties to perform in attending this machine. The main duty for the operator is to keep the input stations full and the output station empty. Since styrofoam liberates small particles when sliding against styrofoam as it does in the styrofoam input station, a vacuum cleaner has been installed in the machine and connected to the styrofoam block input station. To clean this station, the operator has only to activate the vacuum cleaner by turning a switch on the control panel and allow the vacuum cleaner to run for about 15 seconds every 15 minutes of operation. The only other duties for the operator are to observe the machine while it is running to be sure that it is functioning properly and to clean the machine at the end of the run.

As stated in the description of the individual stations, cut-offs were incorporated into the machine to prevent malfunctions due to over-abundance or lack of necessary components. In addition, the machine is sequential in design, thus one operation must be completed before the next operation is initiated. This ensures that one station is not jeopardized by the malfunction of any other station. If the air supply drops below the minimum pressure needed for operation or if an electrical power failure occurs, the machine will automatically stop. Once the machine has stopped, either manually or automatically, the machine will only start again after the reason for stopping has been corrected and the operator pushes the "Start" button on the control panel. All moving parts such as gears and pushers are properly guarded and the protective hood (Item 3, Figure 5.11-1) which covers the mechanisms on the top of the machine is inter-locked so that if the hood is raised the machine will stop. This prevents the operator from reaching into the mechanisms while running.

There are no critical maintenance items on this machine as most mechanisms are relatively simple. The only frequently occurring maintenance required would be maintaining the oil level in the RFL unit and light lubrication of gears and moving parts.

III Machine Development

The previous unmechanized process for Packaging was one of merely placing 100 diodes in a plastic box with a suitable amount of filler material. Such a package offered little protection as far as lead straightness was concerned. In addition, ease of unit identification, adaptability to mechanical insertion equipment, and inventory control were detrimental characteristics. Inventory control was one of the more serious areas. Initially, the accuracy of the number of units in the box was a result of the operators count. Also, once a box was opened to make a partial shipment, it had to be marked and kept separate from full boxes.

The main problems encountered during the feasibility study did not concern the machine itself but rather involved the selection of a type of package that gave the most advantages. To arrive at a decision as to the type of package, two areas were considered: One of these areas was the needs and desires of the ultimate users of the diodes. The principle consideration in this area was to give the user a package that he could use with any present or future mechanical insertion equipment and at the same time give good protection to the units and incorporate the maximum number of desirable properties of a good package. In conjunction with this investigation, a survey was made to determine the types of packages used by other manufacturers and commercial machinery available. Six different basic types of packages that warranted consideration were the results of the survey. The following items were used as basic criteria for evaluating each of these package types:

1. Protection to the unit and maintaining lead straightness
2. Ease of identification of unit
3. Adaptability to mechanized insertion equipment
4. Availability of machinery
5. Cost of package
6. Inventory control
7. Ability to test unit while still in package

The following is a resume of each type of package considered and its relationship to the aforementioned criteria:

1. Poly-Cell Pack

   This type of package consists of heat sealing the diode between two layers of plastic film. The diodes could be supplied in a continuous plastic strip and wound on a reel or cut into desired lengths. The main disadvantages of this type of package were that it offered no assurance of maintaining lead straightness and was not at all adaptable to use with mechanized insertion equipment.

2. Lead Taping

   This type of package consists of taping both leads to a continuous strip of paper. Lead taping offers a good degree of protection to the leads and seemed to meet all criteria. However, when using this type of package great care must be taken in selection of the adhesive used on the tape so that no residue is left on the leads when the tape is removed. This one problem seemed to have caused many users trouble in that such a residue affects the solderability of the leads.

3. Body Taping

Body taping offers little protection to the leads since they are not confined and are free to entangle with one another or with other objects. Since the body of the diode is covered with tape (one or both sides), identification of the diode is difficult and again considerable care must be given to the selection of the adhesive.

4. I.R.C. (International Resistance Corp.) Grip Strip

With this package, the unit is held on a patented paper strip by inserting the leads into a slot. The units are held by the leads at a point near the body; therefore, the leads are free and afforded a minimum of protection. This type of package lends itself to use with mechanical insertion equipment; however, at the time of the survey, machinery for this type of package was not available.

5. Corrigated Pack

This type of package utilizes the voids in a single face strip of corrigated cardboard. The units are placed in the voids and held in place by a piece of tape placed below the body of the unit. Reel type packaging is not feasible with this type of package and it does not lend itself to use with mechanical insertion equipment.

6. Styrofoam Blocks

This type of package consists of inserting one lead of the unit into a styro. ɔam block. A similar package is used for resistors.

Based on the survey of package types and consultation with the customer, it was decided to use the styrofoam block type of package.

Once this decision had been reached, the basic machine concept was formulated. Since the units would be in a handling rack which holds 24 units, it seemed feasible to simultaneously insert 24 units into styrofoam. A simple fixture proved the feasibility of this concept.

It was decided at this time that,even though the body of the units were exposed for identification, it would be advantageous to mark the styrofoam block for easy identification. From this concept grew the output station with the printer-pusher. The concept used for the handling rack input and output stations was duplicated from another machine having a similar application. With these concepts as a basis, design was begun. Design of the machine was completed with no particular problems encountered. The construction of this machine also progressed without trouble and mechanical prove-in was completed.

IV Operational Problems

After construction and mechanical prove-in were completed, the machine was moved from the construction shop to the prove-in area where a more detailed prove-in was undertaken. It was obvious from the very first trial that the incoming diodes must have straight leads; therefore, all subsequent diodes used during prove-in were straightened prior to Packaging.

During prove-in some modifications were made to improve and increase the reliability of the machine. The following is a discussion of these modifications:

At the output station, the loaded styrofoam blocks had a tendency to tip over as they were pushed into the aluminum storage tray. This problem was overcome by adding a spring loaded support that held them upright and collapsed after the styrofoam block was well engaged in the guides where there was no further danger of tipping. The original design of the rack output station utilized two flat springs to hold back the racks after they were removed from the elevator and placed in the output track. After considerable running, these springs failed due to fatigue. This problem was overcome by replacing these two springs with a more positive flipper type arrangement which proved to work very well. Also after running the machine for an extended period it became apparent that the tolerances on the commercial styrofoam blocks were in excess of those for which the machine was designed. To alleviate this problem the openings in the tracks leading the styrofoam into and out of the elevator, as well as the elevator itself, were increased to accept these larger styrofoam blocks. To increase reliability and to accomplish a smooth lead-in, all corners which the styrofoam might touch were chamfered. These changes overcame the problem of the oversize styrofoam.

During prove-in two concepts were changed which caused slight modifications in the machine. The original printing concept required that the rubber type be permanently mounted on plates which meant that each code had its own plate and, therefore, the printer had very little flexibility. To increase this flexibility, the printing portion of the output station was revised so that individual characters could be set and locked in place. This not only increased the flexibility but also reduced the inventory of rubber type necessary to accommodate all codes. The second change in concept dealt with the ultimate package at the output station. The original concept was that the completed styrofoam blocks would be placed in an aluminum storage tray as shown in Figure 5.11-3. Since the diodes would ultimately be shipped in a cardboard box (Figure 5.11-2) it was felt that it would be advantageous to place them directly into the box. Therefore, this feature was added by making a few slight modifications to the output station and by adding the box holder shown as Item 4 in Figure 5.11-2. Now the machine can load packaged diodes into either the aluminum tray or the cardboard box and maintain the automatic shut-off feature.

With the aforementioned modifications completed, prove-in was concluded.

V Shop Trial

During prove-in, this machine was run quite extensively with very few problems involved. Therefore, shop trial was conducted using 3,500 units. The results of this run showed two malfunctions which damaged three units. Each malfunction was attributed to oversized styrofoam. In both cases the thickness of the styrofoam was greater than allowable. These were in excess of the dimensions allowable even after relief of elevator and track had been added. As the oversized styrofoam entered the elevator, it was compressed due to binding in the track. This compression shortened the block so much that the end diode was not inserted and thus dropped out of the combs when they were opened and was then damaged by the incoming handling rack. This was the case in both malfunctions.

No maintenance has been required on the machine except for cleaning and lubrication.

VI Evaluation

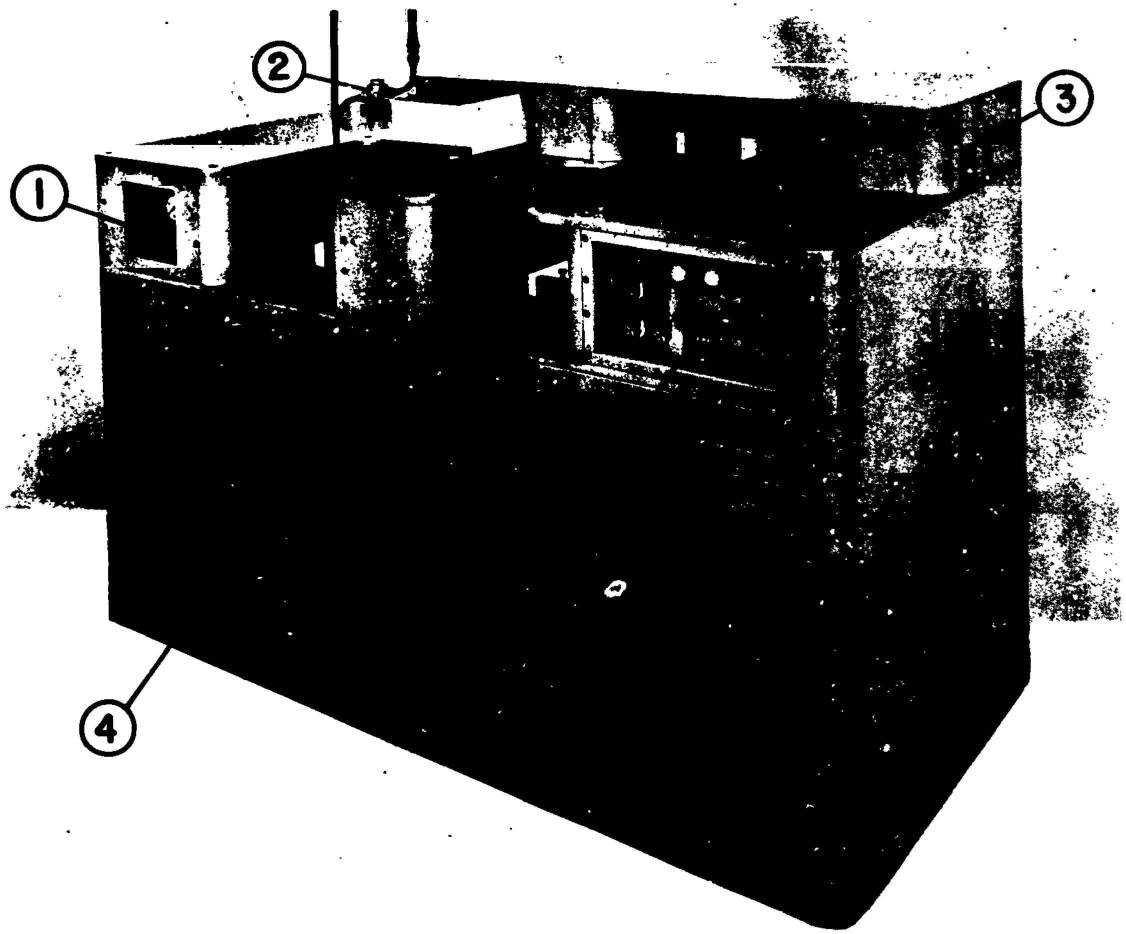
The Packaging Machine has proven to be very reliable in operation if the styrofoam blocks are within the allowable tolerances and if the leads of the diodes are reasonably straight. There have been no component failures in either the electrical, mechanical or pneumatic systems. The reliability of operation has shown that the operators duties will be relatively simple, consisting primarily of loading and unloading.

This new package and packaging method is considerably better than the previous plastic box type of package. Inventory control is greatly enhanced and the package itself is superior in all six criteria used to evaluate packages during the feasibility study.

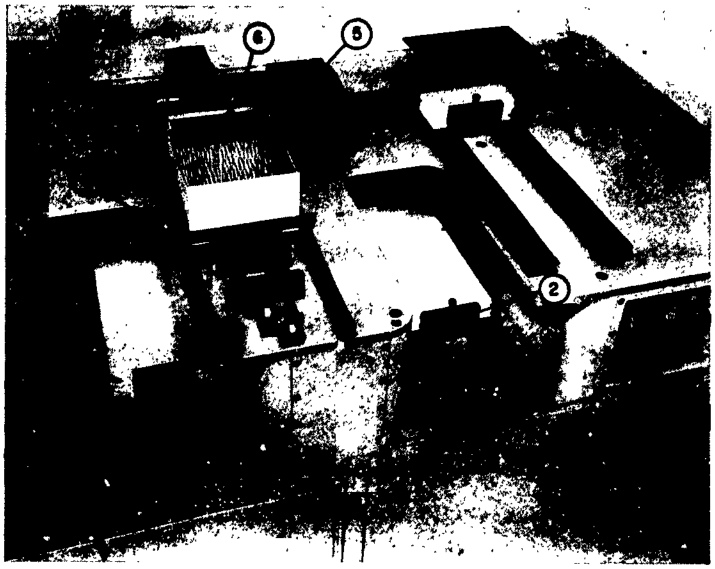
VII Conclusion

The mechanized Packaging Machine was designed and built to meet the anticipated Nike Zeus production not only in output but also to provide a better package. The production rate of from 6,000 to 20,000 units per hour makes this machine a high volume piece of production equipment.

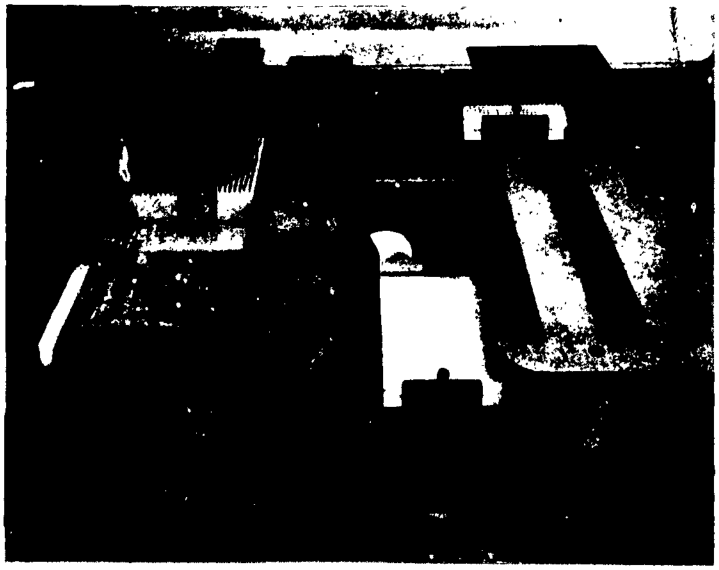
Integration of this machine to use manually produced diodes constitutes some difficulties. Since the machine must have straight diodes delivered in handling racks, diodes from the manual production line must be straightened and racked as separate operations. These operations are somewhat slow and, therefore, at the present time, it is economically unfeasible to package units from the manual line. However, when the mechanized line is producing straight and racked units, this machine will be used in regular production.



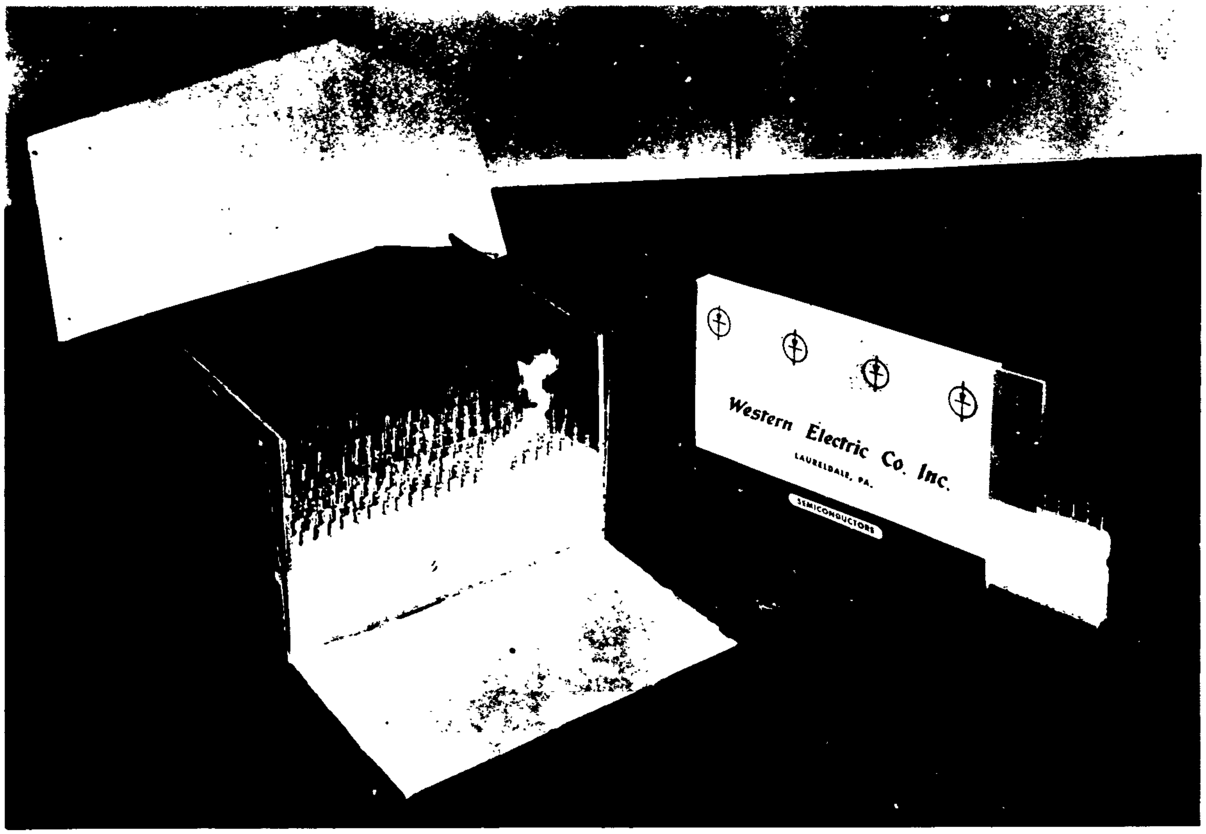
PACKAGING MACHINE
FIGURE 5.11-1



INPUT AND OUTPUT STATIONS OF PACKAGING MACHINE WITH
CARDBOARD BOX IN THE OUTPUT STATION
FIGURE 5.11-2



INPUT AND OUTPUT STATIONS OF PACKAGING MACHINE WITH
ALUMINUM TRAY IN THE OUTPUT STATION
FIGURE 5.11-3



PACKAGING CONTAINERS FOR .4 WATT DIODES
FIGURE 5.11-4

SECTION 5.12

WAFER PREPARATION

W. A. Schlemm

WAFER PREPARATION

I General

The process to be mechanized is the production of circular wafers from diffused and plated silicon slices, which are approximately 13/16 inch in diameter and .0075 inch thick.

The five types of wafering processes investigated were Single Etching, Double Etching, Scribing and Breaking, Sandblasting and Ultrasonic Cutting. Single Etching is the process used in the manual production line. Ultrasonic Cutting was selected as the means of producing wafers for the mechanized line because this process produced wafers of a more uniform size and shape. To cut these wafers, a Sheffield Ultrasonic Cutting Machine was purchased as part of the PEM portion of the Facility Contract No. DA-36-039-SC-26645. Efforts under this Mechanization Program were then limited to process and tool development.

During Quarters 3 and 4 of this Contract, 1N673 diodes were fabricated utilizing wafers cut ultrasonically with a cluster-type tool and a solid-type tool. The cluster tool was fabricated from 150 half-inch long pieces of steel tubing brazed parallel to each other in a hexagonal patterned cluster. One end of the tubes was then brazed onto the bottom of a commercial ultrasonic cutting tool holder. The solid tool was a 1/2-inch-thick steel disc with 150 holes drilled 1/4 inch deep into the end. The undrilled end was then brazed onto the end of a toolholder. The assembled diodes were tested to determine if ultrasonic cutting had any adverse effects on the physical properties of the wafer. Diodes assembled with wafers cut with the solid tool had comparable yields to those of the manual production line. The diodes assembled with wafers cut with the cluster tool had mechanical yields comparable to those of the production line but had poor electrical yields.

A study of the wafers cut with the cluster tool and the solid tool disclosed the following. The sides of the wafers cut with the solid tool were relatively smooth, whereas the other wafers were rough. This damage was in the form of vertical crevices and gouges. Further investigation showed that foreign material accumulated in these imperfections and was not being removed at the cleaning operation. The cleaning required to remove this material caused another problem. The acid attacking the silicon would under cut the gold plate which produced "gold-overhang". This gold would short the junction of the wafer. Since the cleaning process would not alleviate the problem of poor yields, another study of the tool was necessary to determine if this type tool could cut without making the imperfections on the wafer. A new tool was fabricated and a number of slices were cut at different speeds. All the wafers showed some degree of previously noted imperfections. Since the tubes were brazed together it was concluded that a relative small side motion between the tubes was being introduced by the ultrasonic waves and therefore the tool was driving the cutting compound against the side of the wafers. This phenomenon could not occur with the solid tool; therefore, the cluster-type tool was discarded.

A change from a soldering technique to a thermocompression bonding technique, for attaching the wafer to the stud and the internal lead to the wafer, demanded that the wafer cutting experiments be repeated since the wafers were now being subjected to higher stresses and higher temperatures during assembly. Therefore, a final experiment designated #1001 was run and the resultant electrical yields compared favorably to the yields of the diode manufactured on the production line during the same period. In addition to the electrical evaluation, an extensive study of the mechanical properties of the diode was conducted. The resultant shock and centrifuge yield was comparable to the yields obtained by the production line, which assembled diodes with etch cut wafers. A sample of the good units taken from Experiment #1001 passed all tests of Military Specification 19500/149 (SIG C) for the 1N673, .4 watt diode.

II Unmechanized Process

The unmechanized wafering process consists of the following procedure. The slice is mounted on a glass slide utilizing Lakeside cement and then a metal mask is placed over the slice and "Apiezon" wax is sprayed through the mask; this leaves the slice covered with dots of wax the size of the desired wafers. The slice is then submerged in aqua regia which attacks the exposed gold webbing between the wax dots. An operator visually determines when the gold is etched away. The slice is then washed in deionized water and placed in an acid solution which etches through the silicon. Again the operator must determine when to stop the etching. This is done by constant observation until the underside of the gold on the other side of the wafer is seen. The slice is removed from the acid, washed in deionized water and placed back into the aqua regia to etch away the gold. Here again the process must be observed so that the slice can be taken out of the aqua regia as soon as the gold is gone and the cement is visible. The slice is then washed in deionized water. The etched cut wafers are then removed from the slide by dissolving the cement in hot water. The resultant wafer does not lend itself to mechanized handling since the diameters vary from .030 to .055 inch depending on operator attention and the thickness and porosity of the gold plate. Also the contour of the wafer varies, in that the top and bottom diameters are never the same, with the bottom always being .010 to .020 inch larger. A definite fin is formed on the bottom. This fin is brittle and, therefore, chips easily during mechanical handling. In contrast, the ultrasonically cut wafer is cut to .035 inch diameter with a tolerance of ±.002 inch. In addition to this relatively close tolerance, the top and bottom are for all practical purposes the same size.

III Process Development

At the beginning of process development, the decision was made to investigate the following methods of producing wafers from slices: Single Etching, Double Etching, Scribing and Breaking, Sandblasting and Ultrasonic Cutting.

Since our manual production line was successfully using wafers made with the single etching technique, it was decided to investigate its mechanization potential.

In the preliminary experiments with close control on the masking technique and good control of the acid baths, a single slice could be etched into wafers with a tighter distribution of sizes than those produced on the production line. Also the large fin on the bottom was reduced considerably. Further experimenting on a larger scale, ten slices etched in one bath, did not produce wafers any better than the production line product. This reversal from the results of etching one slice at a time was due to the difference in the gold plating. When a group of slices was submerged in aqua regia, this acid would etch thru the gold on different slices at different times. In some groups this time varied 300 percent. On the slices which were not taken out of the aqua regia the instant the gold webbing was etched away, the acid would etch away the gold under the "Apiezon" wax mask. On etching through the silicon with CP-8 acid, this acid would now attack this additional exposed area. Thus a smaller non-uniform wafer resulted from these slices. This problem was reduced by selecting slices which were gold plated in the same bath at the same time and by closer observation, but at no time could the wafer size distributions approach those distributions of the preliminary experiments. Therefore, it was concluded that an operation demanding such close visual observation to produce a wafer, which was not too uniform, did not lend itself to mechanization.

Although it was realized that the double etching process faced the same problem with the gold plating as the single etching process, the investigation into this method was started to obtain size distributions. Double etching entailed masking the slice on both sides with "Apiezon" wax and etching from both sides simultaneously. Utilizing the etching technique of the previous single etching experiments, very good distributions were obtained. But as before, when a group of slices was etched simultaneously, the distributions were not good. An additional problem was encountered in the double etching technique. When etching through the silicon from both sides, the acid did not cut through the slice evenly. The first wafers to drop off the slices fell to the bottom of the container and the acid continued to attack the sides. By the time the last part of the slice was reduced to wafers, the first ones were attacked to the extent that the gold plate was undercut. This type of wafer is not desirable since under certain environmental evaluations the gold can break off and short the wafer junction. Therefore, the double etching technique was eliminated from the mechanization plans.

The third method of Wafer Preparation, Scribing and Breaking, was limited to a feasibility study which produced the following conclusions: (1) Wafers plated on both sides would have to be scribed on both sides to produce a clean cut wafer after breaking. (2) To produce round wafers, as demanded by device specifications, each scribed .035-inch circle on the slice would have to be connected to its adjacent circles with straight scribed lines. Also the outer ring of circles would have to have straight scribed lines intersecting the periphery of the slice. (3) Extensive development work would be required to refine the breaking method used during the feasibility study, to insure an economical slice to wafer yield. Therefore, this process was eliminated as a method of wafering.

The fourth process to be investigated was a method of Sandblasting. This technique was under development at the Bell Laboratories. Slices were mounted on a ceramic slide and masked similar to that method described for single etching. Abrasive particles were then bombarded against the unmasked portion until they cut a path through the plating and the silicon. The wafers were then removed from the slide. Wafers produced by this method were very irregular and exhibited extensive damage to the sides. The size distribution was very poor; therefore, this type of wafer cutting was also eliminated from the mechanization planning.

The last method investigated was Ultrasonic Cutting. Although this was a proven method, it was necessary to determine whether the Ultrasonic Cutting affected the various properties of the wafers. A number of slices were cut, and diodes were assembled and electrically tested. For the first three groups evaluated, the electrical yields were substantially lower than units made on the production line. A fourth group exhibited good electrical characteristics. The one variable introduced when cutting the wafers was the cutting tool itself. As explained in the general portion of this report, a cluster-type tool was used for the first three groups and a solid tool for the fourth group.

Additional slices were cut with both tools and the diodes assembled with the wafers from the cluster-type tool consistently had a lower electrical yield. This degrading of units was not apparent at curve tracing (a process of testing before the units are encased) since the yields were approximately the same. The electrical drop out occurred at process test, which is an electrical test performed after the completely assembled unit has been subjected to an oven bake, temperature cycling, and an alcohol soak. Drop outs of the type experienced at this test are indicative of junction contamination. As explained in the general section, this contamination was attributed to the crevices and gouges which formed potential traps. The cluster tool was discarded and a solid tool was used to cut wafers for further experiments. The resultant electrical tests of diodes made on these experiments were equal to those manufactured with single etch cut wafers. Also the wafers size and shape was such that they could be easily handled in mechanization. Therefore, Ultrasonic Cutting was selected as the method of wafering.

IV Machine and Tool Development

The three types of ultrasonic cutting machines which could be used for cutting wafers were small bench models with a generator capacity of 100 watts, a large floor model with 1-kw capacity and a specially designed machine. On three different occasions the bench model was unsuccessful in cutting the .4 watt diode slice. Therefore, using this type of machine for cutting wafers was not feasible.

A floor model machine was available for experiments in the Shop. Using established cutting rates to cut the .4 watt diode slices, it was determined that the standard single cutting tool would not supply the wafering capacity needed for the Zeus plan in effect at that time. A fixture which piped the energy from the transducer to two tool holders was then tried. The cutting rate was appreciably slower than the single tool, therefore, this arrangement would not supply the required number of wafers.

Also investigated was the possibility of building an octopus type cutting machine where a single transducer would pipe energy to six or eight heads. This approach was feasible but the cost would be relatively high. Therefore, the decision was made to utilize the floor-type machine and expend further engineering development effort investigating the cutting speeds and cutting tools.

On the first approach, the cutting speeds were increased with the single tool so that enough wafers could be cut to meet Zeus requirements. The quality of the wafers was not good enough to pass an established criterion: chips on the top of the wafer may not project in from the periphery more than .005 inch. A change in the abrasive size and added amounts of coolant supplied to the tool did not alleviate the chipping at the higher cutting speeds. At reduced cutting speeds the wafers were acceptable. Since two machines would be required to meet Zeus requirements at the lower cutting speed, it was decided that the second approach, multiple slice cutting with a larger tool, would be investigated.

A large commercial tool holder was purchased and three of the single tools were brazed onto the end. With this tool cutting at the rate of 1-1/2 mils per minute, no appreciable chipping occurred. A second tool holder was fabricated with four tools, and again, good results were obtained since chipping was practically non-existant. Although both tools proved successful for the first few slices cut, trouble was encountered later.

The difficulty with the multiple tools was that one tool would loosen from the tool holder. This tool then flapped and dampened the available energy, thus making cutting for all practical purposes impossible. The next approach was to make a large single tool and bond it to the large tool holder. Here again, difficulty in bonding the complete surface to the holder was encountered and again the tool would not cut properly. Thus, through progressive tool development the final design of the tool was essentially a large tool holder with holes drilled into the bottom. A maximum of four slices was cut economically with this tool.

Development was completed and the final conclusion was that a single commercial machine with the large 1-piece tool was the best method to produce wafers for the Zeus program.

V Shop Trial

The Ultrasonic Cutting Machine was removed from the prove-in area and installed in the production area for a shop trial run. 1N673 diode slices were cut at the rate of 2 mils per minute and the resultant wafers were within the required .035 $\pm$.002 inch diameter. No chipping occurred on the wafers. The wafers were assembled on the manual production line. All shop test results indicated that the completed diode was equivalent to diodes manufactured using etched cut wafers. The lot of units was presented to Environmental Testing and subjected to MIL-S-19500/149 (SIG C) tests. The tests in this specification which would be most critical for an inferior wafer are 1000-hour storage life, 1000-hour power age, shock, constant acceleration, vibration fatigue and variable frequency vibration. The shop trial run lot passed all the environmental tests and was accepted for shipment.

One difficulty encountered in production runs, after shop trial, was the detection of diagonal cracks or crevices on the periphery of certain groups of wafers. This cracking problem was not related to the vertical crevices and gouge problem encountered with the cluster-type tool during early development.

VI Conclusion

The method to produce wafers for the Mechanized Diode Production Line has been established and the necessary tooling has been obtained. Since a Sheffield Ultrasonic Cutting Machine was provided under the PEM portion of Facility Contract No. DA-36-039-SC-26645, development under this Contract were limited to investigation of wafering processes and increasing the cutting capacity of the tools used on the machine. Consequently, Wafer Preparation was deleted from the list of mechanized operations in the contract modification technically accepted December 19, 1962, and the tooling developed was added to the Special Tooling and Test Equipment category.

The periodic cracking of wafers has already been reduced by adding a Sonotrol feeding system to the cutting machine and a refrigerated coolant system for the cutting compound. The origin of these cracks will be investigated during Phase 2 of this Contract.

SECTION 6

DISCONTINUED DEVELOPMENTS

During the transistor and diode mechanization programs, four developments were discontinued after considerable development or design had been accomplished. They are:

1. D-C and Switch Testing (2N560-2N1051)
2. Emitter Etching (2N560-2N1051)
3. Wire Bonding (2N1195 & 2N560-2N1051)
4. Wafer Evaluation

Narratives in this section review work done and status of each of these developments when terminated. Another development, Final Electrical Testing (2N1195), was discontinued in 1961 and then combined with Testing and Date Stamping (2N1094) under Contract No. DA-36-039-SC-72729. In addition to the foregoing discontinuances, a Data Collection Test Set and a Header Lead Trimming and Welding development were discontinued in the initial stages.

The Header Lead Trimming and Welding development was suspended in June 1961 before formal development began. In November 1960, a decision was made to butt weld the collector lead to the underside of the header platform either during or before the Header Assembly operation. Then, only a single semi-automatic lead trimming machine already in use was needed; therefore, this development was deleted in Contract Modification No. 5. Early concepts for Header Lead Trimming and Welding included consideration of a rotary index table for sequencing the automatic operations and magnetic trays or a vibratory feeder for supplying headers to the machine. These considerations led to brief trials at feeding headers from an existing vibratory feeder to determine if feeding rates were adequate when the bowl load was limited.

Development of a Data Collection Test Set was contracted in Modification No. 5, September 29, 1961, to provide adequate equipment for control and analysis of 2N560, 2N1051, and 2N1195 production. In the fourth quarter of 1961, prove-in tests of the Data Handling System, Contract No. DA-36-039-SC-72729, indicated that it had sufficient capacity for Data Collection requirements of this Contract. So, the Data Collection Test Set was deleted in January 1962 before starting formal development.

Narratives on the four other discontinued developments follow:

SECTION 6.1

EMITTER ETCHING (2N560-2N1051)

J. H. Blewett

EMITTER ETCHING (2N560-2N1051)

I General

The Emitter Etching Machine was designed to mechanize the final cleaning operations which are performed on the wire bonded 2N560 and 2N1051 transistor assemblies. It was designed for high volume production not only by providing for a high hourly output, but also by adding process controls not feasible on the manual operation. However, changes in the Nike Zeus production level and development of several new transistors, having characteristics similar to the 2N560 and 2N1051's, led to deletion of the machine from the Contract. These new transistors were of the planar type and, therefore, required no etching or cleaning after wire bonding and it was anticipated that the 2N560 and 2N1051 would follow this device design change.

Through development of the machine, a change was introduced into the manufacturing process for drying the assemblies. This change substituted a hot water dip and hot air blast for the alcohol dip and drying by evaporation. This new process not only eliminated the fire and health hazards, but actually improved the final yield.

II Design

Since construction of the Emitter Etching Machine was cancelled after final drawings were completed, all descriptions of the machine and its operating cycle are based on the completed drawings provided for construction.

The machine was designed as a straight line, batch-type, automatic machine, 3 feet wide by 5 feet high by 16 feet long. The 7 work stations, each 18 inches wide, are enclosed so that the air could be filtered. The air intake and main drive are mounted on the right or unload end; the electrical panel, timers and controls are mounted on the left or loading end of the machine. Storage tanks for the etching stations and the two demineralizers for the deionized water are mounted under the cover at the rear of the machine.

A trolley is mounted on rollers inside the machine so that two magazines, each containing 600 wire bonded assemblies, can be processed simultaneously. (Figure 6.1-1 contains an artist's conception of the trolley and the machine.) One magazine is loaded onto the trolley from the front of the machine and the other from the rear. After loading, the units are automatically programmed through the other six stations: etching, deionized water dip, deionized water rinsing, hot deionized water dip, drying and unloading. The dwell at each work station is governed by timers which can be varied in order to change the cycle. An air cylinder lowers the units into shallow trays for the etching, dipping and rinsing operations.

Indexing of the trolley from one station to another requires 2 seconds. Both indexing and transfer of etchant and water are electrically controlled from a multi-circuit cam-timer having 19 cams on a single shaft. The various cams operate limit switches which control the indexing of the trolley through the various stations, and the delay at each station is controlled by the timer for that position. If all timers were set to zero, the trolley would index and the cam timer would run through the cycle without stopping.

The etchant is stored in PVC (polyvinylchloride) tanks in the rear of the machine and is metered into the etching tray as required. After etching each lot of 1200 transistors for 15 seconds, the etchant is drained into the acid drain and fresh etchant is supplied for the next run. Trays are drained, flushed and refilled automatically by timed solenoid valves tied in with the main timing programmer.

The deionized water dip is a quenching operation which merely stops the etching process and dilutes any acid still clinging to the underside of the units. This station is also drained and refilled after each 15-second run.

The machine then indexes and lowers the units into a tank containing room temperature deionized water for a 10-minute cleaning cycle. A recirculating system continuously pumps the water through two resin demineralizers; therefore, demineralized water consumption at this station is limited to make-up only. A Solu-Bridge is connected in the water line to check the conductivity of the water.

After rinsing, the units are given a 15-second dip in a tray of hot deionized water at 170°F which heats them thoroughly. They are then indexed to a hot air drying station which directs a blast of 150°F air on them for approximately 1-1/2 minutes. A jet of nitrogen between the hot water dip and the air drying stations removes any large drops of hot water which adhere to the underside of the headers. The hot air is filtered before going to the blowers in order to minimize contamination during the drying cycle.

The units are then indexed to the last station, the unloading station, and the machine shuts down until the two magazines are removed. Pushing the return button returns the trolley to the loading station.

The machine can be operated on two automatic cycles; either on a single cycle status in which the trays are filled and drained after the cycle, or on a multi-cycle status where the trays are filled, drained, then refilled, ready for the next cycle. A water flushing system is provided so that the operator can clean and flush the various tanks when shutting down the machine. The operator's other duties are to keep the etchant tanks filled and to load and unload the magazines.

III Machine Development

Initial feasibility studies were made on the arrangement and number of magazines to be processed through the machine during one cycle. The side by side arrangement of two magazines provided suitable machine width, about 30 inches, and an output of 1200 units after each 15-minute cycle or 4800 units per hour.

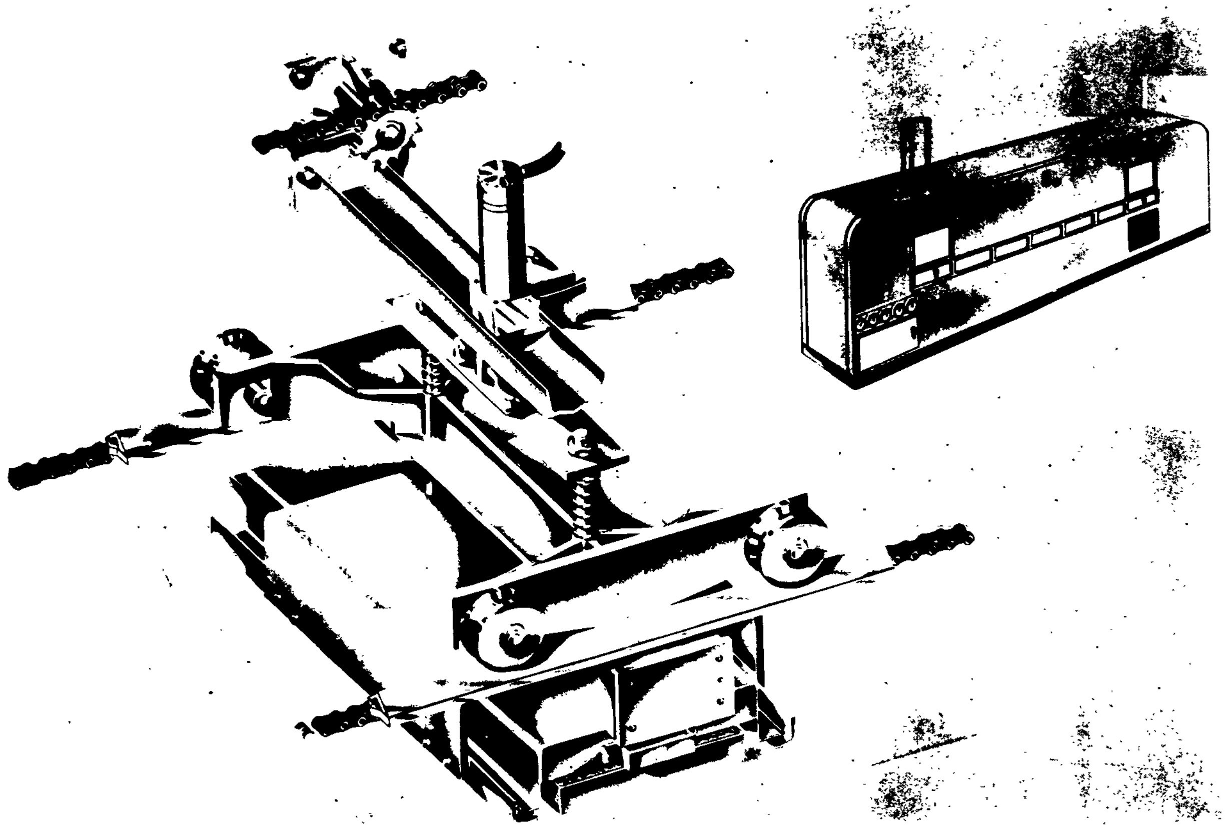
Tests were run on various types of stainless steel and aluminum to determine their resistance to both etching fumes and the etchant. The stainless steel was not visibly affected by the fumes or immersion; however, the aluminum showed slight discoloration but no deterioration. Any parts that come in contact with the etchant were to be made of either PVC or stainless steel. The frame and covers of the entire machine were to be made of aluminum.

In an attempt to eliminate alcohol as a drying agent, studies were made using a hot water dip and a blast of hot, filtered air to dry the units. An air jet was also designed to remove the droplet of water adhering to the underside of each header as it left the hot water dip tray. These studies indicated that 14 minutes were required to dry sub-assemblies with a cold water dip and an air blast at room temperature. Using a hot water dip and a 70°C air blast reduced the drying time to 4 minutes. The addition of the air jet,mentioned above, to the hot water dip and hot air blast further reduced the drying time to 1-1/2 minutes.

Tests were then conducted over the production line on 300 good units to compare alcohol as a drying agent with room temperature air drying and the hot-water-hot-air-blast method of drying. Based on the test yield for alcohol drying, yields for the other two drying methods deviated as follows: plus two percentage points for room air drying; plus twelve percentage points for the hot water dip and hot air drying. (Deviation in this instance is an arithmetic difference.) Since this machine was cancelled the drying process utilizing hot water dipping has been incorporated on the 2N559 Final Cleaning Machine.

IV Conclusion

The development and design of the Emitter Etching Machine provided a fast, easily duplicated and improved process for the final cleaning of 2N560 and 2N1051 transistors after wire bonding. The capacity of 4800 units per hour also provided more than enough capacity to meet the production requirements anticipated for the Nike Zeus program. Before this machine was cancelled, the development of hot deionized water rinsing advanced the state-of-the-art for etching. Experiments and investigations using hot deionized water rinsing were continued on the 2N559 Final Cleaning Machine, Contract No. DA-36-039-SC-72729.



ARTIST'S CONCEPT OF TROLLEY AND EMITTER ETCHING MACHINE
FIGURE 6.1-1

SECTION 6.2

WIRE BONDING (2N1195 & 2N560-2N1051)

H. J. Huber

WIRE BONDING (2N1195 & 2N560-2N1051)

I General

The objective of the Wire Bonding Machine (2N1195 & 2N560-2N1051) was to mechanize the thermocompression bonding process for attaching gold wire from the evaporated stripes on the wafer to the internal header lead posts of the subject transistors. This machine was added to the contract by Modification No. 3 to provide the additional wire bonding capacity required for a balanced mechanized line. At the completion of the design phase, this machine was deleted from the Contract by Modification No. 6 because of the reduced requirements and extended deliveries of the 1961 Nike Zeus production planning, for the 2N560, 2N1051 and 2N1195 transistors. The scheduled wire bonding effort, made available by the deletion of this machine, was redirected toward the overall wire bonding development program.

II Machine Development and Design

Wire Bonding Machine (2N1195 & 2N560-2N1051), although being the second wire bonding machine on the Contract and being provided to supplement the 2N560 and 2N1051 silicon transistor production capacity of the first machine, was the prototype machine for the mechanized wire bonding of the 2N1195 germanium transistor.

The unmechanized operation for wire bonding all three of the transistor codes is performed by the manual wire bonding tool shown in Figure 3.9-1. This tool uses 11 micromanipulators to position cantilevered gold wire and to subsequently position and apply the bonding wedges for making the thermocompression bonds at the wafer stripes and at the internal header lead posts. The operator manually actuates the micromanipulators while viewing the work area under a microscope. Gold wire segments are first mounted in blocks, etched or cleaned, and annealed prior to use on the wire bonding tool. The 2N1195 transistor uses a silver-jacketed 0.0004-inch-diameter gold wire while the 2N560 and 2N1051 transistors use 0.001-inch-diameter gold wire which is supplied either as bare drawn wire or as a silver-jacketed wire. For handling, the bare gold wire is inserted in a nickel tube and crimped in place with gold wire extending beyond the end of the tube. In the case of the silver jacket gold wire, no tube is required but the silver must be etched away to expose a length of gold wire.

The estimated hourly output of these wire bonding operations has ranged from 25 to 50 during the 1959-1961 period and does not include the gold wire preparation which is a separate operation. The numerous operator controlled and actuated positioning movements of the manual wire bonding tool has limited the production rate, the repeatability and the reliability of this operation. As a result, the high production requirements for these transistors in the 1959 - 1960 planning for Nike Zeus necessitated the development of a mechanized wire bonding process which would have increased production rate repeatability and reliability.

The development and design of the second Wire Bonding Machine was initiated at the completion of the construction phase of the first machine. The original concept of the first Wire Bonding Machine for 2N560 and 2N1051 transistors provided for an open loop system in which cam operated mechanisms, having high accuracy and repeatability, positioned bonding tips for making simultaneous bonds at both stripes and both posts after the wire bonding station had been initially positioned over the wafer bonded header.

Since the 2N1195 transistor uses the same TO-5 components as the 2N560 and 2N1051 transistors, the second Wire Bonding Machine was designed to the same basic machine configuration as the first machine using:

1. The in-line operation
2. The header handling trays and magazines for loading, unloading and transferring headers.
3. Optical positioning of the bonding station over a header in a stationary heat sink.

With the exception of the wire bonding station, machine redesign was limited to those items which would materially improve either the ease of machine fabrication, the machine operation, or both. The wire bonding station was the major area of development and redesign because of the differences between the evaporated stripes of the 2N560 - 2N1051 silicon transistors and those of the 2N1195 germanium transistor. The bonding station, instead of having to bond 0.001-inch-diameter gold wires to 0.002-inch-wide stripes having a fixed stripe spacing, was now required to bond 0.0005-inch-diameter gold wires to 0.001-inch-wide stripes having a variation of stripe spacings up to 0.0007 inches.

The development effort was directed towards obtaining physical data on the 0.0005-inch-diameter bare drawn gold wire for (1) feeding the wire from spools and through wire feeding tubes and (2) establishing the parameters for thermocompression bonding of the 0.0005-inch gold wire to the 2N1195 wafer stripes.

Handling of 0.0005-inch-diameter gold wire, having 4 percent elongation, can be satisfactorily performed provided the spool inertia and the frictional drag through a tube does not require a tension force on the wire in excess of 1-1/4 grams. To minimize work hardening of the wire due to elongation, this tension force should be limited to a magnitude of 1/4 gram. Satisfactory thermocompression bonds can be produced on the 0.0005-inch gold wire with bonding forces ranging from 6 to 13 grams depending on the bonding tip configuration. Redesign of the wire bonding station included modifications to facilitate the adjustment of the bonding tips and to improve the accuracy of their programmed travel. The redesign also incorporated a mechanism for the automatic adjustment of the bonding tips relative to each other by 0.0002-inch increments to correct for the variations in the stripe spacing.

In view of the problems encountered during prove-in of the first machine caused by the exacting adjustments to the programmed cam travel of the bonding tips and by the difficulty in obtaining wafer bonded headers manufactured to close tolerances, the design of the second machine was reviewed critically upon completion. Evaluation of the machine design, which considered the problems of the first machine and the inherent problems of keeping machines with complex mechanisms in continuous production, resulted in the decision not to construct a machine to this design but to design and build a machine using simpler concepts with adjustments for stripe size and spacing under operator control.

Prior to the execution of this decision, a review of the technical progress of the Contract in view of the reduced scopes of the 1961 Nike Zeus production planning resulted in the deletion of this machine from the Contract.

III Conclusion

The development of a wire bonding machine, which completes a mechanized, close-tolerance, thermocompression bonding cycle with automatic compensation for wafer stripe variations after a single optical-manual positioning at the bonding station, is not practical at this time because of the present tolerances on transistor headers, wafer stripes and wafer positioning. While such a machine remains feasible for the future, modifications to the present thermocompression wire bonding process would be advantageous for mechanizing this operation.

SECTION 6.3

D-C & SWITCH TESTING (2N560-2N1051)

K. C. Whitefield

D-C & SWITCH TESTING (2N560-2N1051)

I General

The original March 1960 goal for the D-C & Switch Testing Machine was to provide mechanized go no-go electrical testing at the contract production capacity. This testing was then done on 6 different manual test sets and covered 15 tests for 2N560 and 2N1051 transistors. Due to reduced Zeus production requirements, mechanized test equipment will not be provided for these transistors.

II Summary of Actions

Feasibility studies were ordered from Monitor Systems, Inc., Fort Washington, Pennsylvania and Emerson Electric Manufacturing Company, St. Louis, Missouri in April 1960 and their results were evaluated in October 1960. Both studies lacked suitable device contact means and were not integrated with other mechanization planning. In December 1960 magnetic trays for transistor input and mechanized rotary index for transistor transfer between tests were selected. Development of a side-entry test socket was then started. It was compatible with the handling systems chosen and the required testing capacity.

Mechanical design work was started on March 1, 1961 and checked mechanical drawings were released to construction between July 1, 1961 and October 1, 1961. On October 1, 1961 when this development was halted, mechanical design of the test set was complete, mechanical construction was 50 percent complete, and 2 of the 12 electrical test modules had been designed. Consideration was then given to providing a multi-code combined line test set versatile enough for D-C and Switch Testing (2N560-2N1051).

An evaluation of the side-entry test socket in April 1961 showed that it was suitable for switching time tests. Further tests, in July 1961, demonstrated that it was also suitable for test frequencies up to 250 megacycles and beyond with proper compensation.

To evaluate the basic mechanical design, the completed loading, lead trimming, testing, and reject mechanisms were built into a 4-station hand-cranked manually-indexed Sample Assembly, Figure 6.3-1. The side-entry test socket developed was also a basic component of this assembly. Contact resistance checks of the socket made in the laboratory ranged consistently between .002 and .006 ohms, and D-C and Switching Time tests made on the sample assembly indicated that repeatability and accuracy were easily held within the ±1 percent range. The sample assembly also provided suitable mechanical action at the loading, trimming and reject stations.

On April 1, 1962, mechanization planning was changed again. A decision was then made to use commercially available D-C and "h" parameter test sets supplemented by manual test sets for other parameters until their mechanizable versions can be developed. After this, planning efforts were confined to consideration of making switching time tests by referencing against known delay lines to achieve accurate results with simple circuitry.

III Mechanical System Design

The mechanical system design consists of a variable speed auxiliary drive assembly to accomplish all the mechanical operations performed on the transistors and an electric-clutch-operated rotary index table whose dwell is controlled by the drive assembly. The variable speed auxiliary drive assembly furnishes the power for all the mechanisms except the rotary index table which has its own motor. The electrical control system provides an interlock between the auxiliary drive assembly and the rotary index table. The test probe actuator assemblies and the unload assembly are mounted on the tool table of the rotary index mechanism and are chain driven from the variable speed drive.

Transistors with tip-welded leads enter the test set carried in magnetic trays held in a magazine. When the magazine is in place, the trays are pushed onto a track as space becomes available and indexed down the track to the loading station. Here a magnetic pick-up moves down over the transistor can and then moves horizontally into the side-entry test socket mounted on the rotary index dial. The tray continues down the track under successive tray indexes and, when empty, is pushed off the track into another magazine for withdrawal from the test set.

The 20-station rotary index dial indexes the loaded side-entry test socket to the lead trimming station where the leads are cut to length to remove the tip-welded ends as required for testing. After the leads are trimmed, the test socket is indexed to each test station in succession for the whole series of electrical tests.

Satisfactory transistors pass through all the test stations in order and are removed at the unload station where they pass down a chute into a bin. Test rejects, however, are removed directly after each test and fall into reject bins located between the stations.

IV Electrical Test System

In this system, self-contained test modules were to be mounted on slide-out chassis in a test cabinet supported above the rotary index dial for convenient arrangement of test leads to test stations. Code selector switches for test modules common to the 2N560 and 2N1051 transistors were to be connected so as to prevent operation unless all switches were in the same code position.

Only the BV_{EBO} and the I_{CBO} test modules were designed before the project was abandoned.

V Conclusion

Under current contract planning, commercially available D-C and "h" parameter test sets will provide adequate contract testing capacity for 2N560 and 2N1051 transistors. Other tests will be made on manual testing equipment.

Development of mechanizable switching time test modules should be continued during Phase 2. Then, if future Zeus planning warrants, a simplified design will be available for an auxiliary test set needed to supplement commercial D-C and "h" parameter test equipment.

SAMPLE ASSEMBLY OF D-C & SWITCH TESTING MACHINE (2N560-2N1051)
FIGURE 6.3-1

SECTION 6.4

WAFER EVALUATION

W. A. Schlemm

WAFER EVALUATION

I General

The process to have been mechanized was the electrical testing and sorting of .4 watt diode wafers prior to bonding to a stud lead subassembly. Although the feasibility study, development and design specifications were completed, this machine was not built. Yields from slice sampling plans had improved and manual wafer probing had progressed to the point where one manual test set could provide adequate production control for the diode wafers required by Nike Zeus.

Three critical requirements for the machine were: one, keep the .035-inch-diameter wafer junction clean and undamaged so that accurate testing could be accomplished; two, develop a type of contact to accomplish accurate testing; three, sort the wafer[illegible] four categories.

II Feasibility and Development

At the beginning of this study, the unmechanized process consisted of a probe and plate connected to a direct reading D-C test set. Only low voltage codes could be tested safely with this set up. This first generation manual testing progressed to a protected fixture and a D-C test set. The fixture consisted of a contact plate on the base and a contact on the hinged top. The operator placed the wafer on the plate with a vacuum pickup and closed the lid for testing. The lid was then opened and the wafer was removed from the plate with the pickup and placed in the correct category. High voltage testing was then possible since the contacts are enclosed while testing, but the operation was relatively slow.

To keep the wafer junction clean, the wafers were etched, oxidized, cleaned and dried. To reduce contact resistance, both the pickup and the grounded plate were gold plated. More consistent readings were then obtained.

A study was made to evaluate the feasibility of the process. Groups of wafers were split and half were probed. The units were then bonded and electrically tested and the yields of the probed wafers were higher than the unprobed wafers. After this evaluation, the feasibility and development of mechanized testing was started and run concurrently with the continued development of the process.

Three approaches to handling the wafer were considered, keeping in mind that the wafers had just been etched, oxidized, cleaned and dried and, therefore, must be kept clean to acquire accurate test results.

First to be considered was a combination manual-mechanized feeding system whereby the operator would load trays and then insert the trays into the testing equipment. Second, the operator would singularly load a circular indexing tray which would index under a protected test area. Third to be considered was a vibratory feeding system. With vibratory feeding, the effect of the wafers vibrating on and against each other, and on and against the bowl and track had to be investigated. Wafers were subjected to approximately twenty passes around the bowl, up the track, and dropped back into the bowl after each pass. No appreciable burnishing of the gold plating nor excessive scratching was observed under a 60 power microscope. The wafers were then successfully bonded to a stud lead assembly. From these results it was concluded that vibratory feeding was a method which could be used for feeding a mechanized test set. Also of note is the fact that in all three concepts the operators hands would be isolated from the testing area where as much as 900 volts may be present during testing.

III Design Specifications

A testing rate of 2,400 wafers had been established as the criterion for the mechanized test set; therefore, the vibratory feeding was selected as the most reasonable method to meet this specification. To test on the end of the vibratory feeding track by alternately turning the feeder on and off was not feasible at the 2,400 per hour testing rate; therefore, the wafer would have to be transferred to a stationary test station. Also, since it was necessary to sort the wafers after testing, the following design specifications resulted. A transfer mechanism, depicted in Figure 6.4-1, consisting of two vacuum pickups must be mounted in tandem on a carrier which will traverse three stations; namely, the pickup (end of feeding track), the testing, and the sorting. One pickup is to operate between the pickup and testing stations and the other would operate simultaneously between the testing and sorting stations. The sorting station must be able to accept wafers of four categories; namely, good p-side up, good n-side up, high voltage rejects and low voltage rejects. The good wafers must be stacked in magazines, whereas the rejects can be placed in bulk containers. Also specifically included in the design specifications was the need for protection against electric shock of the operator at the testing station.

Although the mechanical concept was now formulated and the design specifications were written, the electrical test module design had not been formulated. A preliminary study resulted in the following conclusions: The present manual test equipment could not be adapted because it could not test fast enough and extensive changes would have to be made.

At this time, the need for mechanized wafer evaluation for Nike Zeus production was re-examined because the Zeus program had been reduced.

Also, it was determined that the wafers for the switching diodes need not be evaluated since a sampling plan was providing an adequate check for junction capacitance, and voltage breakdown presents no particular problem. In addition, since this project was started, the yields of the high voltage rectifier were at such a high level at testing of the gold bonded assembly that it must be concluded that the slice sampling plan presently used on this code is quite adequate. Thus, only the wafers for regulator diodes would need testing for Nike Zeus.

IV Conclusion

Since slice sampling plans appeared adequate, mechanization of the Wafer Evaluation operation was discontinued after completing the design specifications. This development was then deleted from the Contract by the contract modification technically accepted December 19, 1962. Experience gained during the mechanization run has, however, indicated that more work should be done on the Wafer Evaluation process. Yields of assemblies made from probed wafers were not as high as expected. Therefore, more work should be done in this area during Phase 2 of the Contract.

ARTIST CONCEPT OF WAFER EVALUATION MACHINE

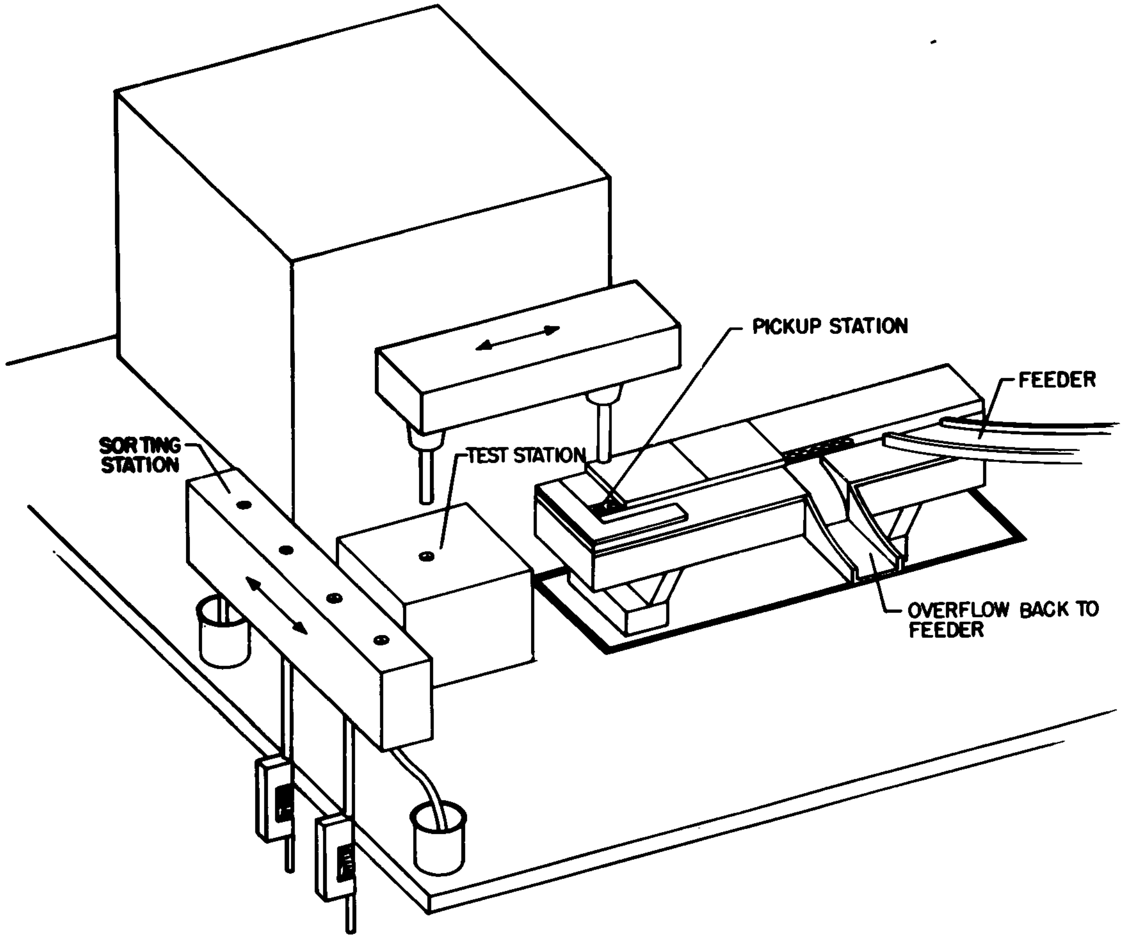


FIGURE 6. 4-1

SECTION 7

SPECIAL STUDIES

Special studies covered in this section are:

1. Diamond Scribing Points
2. Slice Breaking
3. Infrared Control Developments
4. Aging of Test Sockets at Elevated Temperatures

Four special studies under associated Contract No. DA-36-039-SC-72729 supplied information applicable to this Contract. Three studies dealt with wire bonding problems or the Stitch Wire Bonding process. A fourth special study of the associated Contract covered High Frequency Testing.

Developments resulting from the High Frequency Testing study provided basic design information useful in two high-frequency tests:

1. 200 Megacycle Base Spreading Resistance (REh_{ie})
2. 100 Megacycle Common Emitter Short Circuit Current Transfer Ratio (h_{fe})

Various socket considerations for High Frequency Testing were also studied. One socket was developed which promises to be compatible with test requirements of mechanized test equipment.

The subsections which follow summarize the findings and developments resulting from the four special studies conducted under this Contract.

SECTION 7.1

DIAMOND SCRIBING POINTS

R. H. Morrow

DIAMOND SCRIBING POINTS

I General

Mechanization for transistors under Contract No. DA-36-039-SC-81294 has been based on the requirements that the wafers, both germanium and silicon, be square and on size within .0002 inch and have sharp, well defined sides and smooth edges.

Scribing difficulties encountered during prove-in and shop trial of the Wafering Machines led to a Special Study on Diamond Scribing Points. Results obtained are reviewed in this report.

II Diamond Point Evaulations

The diamond scribing points first used on the Wafering Machines were the same as those used for manual scribing. They contained conical diamond tips having an included angle of 60 to 80 degrees and a tip radius of .0005 inch or less and were mounted in a 1/8-inch steel shank.

These points produced sharp, well defined scribe lines while scribing germanium under a pressure of 12 to 15 grams. The wafers produced were square and had smooth edges. Silicon being harder than germanium, presented problems not previously apparent during manual scribing. These problems included not only an increase of scribing pressure but also a variation of the pressure needed from code to code due to apparent variations in hardness of the silicon. Because of its hardness, silicon also caused rapid wear of the diamond points.

To obtain a good clean scribe line in silicon, it was necessary to examine a number of diamond tips under 30 power magnification and select the ones with the smallest tip radius coupled with a sharp plane edge. Only about 10 percent of the diamond tips examined met these criteria.

As a result of these problems, an investigation was started to find a scribing point which would:

1. Scribe equally well on germanium and silicon
2. Have a long life when used with either material
3. Be easy to replace and align

This investigation covered three major types of diamond points: the conical tip, the wedge-shaped tip, and the 4-sided, truncated pyramid. Four suppliers were contacted. Diamond tips supplied by them produced the results indicated:

1. Industrial Abrasives Company, Reading, Pennsylvania
   Conical tips of various angles ranging from 75 to 120 degrees were tried; however, results were no better than with the standard tips (see Item 1, Figure 7.1-1).
2. J. K. Smit & Son, Murray Hill, New Jersey
   J. K. Smit & Son had designed a new wedge-shaped, diamond tip having a 90-degree included angle (see Item 2, Figure 7.1-2). Several were purchased and tested. The points proved to be excellent on germanium. They scribed lines approximately .0001 inch wide and deep which resulted in very good breaking and produced sharp sides on germanium wafers. On silicon, however, the point did not scribe properly.
3. American Coldset Corporation, Teterboro, New Jersey
   The Amercian Coldset Point series CT-1225 was tried with good results on most codes. Various included angles were tried with results as follows:

(a) 90-Degree Included Angle

This tip (Item 3, Figure 7.1-1) produced good scribe lines. Subsequent wafer breaking was also good on all three silicon codes; 2N560, 2N1051 and 2N1072; as well as the 2N559 and 2N1195 germanium codes. On standard silicon codes these points lasted approximately 125 slices; on germanium approximately 200 slices could be scribed. Scribing pressures ranged from 15 to 50 grams.

(b) 110-Degree Included Angles

This tip configuration (Item 4, Figure 7.1-1) increased diamond life. Up to 200 slices could be scribed on standard silicon material and up to 250 slices on germanium codes. Scribing pressures ranged from 15 to 50 grams.

(c) Macle Diamonds Having a 70-Degree Included Angle

The macle (Item 5, Figure 7.1-1) is triangular in shape and has extremely hard planes on the sides of the triangles. Diamond life increased to approximately 225 slices per point while scribing silicon codes with wedge-shaped macle diamonds. Scribing pressures ranged from 15 to 50 grams.

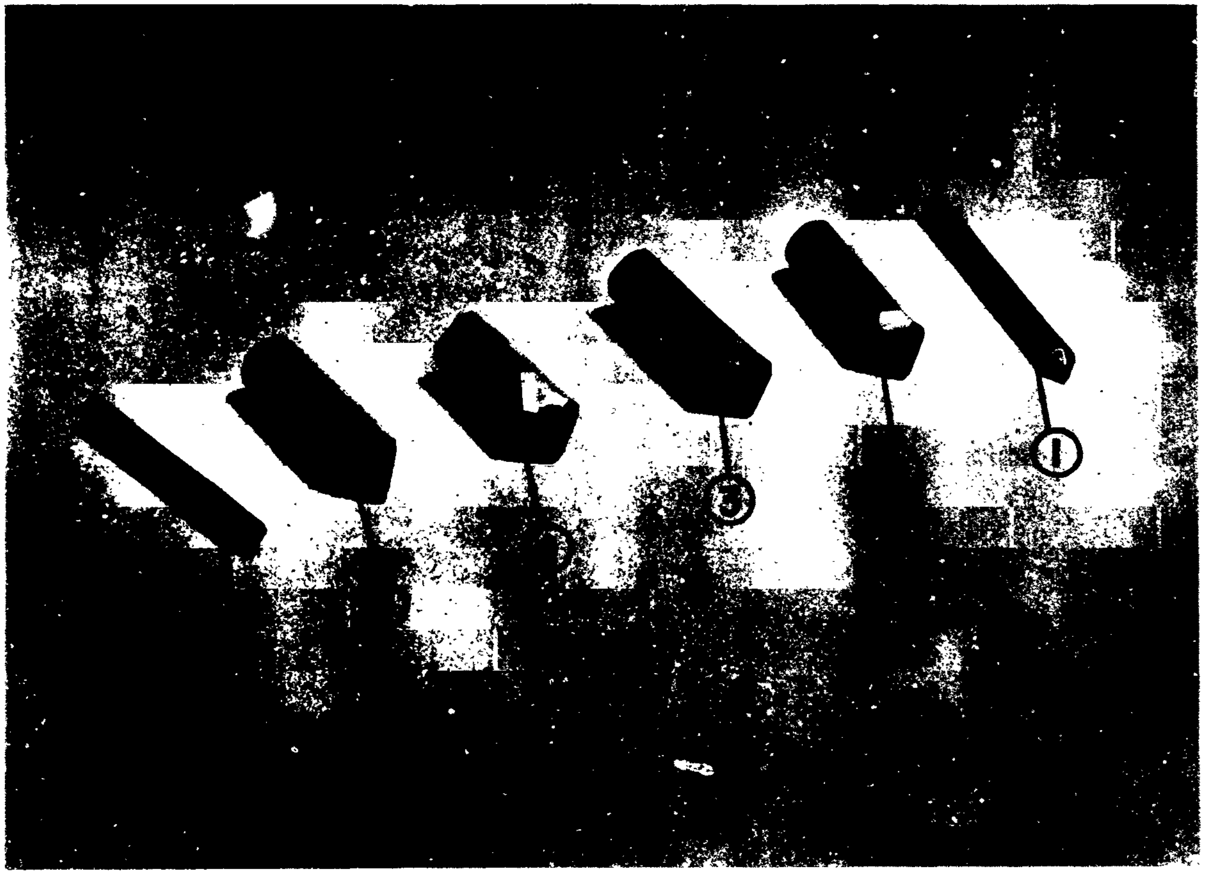
4. Tempress Research Company, Sunnyvale, California

The Tempress TPS-102 (Item 6, Figure 7.1-1), which is a 4-sided truncated pyramid, was tried and proved to be excellent on all codes. Diamond life increased to over 300 slices on the silicon codes and scribing pressures were reduced. Pressures for germanium codes range from

10 to 15 grams while silicon codes require 15 to 25 grams. At the reduced pressures, much smaller slice segments could be scribed than was possible with other tips because the vacuum needed to hold the slices on the vacuum chucks of the Wafering Machines was decreased. Tests conducted over a 3-month period have shown that these points decrease the set-up time needed to replace the diamond point by a factor of four over the CT-1225 series. Scribed lines and the resultant wafers are shown in Figures 7.1-2, 7.1-3 and 7.1-4.

III Conclusion

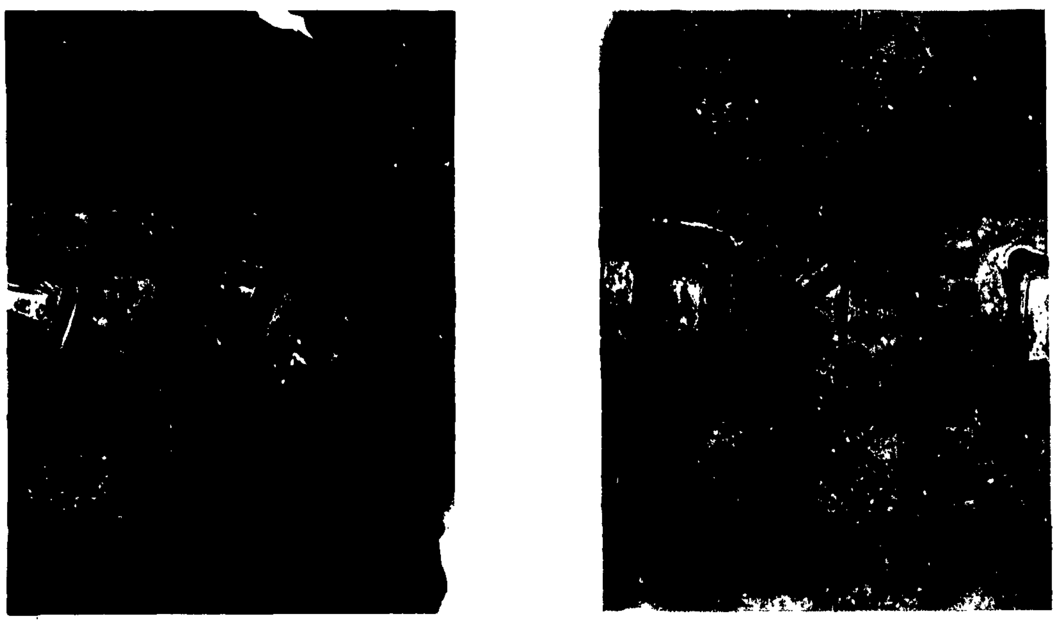
Tempress TPS-102 diamond points used on the Wafering Machines have given the best scribing results coupled with the full attainment of the test objectives, that is, the points have long life, are easy to change and align, and are usable on both silicon and germanium.



DIAMOND SCRIBING POINTS
FIGURE 7.1-1

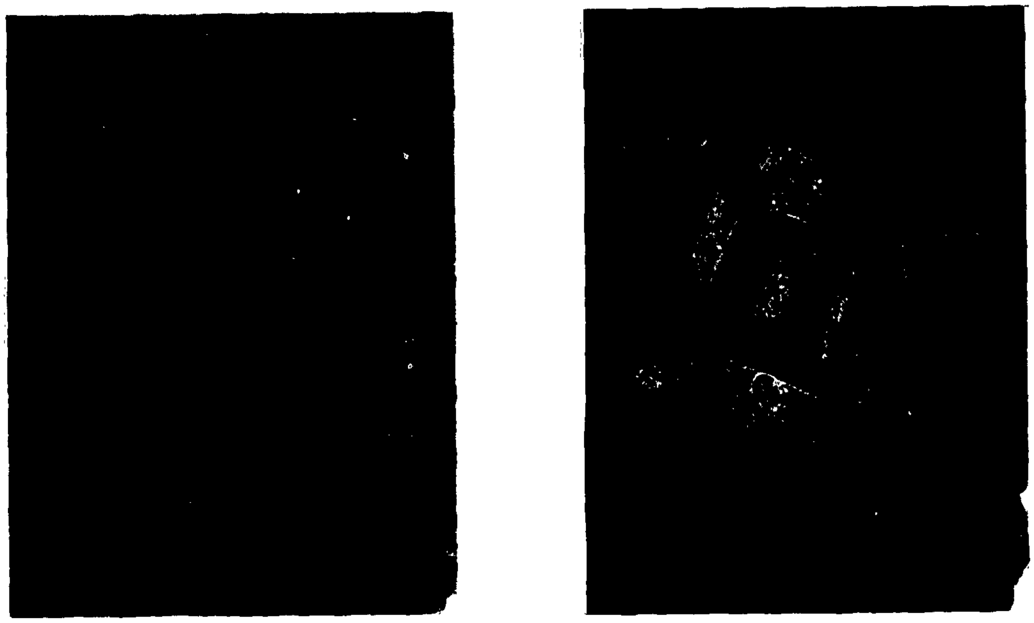
2N1195 GERMANIUM WAFER AND SCRIBING (.020" CENTERS)

FIGURE 7.1-2



2N1051 SILICON WAFER AND SCRIBING (.030" CENTERS)

FIGURE 7.1-3



2N560 SILICON WAFER AND SCRIBING (.020" CENTERS)

FIGURE 7.1-4

SECTION 7.2

SLICE BREAKING

R. H. Morrow

SLICE BREAKING

I General

Early in the development stage of wafer handling mechanisms it was found that wafers had no consistent shape. The random shape of the wafer sides was traced to the random orientation of slices while evaporating the stripe geometry on the slices. For best results during mechanized processing a specific orientation was desired so that all wafers would have a fixed shape. A study into the methods of achieving this fixed shape was started. The results achieved are reviewed in this report.

II Engineering Development

Investigations into the crystal structure of silicon and germanium showed that there are natural cleavage planes available which, if used to advantage, would aid in obtaining consistent wafer geometry. Further study showed that one plane of the (110) family was not only perpendicular to the (111) plane but also at right angles to one side of the (111) plane. This was desirable since lines scribed parallel to the (110) plane would break on the (110) plane giving wafer sides perpendicular to the (111) plane. Lines scribed at right angles to the (110) plane would be parallel to the (111) plane and would break on the natural cleavage plane, (001), which is approximately 15 to 17 degrees off the perpendicular.

In order to take advantage of these planes, crystals were grown, oriented, and marked in such a manner as to identify the (110) plane (see Figure 7.3-1). All further operations were keyed to this plane so that when the completed slices were scribed and broken the wafer took the configuration shown in Figure 7.2-2. This wafer shape provided the key to the design of a reliable wafer handling system. Since the wafer geometry was consistent, the tolerances on the handling system could be tightened.

While the tests on slice orientation were being conducted, new wafer designs were being tried. The wafer sizes were being reduced from .030-inch square to .020-inch square and slice thicknesses were being increased to reduce breakage during preliminary processing. These changes were, however, detrimental to slice breaking. The slices, instead of breaking cleanly, were showing tendencies to shatter which resulted from the tendency of the breaks to follow the natural cleavage planes rather than the scribed lines.

Because of this marked tendency to break on natural cleavage planes, it was decided to try oriented material in an effort to take advantage of the natural planes. A series of tests were conducted using oriented silicon and germanium slices. The results of these tests are noted in percentage figures. These percentages are based on the number of wafers which broke on the scribe lines versus the total number of wafers possible from a slice.

The tests and their results are shown in the following sections.

III Germanium

Germanium slices normally are .0035 ± .0005 inch thick and are scribed on .020-inch centers. This gives these slices a width to thickness ratio (.020 inch to .0035 inch) of from 5 to 6:1. A breaking percentage of 90 to 95 percent is normally obtained. Slices which were .005 ± .0005 inch thick were obtained, scribed, and broken. These slices were also scribed on .020-inch centers and, therefore, had a width to thickness ratio of approximately 4:1. The breaking percentage here was 60 to 65 percent showing a 30 percent decrease in yield with the increase in slice thickness.

A number of oriented slices, .004 inch and .005 inch thick, were obtained and tested as follows. The slices were cut into two pieces.

a. The first half of each slice was scribed taking advantage of the crystal orientation and broken over a sharp edge. The breaking percentage on both thicknesses was 90 to 92 percent.

b. The second half of each slice was scribed approximately 30 degrees off the crystal orientation plane and broken over a sharp edge. The breaking percentages were as follows:

   1. .004 inch thick - 85 to 90 percent

   2. .005 inch thick - 50 to 55 percent

Based upon the results obtained from these tests, it was concluded that slices having a width to thickness ratio of 4:1 produced better wafers when the slices were scribed on the natural crystal planes.

IV Silicon

Normal silicon slices were .005 $\pm$ .0005 inch thick and were scribed on .030-inch centers giving a width to thickness ratio of 6 to 7:1. The breaking percentage was 90 to 92 percent for non-oriented slices. Orientation added only a 2 to 4 percent increase to the breaking percentage (94 to 96 percent), but has the added advantage of producing wafers better suited for mechanized processing. During this study, a process change was introduced which reduced the size of silicon wafers from a .030-inch square to a .020-inch square. This change resulted in a greatly reduced slice yield due to a high amount of slice shattering. An analysis showed that slices scribed on .020-inch centers, depending upon code, ranged from .005 inch to .007 inch thick and had a width to thickness ratio of from less than 3:1 to 4:1.

To determine the usefulness of orientation, silicon slices were obtained and three slices were backlapped to each of the following thicknesses:

.003" .004" .005" .006" .010"

Each slice was cut into two pieces, scribed, and broken with breaking results as follows:

1. One partial slice of each thickness was scribed on .030-inch centers parallel to the orientation planes.
   (a) .003", .004", and .005" thick: excellent breaking, breaking percentage 90 to 95 percent
   (b) .006" thick: good breaking, breaking percentage approximately 90 percent
   (c) .010" thick: good breaking, breaking percentage approximately 80 to 85 percent
2. Two partial slices of each thickness were scribed on .020-inch centers parallel to the orientation planes.
   (a) .003" thick: good breaking, breaking percentage approximately 80 to 85 percent
   (b) .004" and .005" thick: good breaking, breaking percentage 70 to 75 percent
   (c) .006" thick: fair breaking, breaking percentage 25 to 30 percent
   (d) .010" thick: poor breaking - shattering, breaking percentage 10 percent

3. One partial slice of each thickness was scribed on .030-inch centers approximately 30 degrees off one orientation plane.

    (a) .003" and .004" thick: good breaking, breaking percentage approximately 90 to 95 percent

    (b) .005" and .006" thick: good breaking, some shattering, breaking percentage approximately 80 to 85 percent

    (c) .010" thick: fair breaking, some shattering, breaking percentage approximately 65 to 70 percent

4. Two partial slices of each thickness was scribed on .020-inch centers approximately 30 degrees off one orientation plane.

    (a) .003" thick: good breaking, breaking percentage approximately 80 to 85 percent

    (b) .004" thick: good breaking, some shattering, breaking percentage approximately 55 to 60 percent

    (c) .005", .006", and .010" thick: very poor breaking, much shattering, breaking percentage approximately 10 to 15 percent

V Conclusion

These tests showed that a width to thickness ratio of 4:1 or better should be maintained and that slice orientation aided breaking in all cases but was especially helpful when the width to thickness ratio was less than 4:1.

As a result of this and later production tests, all silicon and germanium slices are being oriented to aid in slice breaking. Production processes following slice preparation have been modified to take advantage of this slice orientation.

TYPICAL CONFIGURATIONS OF ORIENTED SLICES

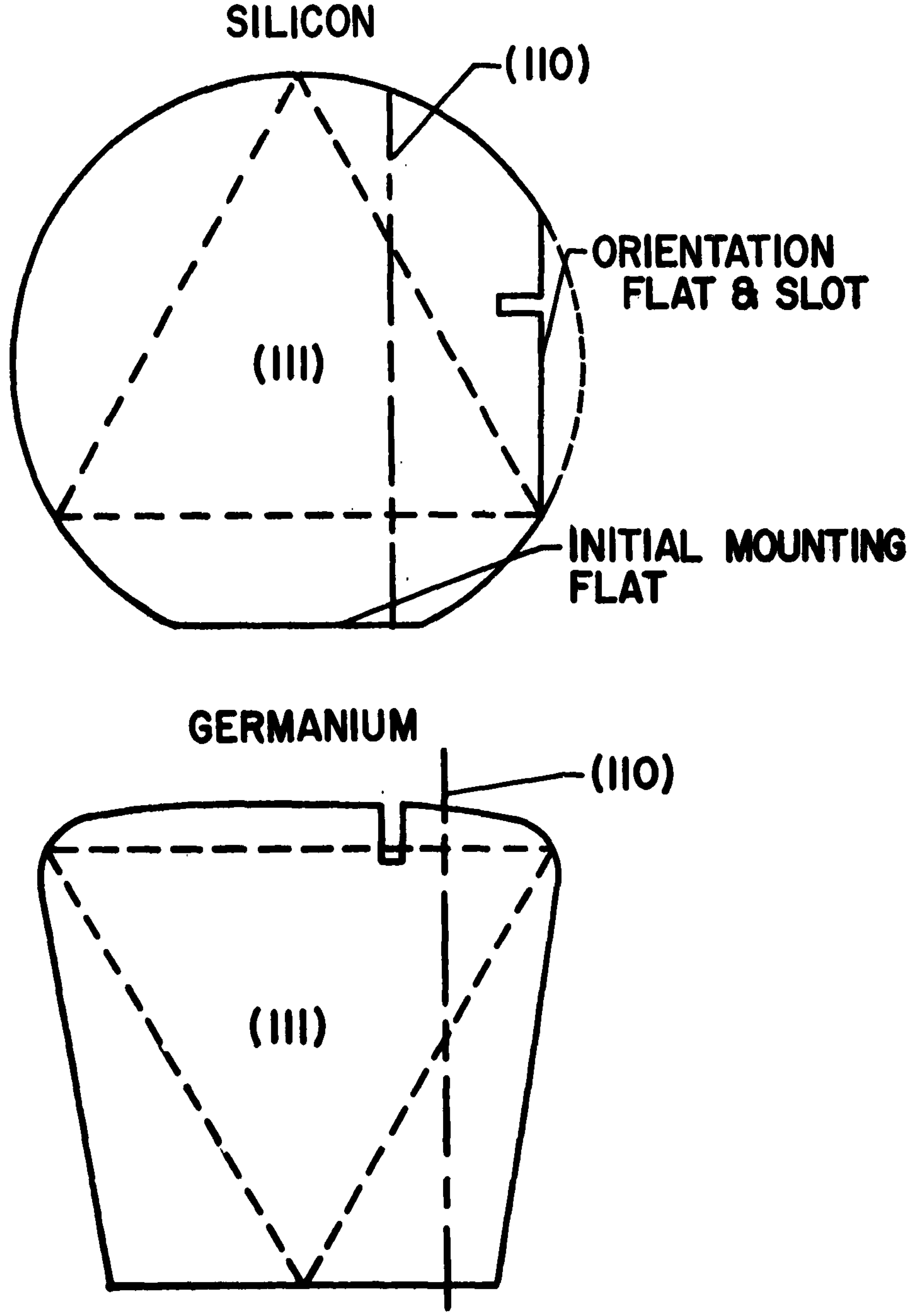


FIGURE 7.2-1

WAFER GEOMETRY

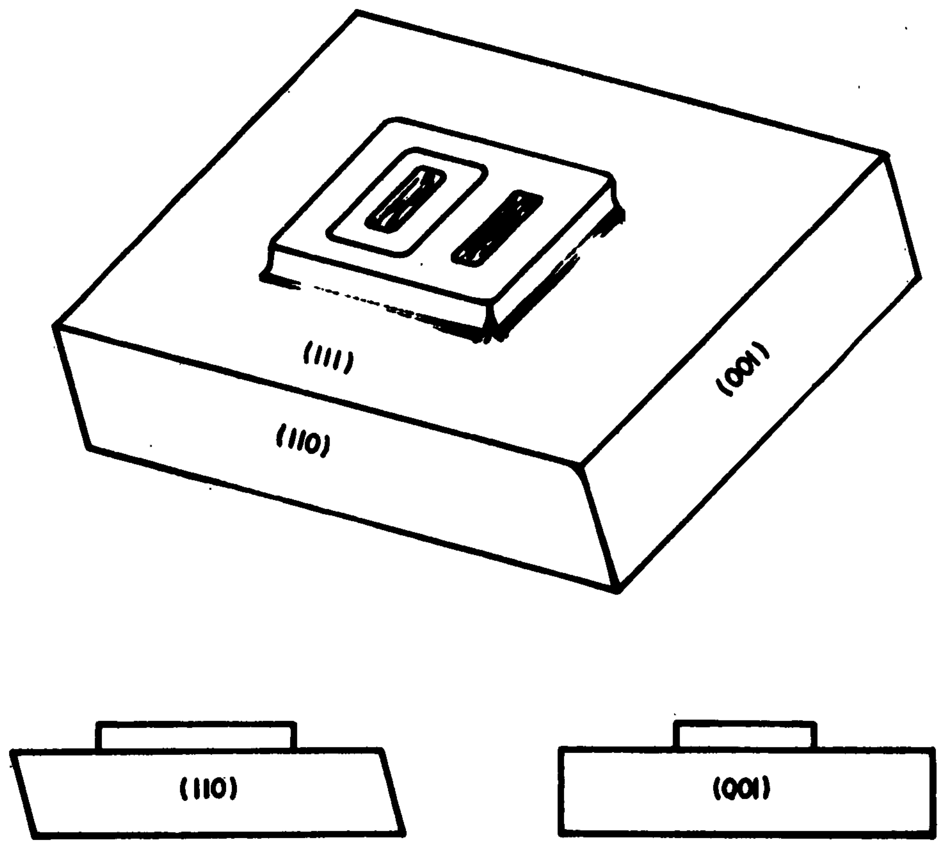


FIGURE 7.2-2

SECTION 7.3

INFRARED CONTROL DEVELOPMENTS

P. A. Lajoie

INFRARED CONTROL DEVELOPMENTS

I General

The ability to wafer bond is to a large extent dependent on the temperature created at the wafer to header interface and the duration of this temperature. The temperature for bonding is essentially the eutectic temperature for gold-silicon (or gold-germanium) and should be held at this level only long enough to produce the desired eutectic flow. The problem of heating a header to the eutectic temperature and maintaining it there does not become great until it is asked that the header rise from room temperature to slightly above the eutectic termperature in 3 seconds and remain there within ± 10 C^{o}.

Since the header is indexed in a nest to the bonding station, is heated by A-C current passage through the header, and indexed out of the bonding station, the measurement of the header temperature by contact means is not compatible with the method of heating nor with the operating times involved in the mechanized equipment. A method of temperature indication and control which would have a fast enough response to prevent overshoot and which would be reliable and repeatable became the objective in the development of an infrared detection and control system.

The use of infrared as a temperature indicator and as a feed back signal for temperature control has a drawback which must be recognized and compensated for when the heat radiating element is not one but many items in succession. The equation relating the intensity of the infrared radiation from and the temperature of a body has a factor called "emissivity". This factor is a property of the body material and surface condition. As long as the emissivity is the same for each item being detected, the infrared radiation is a function of temperature only and, therefore, differential variations in radiation are purely a function of differential temperature variations. However, on a production line, there is no guarantee that all the items being heated have the same emissivity. For variations in emissivity an error will occur in the temperature indication because the differential variations in the radiation become a function of both differential temperature variations and differential emissivity variations. In the infrared control system the nature of the control is feedback such that the infrared radiation is held constant by comparison to a set reference. If the equation relating temperature of a surface to the radiation given off is manipulated to show the effect of emissivity variations, the following is the result:

given $Q = EK\,(T^4 - T_a^4)$

where Q = radiation intensity

E = emissivity

K = constant of proportionality

T = temperature of radiating surface in degrees Kelvin

T_a = Ambient temperature in degrees Kelvin

$$\ln Q = \ln E + \ln K + \ln(T^4 - T_a^4)$$

$$dQ/Q = dE/E + dK/K + 4T^3dT/(T^4 - T_a^4)$$

since dQ is to equal zero by choice

and dK equals zero

then $dT = (T^4 - T_a^4)dE/4ET^3$

if $T = 400°C = 673°$Kelvin

and $T_a = 23°C = 296°$Kelvin

then $dT = -\ .963T/4E\ \ dE$

$dT = -\ .241\ T/E\ dE$

Therefore, a 20 percent spread in emissivity causes a temperature spread of 4.8 percent or ±16C° at 400°C. Since the infrared detectors used in the controllers do not exactly follow the relation just given the emissivity effect is not the same but is, in fact, lessened as shown in Section IV for the presently used controllers.

The availability of infrared sensitive photo-conductive cells lead to the incorporation of these into a pickup device which transmits to them the infrared given off by the heated header. The I-R cells provide a means for converting the infrared to an electrical signal for amplification so that a suitable control signal may be obtained. The control system which acts as a proportioning gate for the A-C current being passed through the header can be one of several that have evolved from the development work. The discussion of the various systems is part of the respective sections of this report which is written on a chronological basis.

II Initial Developments

During the summer of 1960 the first infrared temperature controller was constructed following a design of the Western Electric Research Center at Princeton, New Jersey. The circuit utilized a Kodak Ektron lead sulfide cell as the detecting element in a D-C bridge circuit where the magnitude and direction of unbalance against a set reference became a function of temperature. A stabilized D-C amplifier provided the proper magnitude of voltage with which the phase shifters were caused to provide alternate half waves of 60 cycle voltage at the required phase shift. The phase shift of the half wave was nearly a linear function of the D-C voltage over the range from 3 degrees to 177 degrees. The output of the controller was a push-pull thyratron arrangement in series via transformer coupling with the heating element. The thyratrons were controlled by the phase shifters. The operation of the closed loop system was as follows: (a) the initially cold header provided essentially no infrared radiation to the detector cell which, therefore, unbalanced the bridge; (b) the D-C amplifier, therefore, caused the phase shifters to provide full conduction firing for the thyratrons; (c) the bridge balance was approached as the header approached the desired temperature; (d) the decreased output of the D-C amplifier caused the phase shifters to lag the firing of the thyratrons thereby reducing the average conduction in series with the heating element; (e) the system stabilized at a constant firing angle when the heating element provided only the necessary power to maintain the infrared radiation at the desired level. Figure 7.3-1 shows the system block diagram. Focusing of the infrared on the detector cell was accomplished by sapphire light pipe transmission. The .050-mil diameter light pipe was held within a stainless steel collet, and with one end located approximately 1/8 to 1/16 inch from the header the infrared was carried to the cell at the other end. The attempt was to keep the cell physically as far away from the heated header as possible yet optically as close as possible.

The two serious drawbacks of the system were circuit instability and cell fatigue. The system would remain fairly stable only for short periods and then begin to drift badly. Little or no improvement resulted from attempts to cool the cell and the circuit.

The initial heating method was to use infrared projection from beneath the header. See Figure 7.3-2. A two lamp system drawing approximately 300 watts focused the infrared on a 1/2-inch-diameter area. An insulating material held the ceramic nest which in turn held the header. Since at the time only the TO-5 header was being considered for I-R control, the loss of more than 75 percent of the radiant energy did not seem unreasonable. The TO-18 header would have resulted in more than 95 percent loss of energy. While different heating lamps were being investigated at the Princeton Research Center, the experiment here uitlized the original projection lamp system of two Sylvania Tru-Focus lamps. The short life of these lamps, especially when mounted in the horizontal position, created a problem which spurred the search for a more suitable product. It also became apparent that the infrared from the heating lamps was interfering with the control system. This occurred because of the transmission through the glass around the leads on the header. Careful placement of the sapphire light pipe pickup alleviated the problem to a degree. In the light of the above facts, it was decided to investigate a different heating method altogether.

The passage of high current through the header, by the means shown in Figure 7.3-3, caused the header to generate its own heat. The rate of temperature rise was a marked improvement over that of the infrared heating system, and the efficiency was such that only 75 watts of power were needed to provide the same temperature as the 300 watts generated by the infrared lamps. Direct heating by the i^2r of the header eliminated the problems associated with the indirect radiation system and the bonding equipment developed around this concept.

III Chopper Type Controller

Early in 1961 the Princeton Research Center provided us with an improved infrared control system design for resistance heating. The detector cell was placed in an air driven chopper such that the infrared passed up from the header by the sapphire light pipe would be interrupted at a frequency of 300 to 500 cycles per second. This provides an A-C signal which can be amplified more readily and with greater stability. Drift of the cell itself is negated by allowing the cell to view an infrared reference source during the time the infrared from the header is interrupted. The A-C signal then becomes a function of the difference between the infrared from the header and that from the reference. With a synchronous signal developed within the chopper, phase comparison is made in a synchronous ring demodulator after several stages of amplification. The signals at this point are large enough and the demodulation of the two signals provides a D-C voltage the amplitude of which is proportional to the infrared difference and the polarity of which is indicative of the direction of the difference. In place of the thyratron arrangement which had to be transformer coupled, two silicon controlled rectifiers (SCR's) are used to directly control the current in the primary of the Flexiformer which steps up the current from 1 ampere to 80 amperes. The SCR's are gated in much the same way as the thyratrons. A phase shift network controlled by the D-C voltage from the demodulator provides the trigger circuit with a timed signal which allows the SCR's to conduct for the required duration of each half cycle of the A-C through the header. The percentage of conduction is proportional to the magnitude of the D-C voltage from the demodulator. In essence, the system provides for full A-C to pass when the header is cold and, as the infrared emitted approaches that of the reference, the demodulator provides less D-C voltage thereby causing the SCR's to conduct for only a percentage of each cycle of the A-C. The system balances, as did the previous system, when the header generates enough infrared such that any less would cause increased current and any more would cause decreased current. By varying the reference source, the header can be made to remain at any desired temperature up to that caused by 100 percent conduction. The system block diagram is shown in Figure 7.3-4.

The increased stability of the system, however, did not correct some of the problems which were associated with the mechanized approach to wafer to header bonding by resistance heating. The greatest problem was that of proper viewing on the header by the detector cell. The close viewing shown in Figure 7.3-8 proved to be a hazard because occasionally a cocked header would hit the light pipe collet causing damage to the sapphire rod. Also the proper relationship between the best current path, the best point to wafer bond, and the best practical place to view still had to be established. The 50-mil-diameter light pipe at a 45-degree angle with the header surface requires a viewing area of an equivalent 70-mil-diameter pipe excluding any spread which may exist from the tip of the light pipe to the header surface. There exists little tolerance in header positioning because of this requirement since it is undesirable that the viewing area include any of the lead holes or any of the eutectic flow. Attempts to view the side of the header did not result in any improvement and in some cases proved to be a definite disadvantage. The circuit itself was changed slightly just prior to the construction of two complete systems intended for use on the 8-station Wafer Bonding Machines. The use of a single SCR in a diode bridge corrected a condition which cropped up at intervals; namely, misfiring of one of the SCR's. No two SCR's fire exactly the same; and, if for some reason the trigger circuit varies, one SCR may not fire thereby causing half-wave rectified current in the Flexiformer primary. Currents approaching 50 amperes caused damage to the SCR's, switches, slip rings, and other associated equipment.

The two infrared temperature controllers constructed per a finalized design (see Figure 7.3-6) based on the prototype were installed on two of the Wafer Bonding Machines in June of 1962. It soon became apparent that their use for temperature control was not entirely satisfactory and the development of a new type of controller was begun. A great deal of maintenance on the two controllers (mainly in the chopper) caused concern as to their reliability. Damage to the light pipe was severe because of header cocking and improper setup. The systems did not appear to significantly improve the bonding and when the systems were not operating correctly there was little or no indication of the malfunction until it became serious.

IV Modular Type Controllers

The presently used infrared temperature control system resulted from the need to provide more than just a "blackbox" device and the need to eliminate the maintenance requirements with which the previous systems were plagued. In any control system used on production machinery, the operator, setup people, and maintenance must be provided with indications of what is taking place and if it is taking place correctly.

The modular type I-R controller is entitled so because of its modular design which lends itself to easy construction and maintenance. The availability of packaged circuit modules which can perform the desired functions made possible the rapid development of this control system using mathematics and block diagram planning (see Figure 7.3-5). A commercially available infrared pyrometer made by Infrared Industries has the features necessary for our purposes. Called a "Thermodot", this instrument provides a zero to 5 volt D-C output which is proportional to the fifth power of the viewed temperature. The optical pickup (see Figure 7.3-9) of the infrared on areas as small as 0.015 inch in diameter at a focal distance of 5 to 8 inches eliminates the crowding on the header experienced with earlier pickup methods and makes possible more desirable viewing especially on the TO-18 header. The control signal is obtained by amplifying the difference between the "Thermodot" output and a reference. The reference is taken from the positive power supply and can be varied from zero to 5 volts D-C. The differential amplifier is a packaged device which provides the function, $e_c = G (e_R - e_s)$. The gain G is determined by the resistor combination as shown in Figure 7.3-10. The two power supplies are also packaged circuits. The output of the amplifier is fed to a packaged SCR firing circuit designed to provide gate pulses for varying the percent current conduction of an SCR. The percent conduction is a nearly linear function of the amplifier output, and the relationship between the control functions is illustrated in Figure 7.3-11. The SCR is in a diode bridge exactly as in the chopper type controller (see Figure 7.3-12) and the action is the same as described in Section III. Essentially there is little difference in the way the modular controller works as compared to the chopper controller. The advantages gained are purely on operating and maintenance. The controller is shown in Figure 7.3-7.

The "Thermodot" unit, from which the control signal is obtained, having been designed as a laboratory instrument has features which are highly desirable for the type of device being heated. The optical system which eliminates the crowding at the header also provides a magnified view of the header so that line-up of the system on a particular spot on the header is easily made. The cross hairs in the eyepiece can also be used to assure that each station brings the headers in to exactly the same point. Periodic checks can be made on the viewing position and the header alignment simply by looking into the eyepiece. The meter on the "Thermodot" provides an indication of the temperature rise, the duration of the temperature rise, the duration of control, and (if it occurs) the lack of control. The meter is also used to set the reference simply by adjusting the reference such that the meter indicates control at a desired infrared level. This eliminates any error which may occur because of long term variations in the reference source which cannot otherwise be determined except by actually monitoring the reference directly.

In addition to alleviating the major operating problems associated with the previous control system, the prototype modular controller has required no maintenance since it was placed on the Wafer Bonding Machine in August of 1962.

The performance of the modular controllers has been very satisfactory except for the emissivity problem which has yet to be solved. At present a procedure has been adopted to minimize the effect of emissivity variation among the headers. Headers of different plating lots are not mixed but kept separate from one another, and only headers of a particular color and texture are used on a particular machine. This method of visual segregation of headers has helped to increase the yield on the bonding machines by allowing tighter temperature control and preventing the frequent adjustment of the reference. The following mathematical analysis shows the emissivity variation effect on temperature control.

given $S = EKT^5$ (from Thermodot Manual)

where S = Signal from Thermodot in volts

E = Emissivity of object

K = Constant of proportionality

T = Temperature of object in degrees centigrade

$$\ln S = \ln E + \ln K + 5 \ln T$$

$$\frac{dS}{S} = \frac{dE}{E} + \frac{dK}{K} + 5\frac{dT}{T}$$

since dS is to equal zero for control

and dK equals zero

then $dT = -dE \dfrac{T}{5E}$

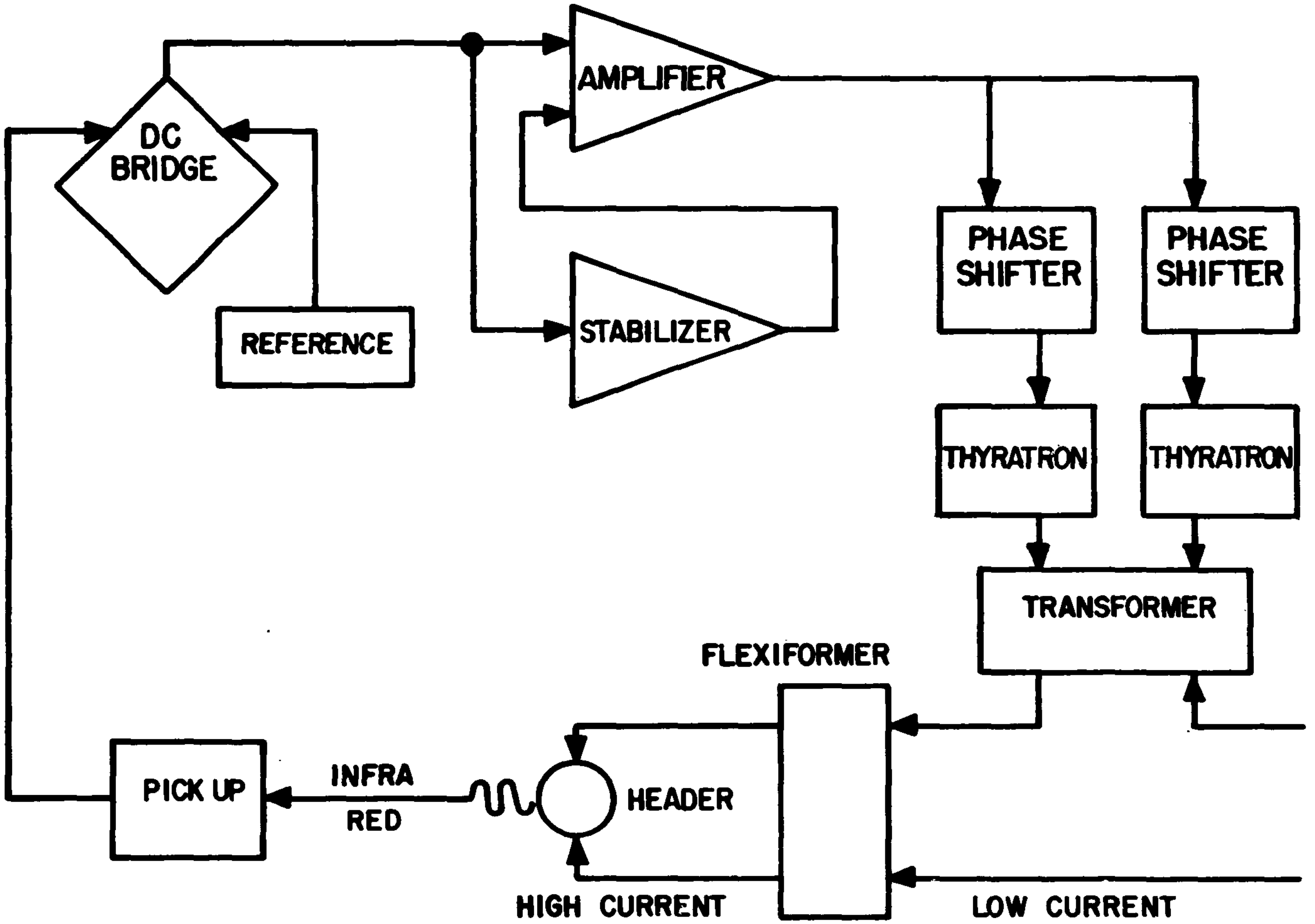
For a 20 percent spread in emissivity the temperature spread is only 4 percent or ±8 centigrade degrees at 400°C.

V Conclusion

Neglecting for the moment the emissivity problem, the only major improvement which would be desirable in the infrared controllers is that of faster response time. The chopper type controllers have only the short delay time associated with the filtering of the D-C out from the demodulator circuit which is in the order of a 25 milliseconds or less. The modular controller has a 30-millisecond response time associated with the "Thermodot" unit and a 30-millisecond response time associated with the magnetic firing network to total 60 milliseconds for the whole system. Investigation is being made into an infrared indicating instrument comparable to the "Thermodot" but with a 10-millisecond response time; and an SCR firing package capable of microsecond response time. At present the 60-millisecond response time of the modular controllers does not appear to be degrading except under adverse conditions where a particular header or group of headers may heat very rapidly for the particular initial power setting.

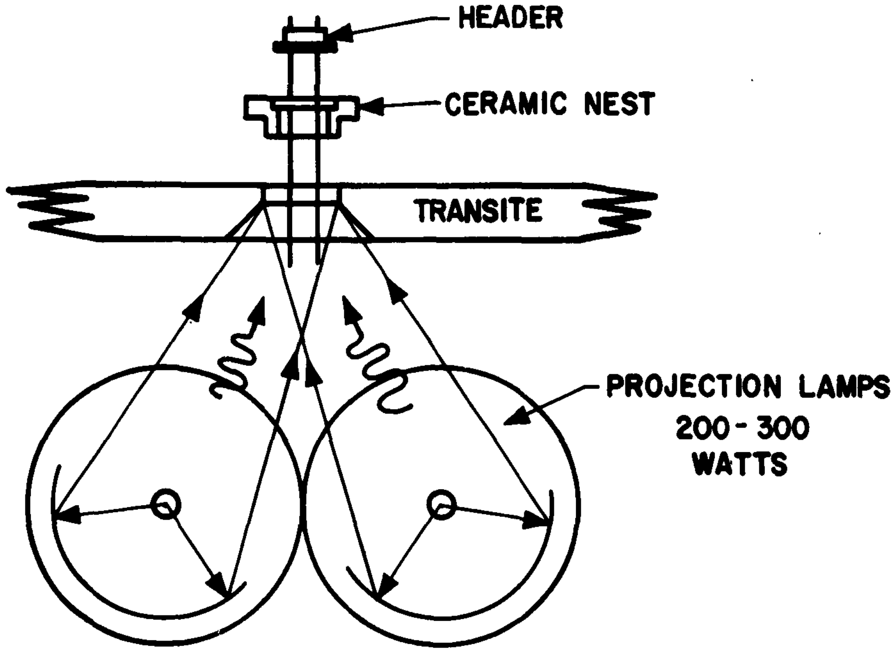
The effectiveness of the modular controllers makes them superior to any other system for use on mechanized wafer bonding equipment if this effectiveness is evaluated in the light of not only the actual control performance but also the operating and maintenance requirements.

Once it has been learned how to cope with the emissivity variations in the headers and the removal of this variation from the control function has been attained, then it can be said that the infrared control system will truly be a temperature control system of the first order. It will be a system capable of control within the temperature range of 250°F to 3000°F and capable of handling up to 75,000 watts of power (depending on the particular SCR used). Its application is unlimited although it has been developed here primarily for temperature control on mechanized wafer bonding equipment.



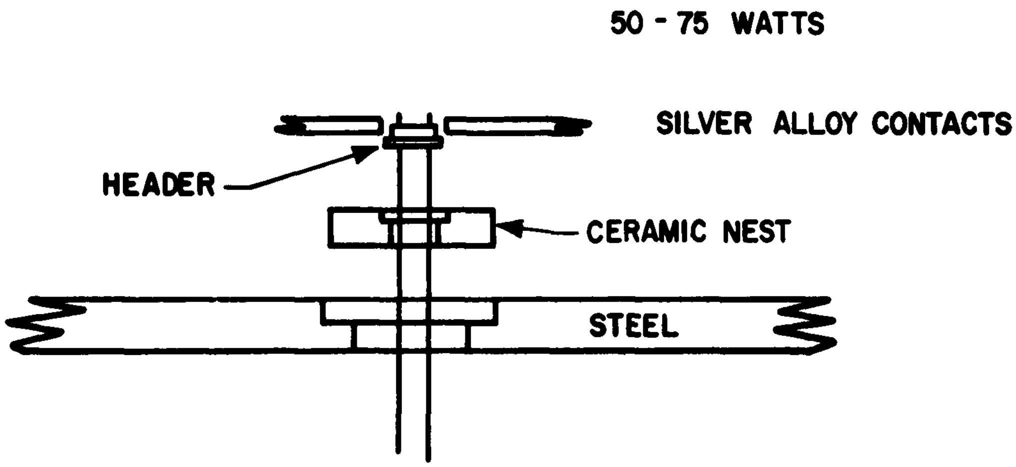
ORIGINAL INFRA RED CONTROLLER (MES-45631) 9/9/60

FIGURE 7.3-1



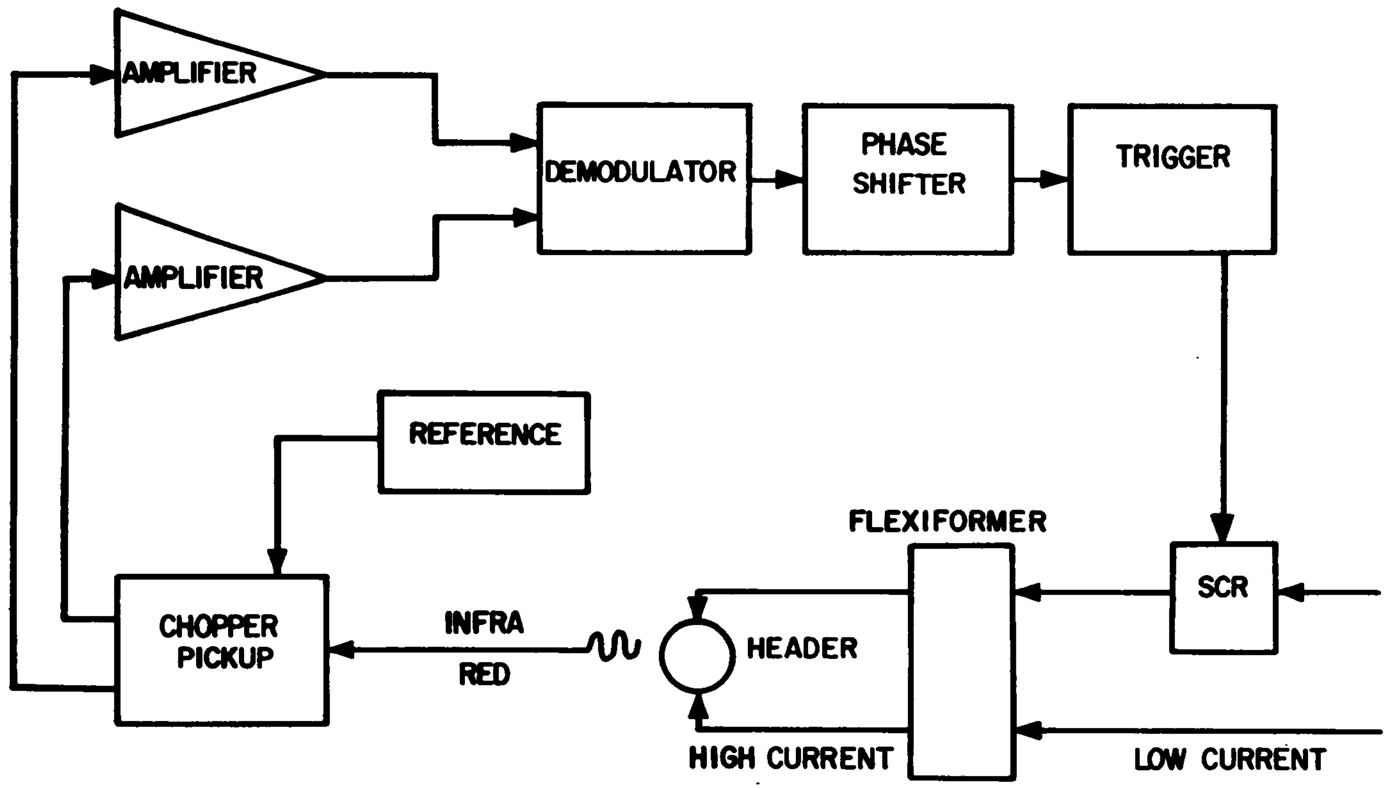
INFRA RED HEATING

FIGURE 7.3-2



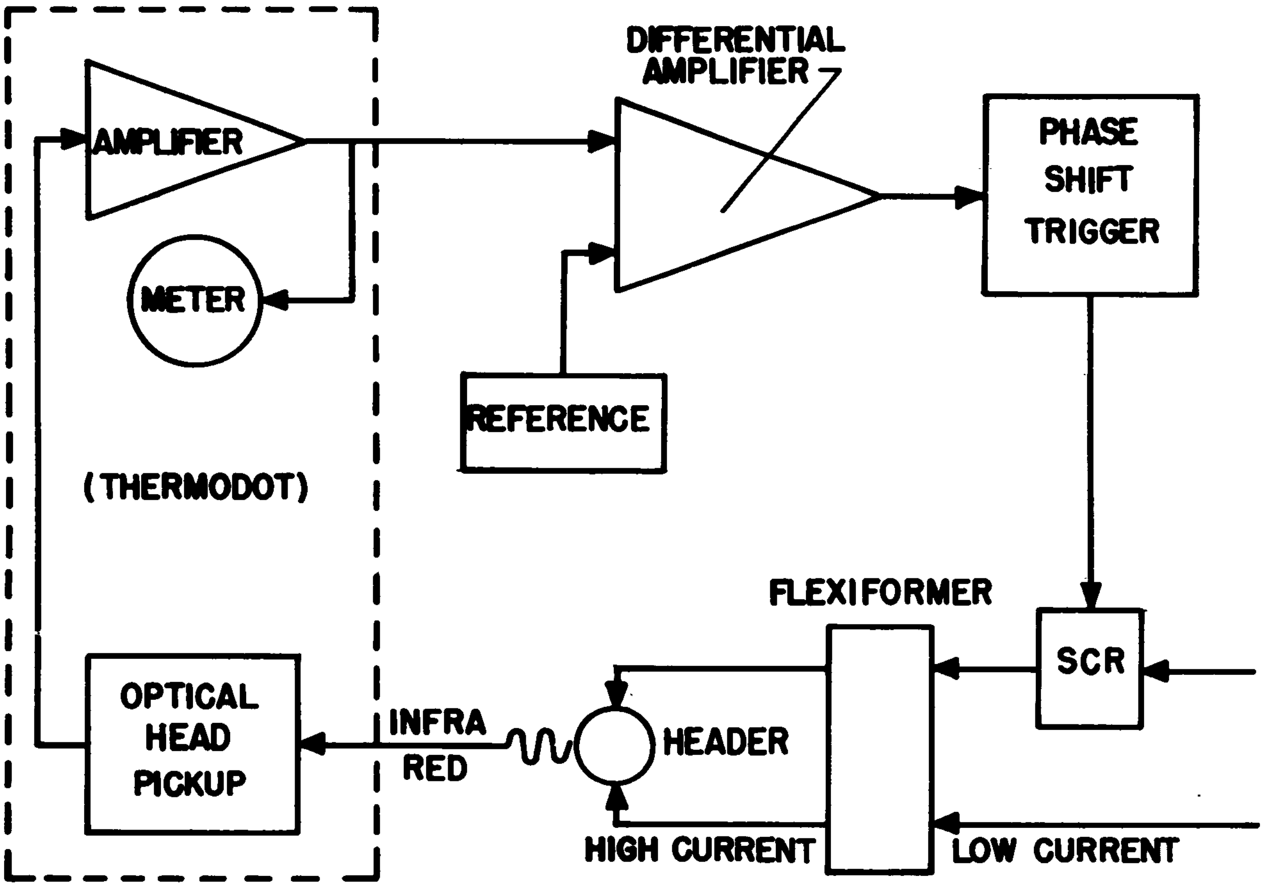
RESISTANCE HEATING BY HIGH CURRENT

FIGURE 7.3-3



CHOPPER TYPE INFRA RED CONTROLLER (SID-308204 12/12/61)

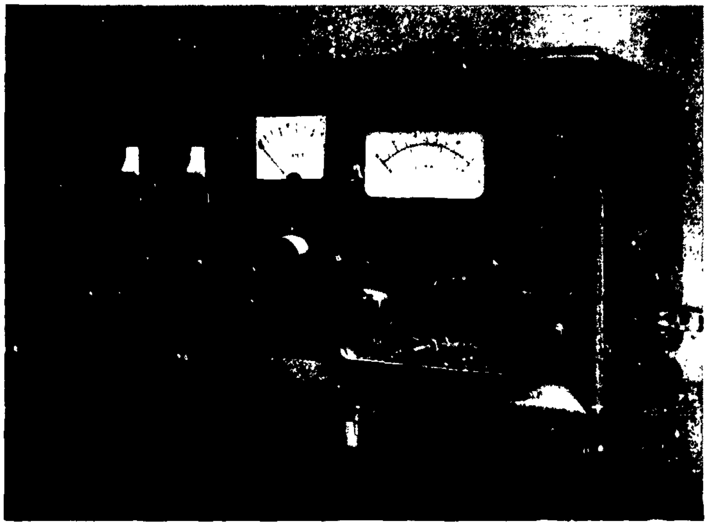
FIGURE 7.3-4



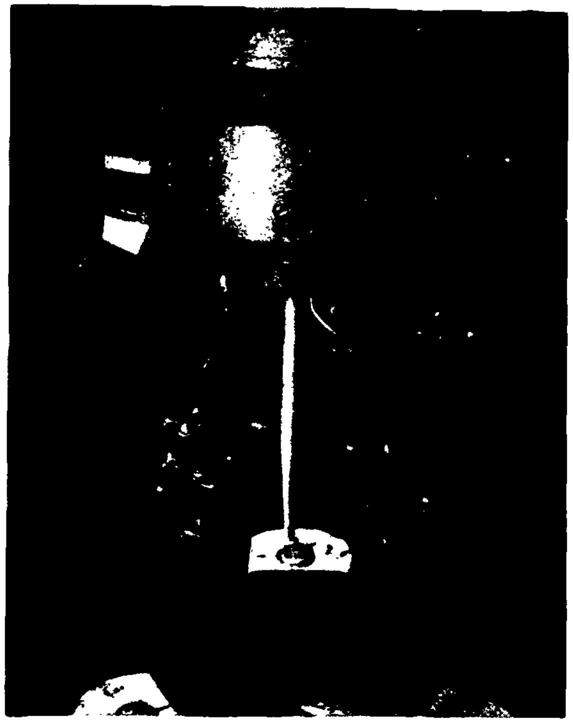
MODULAR TYPE INFRA RED CONTROLLER (SID 308244 10/8/62)

FIGURE 7.3-5

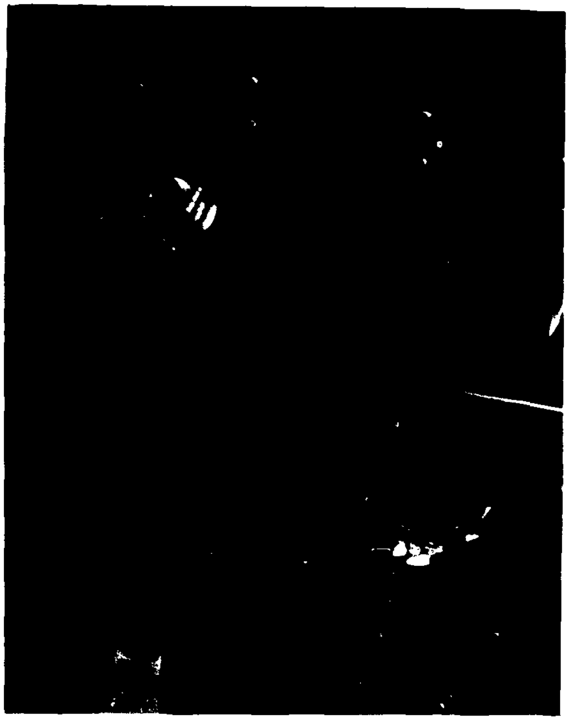
CONTROL CABINET OF CHOPPER TYPE CONTROLLER
FIGURE 7.3-6



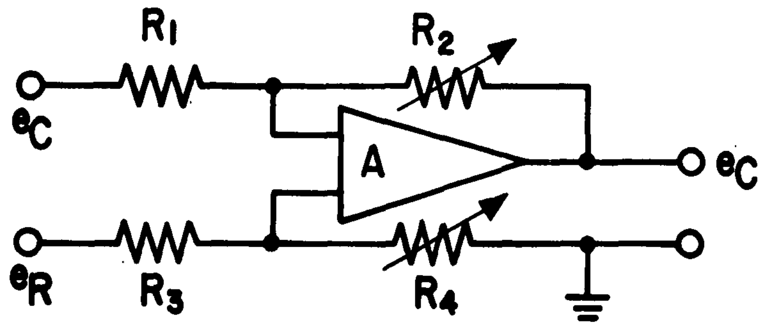
CONTROL CABINET OF MODULAR TYPE CONTROLLER
FIGURE 7.3-7



CHOPPER FOR CHOPPER TYPE CONTROLLER
FIGURE 7.3-8



OPTICAL PICKUP FOR MODULAR TYPE CONTROLLER
FIGURE 7.3-9



$$e_C = (R_4/R_3)e_R - (R_2/R_1)e_S$$

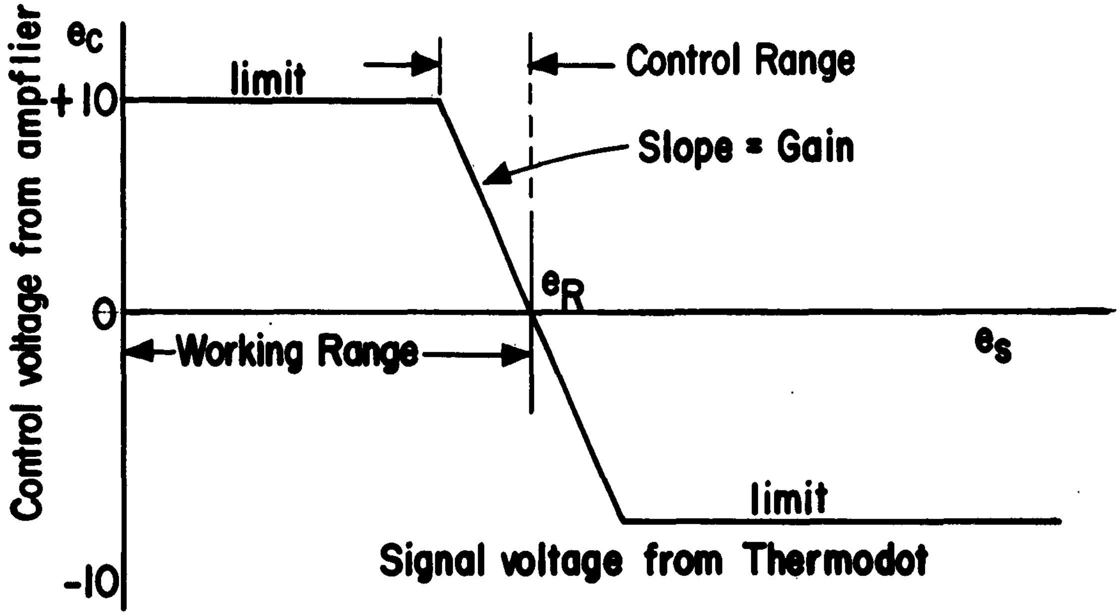
if $R_4 = R_2$ and $R_3 = R_1$

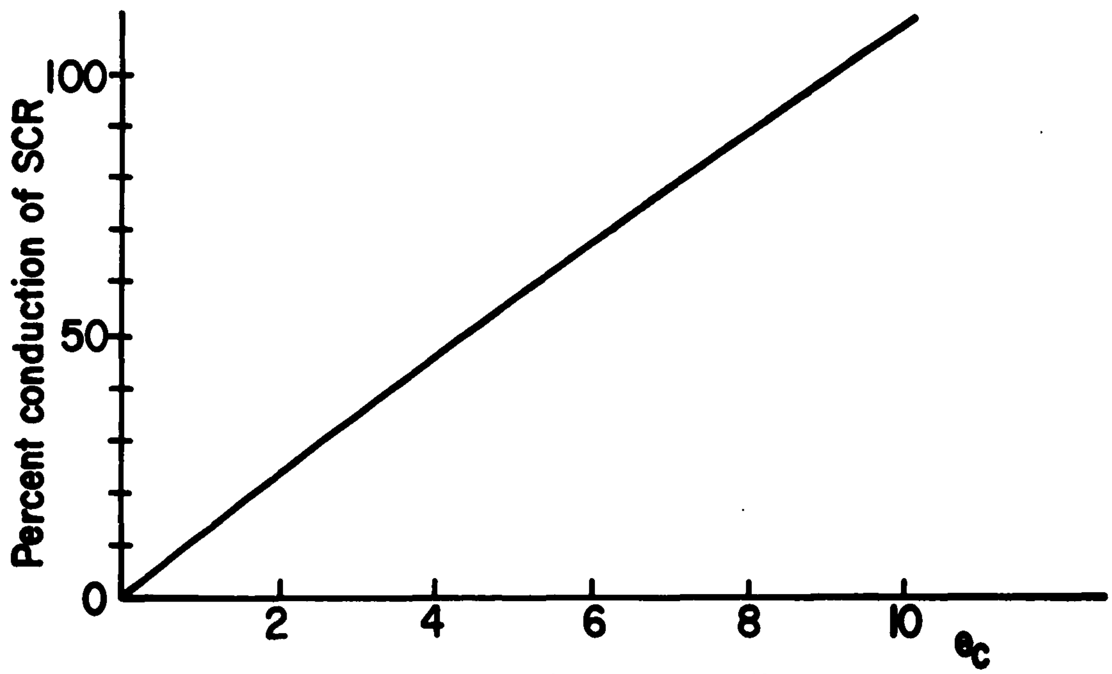
$$e_C = (e_R - e_s)\,R_2/R_1 \qquad R_2/R_1 = \text{Gain}$$

Increased gain provides closer control and greater sensitivity but can also lead to an oscilatory condition if it is set too high because of the time constants within the other components of the system.

MODULAR GAIN CONTROL

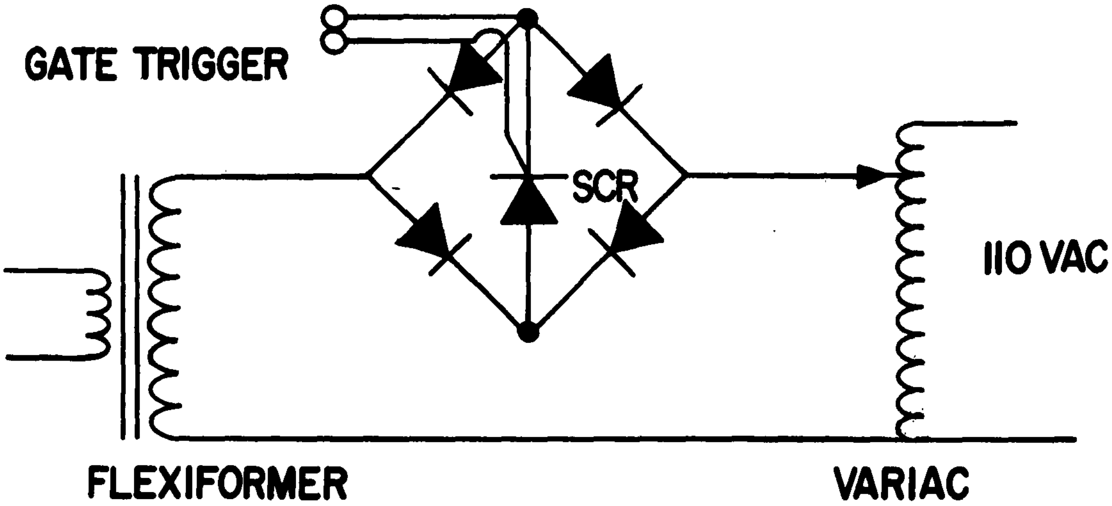
FIGURE 7.3-10



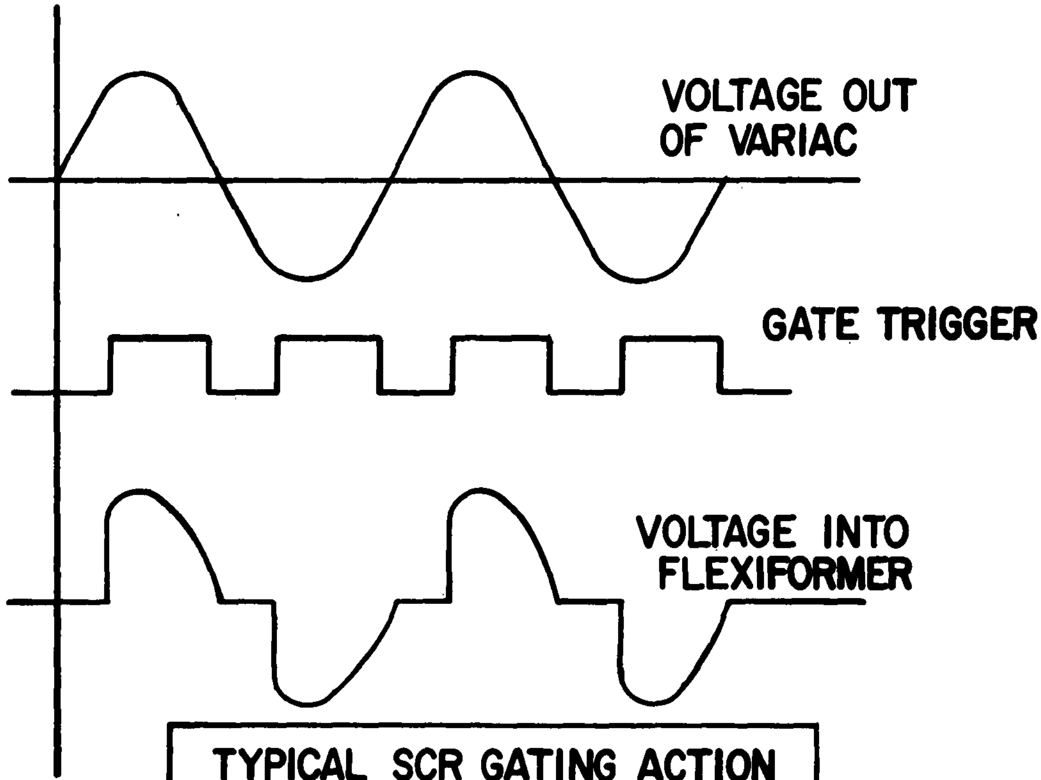


MODULAR CONTROL FUNCTIONS

FIGURE 7.3-11



DIODE BRIDGE



TYPICAL SCR GATING ACTION

FIGURE 7.3-12

SECTION 7.4

AGING OF TEST SOCKETS AT ELEVATED TEMPERATURES

K. C. Whitefield

AGING OF TEST SOCKETS AT ELEVATED TEMPERATURES

I General

This Test Socket Special Study covers work performed as a result of the October 1961 consideration of a combined production and data collection testing machine. At that time a change in the test specifications for Nike Zeus transistors was being proposed. It would have limited the amount of change in transistor characteristics due to elevated temperature aging. This study was made to evaluate the effect of elevated temperature aging on various commercial test sockets that might be used for such testing without removing the transistors from the test socket during aging.

The electrical characteristics of the sockets were checked by measuring their capacitance and resistance during aging. Several were found suitable for extended use at elevated temperatures.

II Sockets Tested

The sockets tested were those listed below:

Socket	Description
Loranger #2193	Standard black phenolic plastic body with in-line contacts
Loranger #2293	High temperature rated phenolic body with external brass studs for each contact
Jettron #72-104 & 72-106	Glass fiber reinforced diallyl-pthallate body with contacts on 200-mil pin circle
Atlantis #TS-187	Glass fiber reinforced black phenolic body with in-line contacts

Atlantis #TS-187-R Same as TS-187 except with special high temperature rated plastic body

III **Test Results**

Capacitance and resistance readings at 100 kc and 30 volts were made on a Boonton Capacitance Bridge 74C-58. The resistance readings indicate a power factor type of measurement reflecting the A-C power loss. The tests were continued for 63 days on a continuous basis with the following results being the average for the two samples of each socket tested:

Capacitance Test Data

Socket	Temp. °C	Contacts Checked	Start	7 Days	35 Days	63 Days
			Picofarads			
Loranger #2193	200	Collector-Base & Emitter Base	1.7	1.5	1.3	*
		Emitter Coll.	1.1	.9	.75	*
Loranger #2293	200	C-B & E-B	2.6	2.1	1.5	1.3
		E-C	1.8	1.5	1.05	1.0
Jettron #72-104 & 72-106	200	C-B & E-B	.8	.55	.6	.56
		E-C	.58	.42	.43	.4
Jettron #72-106	250	C-B & E-B	.8	.32	*	*
		E-C	.58	.35	*	*
Atlantis #TS-187	250	C-B & E-B	1.5	1.2	1.2	1.5
		E-C	1.0	.6	.6	.7
Atlantis #TS-187-R	300	C-B & E-B	1.55	1.32	1.4	1.2
		E-C	.8	.74	.78	.66

*These tests were discontinued due to physical deterioration of plastic body.

Resistance Test Data

Socket	Temp. °C	Contacts Checked	Start	7 Days	35 Days	63 Days
			Megohms			
Loranger #2193	200	C-B & E-B	50.0	100.0	Inf.	*
		E-C	55.0	Inf.	Inf.	*
Loranger #2293	200	C-B & E-B	3.5	8.1	10.5	12.5
		E-C	3.8	10.0	12.0	16.0
Jettron #72-104 & #72-106	200	C-B & E-B	Inf.	Inf.	Inf.	Inf.
		E-C	Inf.	Inf.	Inf.	Inf.
Jettron #72-106	250	C-B & E-B	Inf.	Inf.	*	*
		E-C	Inf.	Inf.	*	*
Atlantis #TS-187	250	C-B & E-B	12.0	45.0	14.0	6.0
		E-C	13.0	60.0	16.0	6.5
Atlantis #TS-187-R	300	C-B & E-B	Inf.	Inf.	Inf.	Inf.
		E-C	Inf.	Inf.	Inf.	Inf.

*These tests were discontinued due to physical deterioration of plastic body.

IV Observations

1. The copper alloy contacts all exhibited discoloration due to oxide formation but no oxide removal was necessary during the tests.

2. Much of the decrease in capacitance during these tests is due to the more complete polymerization of the plastic to provide a lower dielectric constant. The increase in resistance is also due to more complete polymerization of the plastic and subsequent decreases are due to degradation of the plastic into conductive material, usually carbon.

3. The greater change of these electrical characteristics

experienced in the first seven days is typical of most commercially molded thermo-setting plastic which is rarely completely polymerized as molded. Since the electrical characteristics are improved by the first seven days of aging at elevated temperatures, it may be desirable for some applications to apply such aging at 150°C to 200°C.

V Conclusions

1. The Atlantis TS-187-R appears suitable for 300°C use for several months.

2. Four sockets appear suitable for even longer use at 200°C - Loranger #2293, Jettron #72-104 and #72-106, and Atlantis #TS-187.

3. Periodic replacement of sockets or removal of oxide from the contacts would be required at these elevated temperatures.

SUMMARY

The 30 machines developed under this Production Engineering Measure provide the high volume production capability needed for the 2N560, 2N1051, 2N1072 and 2N1195 Transistors and the .4 Watt Family of Diodes. Material handling systems developed or procurred have minimized manual handling of the semiconductor devices and subassemblies. These systems maintain lead straightness and wafer and header orientation which are conditions required to operate the machines efficiently. As a result of the lead straightness requirements, three batch-type operations were mechanized not to increase the output but to preserve lead straightness for succeeding operations. Even so, a Lead Straightening and Racking Machine was needed for the diodes. Six mechanized diode operations follow a series of 11 process operations in which diodes are handled in bulk and individually.

Operation of the machines is, for the most part, simplified to the point that machine surveillance and periodic supplying and removing of materials now constitute the major duties of the operator. Loading and unloading of the five following machines still requires the full attention of an operator or operators. Intermediate steps are, however, timer controlled or performed automatically as the machines cycle.

1. Collector Lead to Platform Welding
2. Can to Header Closure Weld
3. Packing (Transistors)
4. Lead Straightening and Racking
5. Gold Plating

Three Wafer Screening Machines and the Wire Bonding Machine mechanize material handling, but require the full attention of an operator. Cycling of the Wafer Screening Machines is dependent on the rate at which an operator makes accept-reject decisions. Between successive cycles of the Wire Bonding Machine, the operator completes four wire bonds.

Since establishing machine production rates in the early part of Phase 1, transistor production requirements were halved. A number of transistor machines then had excessive production rates. Through adopting the integrated line concept, this capability has been made available for 2N559 and 2N1094 production of Contract No. DA-36-039-SC-72729. Nine machines are now scheduled for 2N559 and 2N1094 as well as 2N560, 2N1051 and 2N1195 processing. Four were modified so the TO-18 transistor of Contract No. DA-36-039-SC-72729 as well as the TO-5 transistors of this Contract can be processed.

Of the 19 transistor machines developed under this Production Engineering Measure, the following machines make special contributions to the Mechanized Transistor Production Line. All can be used for 2N559 and 2N1195 production as well as 2N560, 2N1051 and 2N1195 production.

1. Wafer Bonding (2 Machines)

   The mechanized eutectic bonding technique effected on these machines has improved the collector voltage, collector leakage current and saturation voltage characteristics on both germanium and silicon transistors. Adapting these machines for bonding the germanium wafers of 2N559 and 2N1094 transistors was readily accomplished. One machine was initially designed to eutectic bond germanium as well as silicon transistors.

2. Painting and Coating

This is the only transistor machine provided on either PEM Contract for Painting and Coating. It was modified late in Phase 1 to process 2N559 and 2N1094 transistors. A modification made near the end of Phase 1 simplified intermixing TO-5 and TO-18 transistor finishing. The machine can now be quickly set up to paint or varnish coat either package size.

3. Coding

A change in 2N559 processing led to modification of this machine so it could process TO-18 as well as TO-5 transistors. The smallness of the TO-18 package complicated transistor handling but the problem was resolved satisfactorily. Development of a combined driver-stamp has simplified setup and code changing. But a stamp cleaning problem must be overcome to reduce stoppages.

4. Packing

A highly reliable Packing Machine was provided by modifying a commercial packaging machine and adding a feeding mechanism. It will package a wide variety of semiconductors devices in a thin plastic package so long as the dimensions do not exceed 1/2 by 1/2 by 4 inches. The semiconductor case must, however, contain enough ferrous material to magnetically hold the device during packaging.

The reduction in .4 watt diode production requirements was one-third as great as for the 2N560, 2N1051 and 2N1195 transistors. So most of the production capability designed into the diode machines is still needed. Significant increases in output were realized at all mechanized operations except Stud Lead Cleaning and Gold Plating. Since these were batch-type operations capable of high output, lead straightness not high output were the primary goals of these two developments. A major portion of the engineering effort for the .4 watt diode mechanization program was expended on the following machines. They perform the more time consuming and critical operations and, therefore, have the most direct effect on the output and quality.

1. Gold Bonding

   This machine has multiplied the output per operator approximately 10 times. In addition, it eliminated a separate internal leads forming operation. A screening system added during the last months of Phase 1 not only screens the output but also monitors the quality. It automatically eliminates faulty assemblies and stops the machine if a series of faulty assemblies are made.

2. Etching, Oxidizing, Cleaning, and Drying

   The batch-type operation performed by this machine has an approximate output of 2,880 units per hour. While this output is in excess of the production requirements, it is a natural consequence of this type of operation. The machine furnishes control of the operation and ambient conditions and minimizes the influence of the operator.

3. Assembling Case to Stud and Welding

   Two significant contributions were made to the Mechanized Diode Production Line by the Assembling Case to Stud and Welding Machine.

   (1) It combines a manual assembly operation and a semi-automatic welding operation.

(2) It eliminated the uncontrolled ambient conditions of the semiautomatic welding operation.

The output of the machine will be increased additionally during Phase 2 by eliminating loading and unloading problems at the welding head.

4. Final Electrical Testing

A maximum output of 1800 diodes per hour can be realized from this machine. This significantly increases the capacity of the testing operation. It also provides a consistency and reliability unattainable manually. Bias conditions are preset for the ten .4 Watt Diode types. A self-checking system automatically rechecks all test modules for proper operation periodically. Any checking interval can be selected between 15 minutes and 24 hours. Correlation and repeatability evaluations indicated that the test decisions of the Final Electrical Testing Machine are consistent and reliable.

The mechanized production runs performed in the last months of Phase 1 afforded the first opportunity to evaluate the mechanized lines. Most machines were tested individually during shop trials, and major operating problems were overcome. Certain alternations were delayed until the mechanized runs were completed. Operating experience to date indicates that the output and efficiency of the mechanized lines can be increased by improvements in the following areas:

1. Simplifying setup and maintenance.
2. Reducing transistor and diode lead misalignment or developing handling systems with less critical lead straightness requirements.

3. Increasing reliability of vibratory feeders of the transistor feeding systems.

4. Mechanizing certain manual load and unload operations.

Engineering efforts will be directed toward improving these area and updating the mechanized lines during 1963. Associated operations as well as the mechanized operations will be improved. Mechanized production runs will be repeated during the last months of 1963 to evaluate the modification made earlier in the year.

While improvements in the foregoing areas will increase the production capability, they were not needed to complete the Phase 1 mechanized runs satisfactorily. Mechanized production runs were performed for each of the following transistor types - 2N560, 2N1051 and 2N1195. Similar runs were performed for the following ten diode types - 1N664, 1N665, 1N666, 1N667, 1N668, 1N669, 1N673, 1N697, 1N675 and 1N701. The mechanized run production of each device type passed all Group A and Group B inspection criteria and the distributions of Group A electrical parameters were normal. Thus, the quality level of all devices was maintained at the production levels established for Nike Zeus.

KEY PERSONNEL

Western Electric Engineering Personnel listed below had prime responsibility for administering the mechanization program and developing machinery during Phase 1 of the Contract:

J. F. Anderson

M. K. Avedissian

J. E. Beroset

J. H. Blewett

J. L. Chapman

D. D. DeMuzio

P. F. Fundinger

R. S. Greenberg

H. A. Griesemer

H. C. Grunewald

R. C. Hermann

H. J. Huber

R. W. Ingham

C. A. Karnish

P. A. Lajoie

R. P. Loeper

G. B. Loughery

C. A. Lowell

R. E. Moore

W. A. Schlemm

E. Sirianni

F. E. Tweed

K. C. Whitefield

Approximately 130,200 engineering hours were spent by Engineering Personnel of the Western Electric Company, Laureldale, Pennsylvania on the 2N559-2N1094 Mechanization Program during Phase 1, June 26, 1959 to December 31, 1962. At least one-third of these engineering hours were required for engineering services such as design, drafting, factory planning, and laboratory analysis.

During this same period, Bell Telephone Laboratories Personnel spent approximately 4,600 hours on technical problems and design changes associated with this mechanization program. Western Electric Engineers temporarily assigned to the Laboratories spent approximately an additional 1,800 hours on design and technical problems.

PUBLICATIONS AND REPORTS

Quarterly Progress Report No.	Period
1	June 26, 1959 to September 26, 1959
2	September 26, 1959 to December 26, 1959
3	December 26, 1959 to March 26, 1960
4	March 26, 1960 to June 26, 1960
5	June 26, 1960 to September 26, 1960
6	September 26, 1960 to December 26, 1960
7	December 26, 1960 to March 26, 1961
8	March 26, 1961 to June 26, 1961
9	June 26, 1961 to September 26, 1961
10	September 26, 1961 to December 26, 1961
11	December 26, 1961 to March 26, 1962
12	March 26, 1962 to June 26, 1962
13	June 26, 1962 to September 26, 1962