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3000-HP ROLLER GEAR TRANSMISSION DEVELOPMENT PROGRAM. VOLUME III. ROLLER GEAR MANUFACTURE

G. F. Gardner, et al

United Technologies Corporation

Prepared for:

Army Air Mobility Research and Development Laboratory

July 1975

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3000-HP ROLLER GEAR TRANSMISSION DEVELOPMENT PROGRAM

Volume III - Roller Gear Manufacture

Sikorsky Aircraft
Division of United Technologies Corporation
Stratford, Conn. 06602

July 1975

Final Report

Approved for public release; distribution unlimited.

Prepared for

EUSTIS DIRECTORATE
U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
Fort Eustis, Va. 23604

EUSTIS DIRECTORATE POSITION STATEMENT

This report is one of six volumes of the final report under this contract. The objective of this program is to conduct research on the feasibility of a high-reduction-ratio roller gear transmission of 3,000 horsepower. The roller gear unit is the 20:1 output stage of a growth S-61 aircraft type main transmission. This report covers the manufacturing methods phase of the overall program.

Extensive use was made of electron beam welding in the assembly of the components of the roller gear unit's compound pinions. Lack of previous electron beam welding experience for this complex hardware has been the primary reason for weld joint failures exhibited in the follow-on bench and aircraft tiedown tests, which are presented as individual reports in other volumes of this report. Ultrasonic inspection techniques were developed for the ultimate inspection of the welds and were used very successfully for the detection of weld voids when normal inspection techniques were ineffective.

The technical monitors for this contract were James Gomez and L. M. Bartone, Technology Applications Division.

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This report presents a survey of the manufacturing methods used in the production of the roller gear transmission. The bulk of the material contained herein deals with the roller gear components of the transmission because of the unique manufacturing problems they presented. No attempt is made to describe in detail the more conventional manufacturing processes employed in this program.

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The most significant aspect of the manufacture of the roller gear components was the extensive use of electron beam welding. This method of assembly was completely satisfactory with respect to holding critical dimensional tolerances; however, weld integrity, particularly in certain highly stressed joints, was a continual problem. Although weld joint design certainly contributed to the problems encountered, the presence of weld voids was certainly a major factor in the weld related fractures.

Ultrasonic inspection of the electron beam welds was very successful in the detection of weld voids. This method was developed when weld inspection by magnetic particles and X-rays proved ineffective. All three of these methods are discussed in detail as they relate to the roller gear program.

One other aspect of the roller gear program was the use of ZE41A magnesium alloy for the main housing instead of the more conventional AZ91 alloy. The use of the ZE41A alloy was very successful in this particular application.

PREFACE

This report, the third of six volumes dealing with the 3,000-HP Roller Gear Development Program, covers the manufacturing methods employed in this program. The program was conducted by Sikorsky Aircraft for the Eustis Directorate of the U. S. Army Air Mobility Research and Development Laboratory under Contract DAAJ02-69-C-0042 (Task 1G162207AA7201). The program was conducted under the auspices of Mr. L. Bartoné and Mr. J. Gomez of USAAMRDL. Mr. L. R. Burroughs was the Program Manager at Sikorsky Aircraft.

Appreciation is extended to Messrs. J. E. Keogan and P. Marinaccio of Sikorsky Aircraft and Mr. C. McCarty of The Buehler Corporation for their assistance in the preparation of this report.

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INTRODUCTION

With the advent of the improved turbine power plants and with the demand for better performance, it has become necessary to provide helicopters with lighter, more efficient, more reliable transmissions. One of the more interesting results of this search for improved transmissions has been the development of the roller gear drive transmission.

The roller gear drive consists of a roller friction drive compounded with a gear drive in a planetary or epicyclic arrangement. Earlier studies of feasibility and performance parameters by TRW, Bell and Sikorsky,[1-4] indicated that numerous advantages could be gained through the use of a roller gear drive in a helicopter transmission. Among these are improved efficiency, improved reliability, reduced height, reduced weight, and reduced gear noise.

Of primary importance to the operation of a roller gear drive such as that designed for the S-61 transmission shown in Figure 1 is the integration of rollers with the gears of the planetary gear train. These rollers, located on either side of the gear as shown in Figure 2, have outside diameters coincident with the pitch diameters of the gears. Besides contributing to the transmission of torque through friction, these rollers support

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1. Nasvytis, A.L., and Bauer, J.E., PARAMETRIC STUDY ON THE ROLLER GEAR REDUCTION DRIVE, Thompson Ramo Wooldridge, Inc.; USAAVLABS Report 64-29, U.S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, June 1965, AD619294.

2. Burroughs, L.R., and Chiavaroli, N.L., CH-54A HIGH SPEED ROLLER GEAR TRANSMISSION FEASIBILITY STUDY, Sikorsky Engineering Report SER-64202, Sikorsky Aircraft, Stratford, Connecticut, February 1967.

3. Bowen, C.W., Braddock, C.E., and Walker, R.D., INSTALLATION OF A HIGH REDUCTION RATIO TRANSMISSION IN THE UH-1 HELICOPTER, Bell Helicopter Company; USAAVLABS Technical Report 68-57, U.S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, May 1969, AD855747.

4. Nasvytis, A.L., and Hemlein, J.H., 1100 HP ROLLER GEAR DRIVE, TRW Mechanical Products Division; USAAVLABS Report 70-3, U.S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, January 1970, AD867795.

the gears in the optimum mesh position, i.e., parallel to each other at the pitch diameters. Parallel operation of gears at their pitch diameters is always desirable because in that position sliding friction is minimized, load is most evenly distributed, and contact is made across the greatest percentage of face width. With conventional means of support, positioning gears parallel to each other for operation at their pitch diameters is often difficult because of differential thermal expansion, manufacturing tolerances, and shaft deflections. These factors are eliminated or minimized with the roller gear drive.

Because of the use of rollers for support, conventional bearings are eliminated in all but the last row pinions where they are necessary to react the torque through the planetary system. A twofold saving of weight results from the elimination of the bearings. First, the total weight of the extra rolling surfaces on the gear cylinders is less than the corresponding bearing and bearing shaft weight. Second, the elimination of the bearings permits the use of the smallest gears compatible with load carrying ability. In conventional planetaries, the use of larger gearshafts is sometimes necessary to accommodate larger bearings needed to react shaft loads. In addition, the roller gear drive eliminates the centrifugal forces induced on bearing rollers or balls, making the roller gear design one of inherently longer life.

Development of the roller gear drive began in 1963 with a parametric study of the concept at TRW, Incorporated, under the direction of Dr. A.L. Nasvytis, the inventor of the roller gear drive. This study examined the applicability of the roller gear drive principle to helicopter power trains. Various basic designs were examined to assure that no obstacles would preclude the use of the roller gear drive in helicopter transmissions. The possible effects on helicopter drive trains were also examined considering only state-of-the-art design methods and materials. The conclusion of this study was that the roller gear drive appeared superior to conventional planetaries with respect to weight, reliability, vibration, life and efficiency.

Development work at TRW, Incorporated, continued in 1964 and 1965 with the design, fabrication, and testing of a roller gear power transmission capable of accepting 200-horsepower loads at 28,000 rpm. This transmission was tested for over 1000 hours in a regenerative test stand at TRW under the direction of Dr. Nasvytis. The successful completion of this test, with gearbox efficiencies running 98 percent and better, indicated that the roller gear drive was indeed a potentially valuable addition to helicopter transmission technology. It remained, however, to test a roller gear drive transmission at powers more representative of actual aircraft conditions.

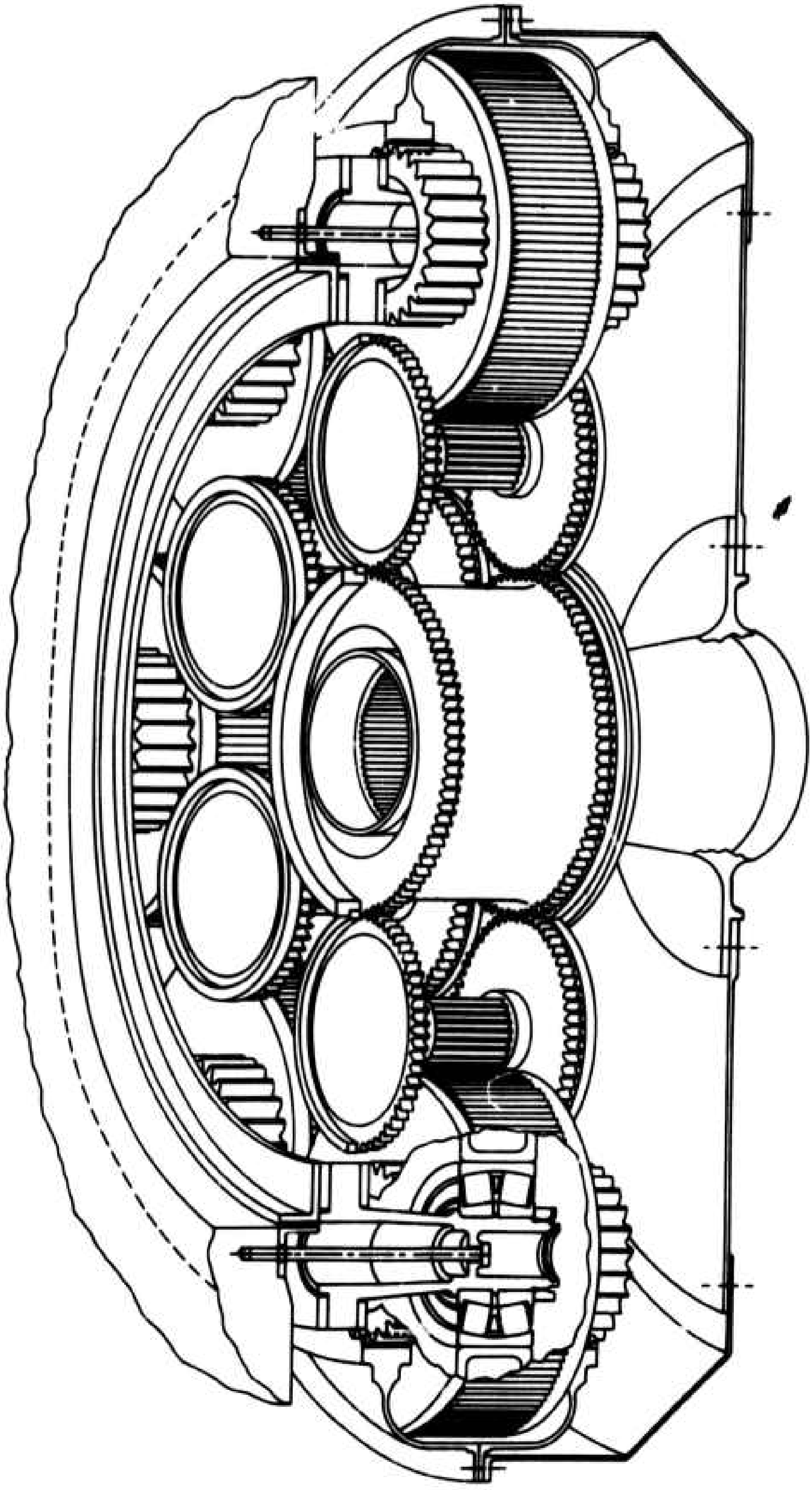

Figure 1. Sikorsky Roller Gear Drive.

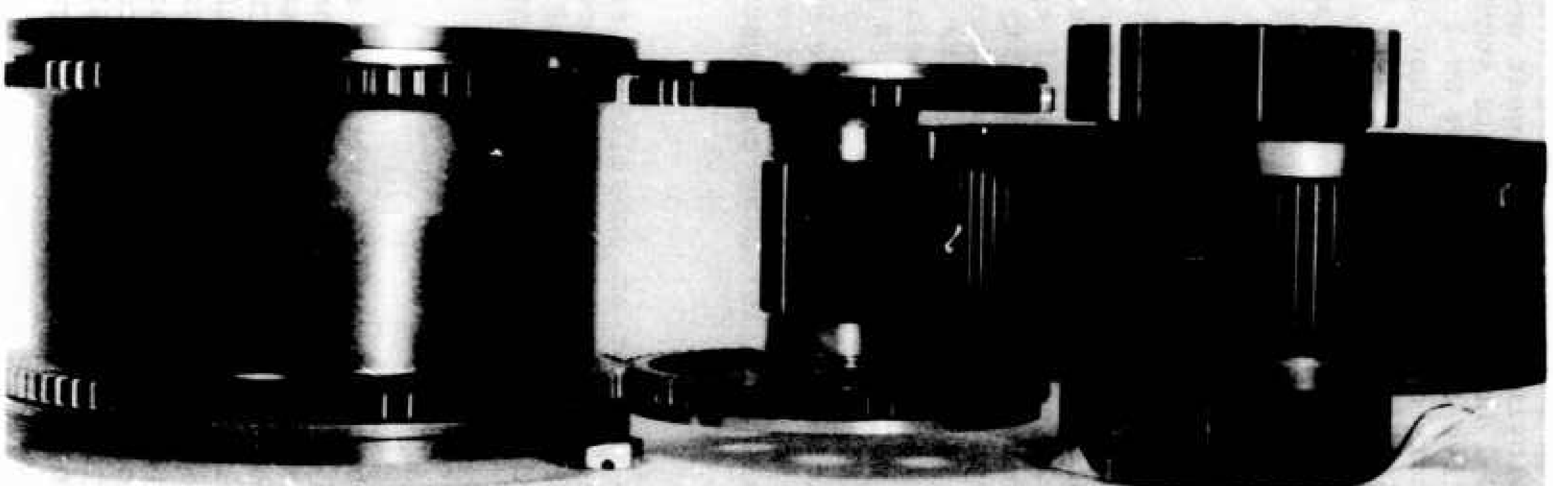

Figure 2. Sun Gear, First-Row Pinion, and Second-Row Pinion Arrangement.

In 1968 and 1969, the Bell Helicopter Company of Fort Worth, Texas, conducted an engineering design study to determine the feasibility of employing the roller gear concept in a transmission for the UH-1 helicopter. This study, which compared the roller gear drive to the existing UH-1 transmission and a new 3-stage planetary design, showed that in the areas of efficiency and reliability the roller gear drive was the potentially superior design. The roller gear drive ranked last only in fabricability/cost of the areas examined, while ranking second to the new 3-stage planetary in weight.

Meanwhile TRW had proceeded to design and fabricate an 1100 hp roller gear drive unit for the U. S. Army Air Mobility Research and Development Laboratory. This transmission, which converted an input speed of 21,000 rpm to an output speed of 325 rpm, was then tested in a regenerative test facility. Initial testing of this transmission in early 1969 resulted in failure after less than 3 hours at full load. While the failure investigation was inconclusive, it was believed that failure was caused by the rotation of rollers on a gear. These had been assembled by means of a shrink fit. This same transmission logged 76.5 hours of back-to-back testing before failure occurred in the gear, after design modifications. Again, the cause of failure was a roller gear component.

While this program was not an unqualified success, certain results, particularly efficiency, were especially encouraging and the program served to delineate some of the difficult problems associated with the design and manufacture of a roller gear unit.

Sikorsky Aircraft became involved with the roller gear drive with a feasibility study conducted under the direction of Mr. L. R. Burroughs in 1966. This study examined the potential application of a roller gear drive to the CH-54 helicopter main transmission. While this study concluded that the roller gear drive was not feasibly applicable to this particular aircraft, this study and subsequent independent research and development studies into the roller gear drive by Sikorsky Aircraft led to the present roller gear program for the S-61 aircraft. A brief outline of this program is presented in Figure 3.

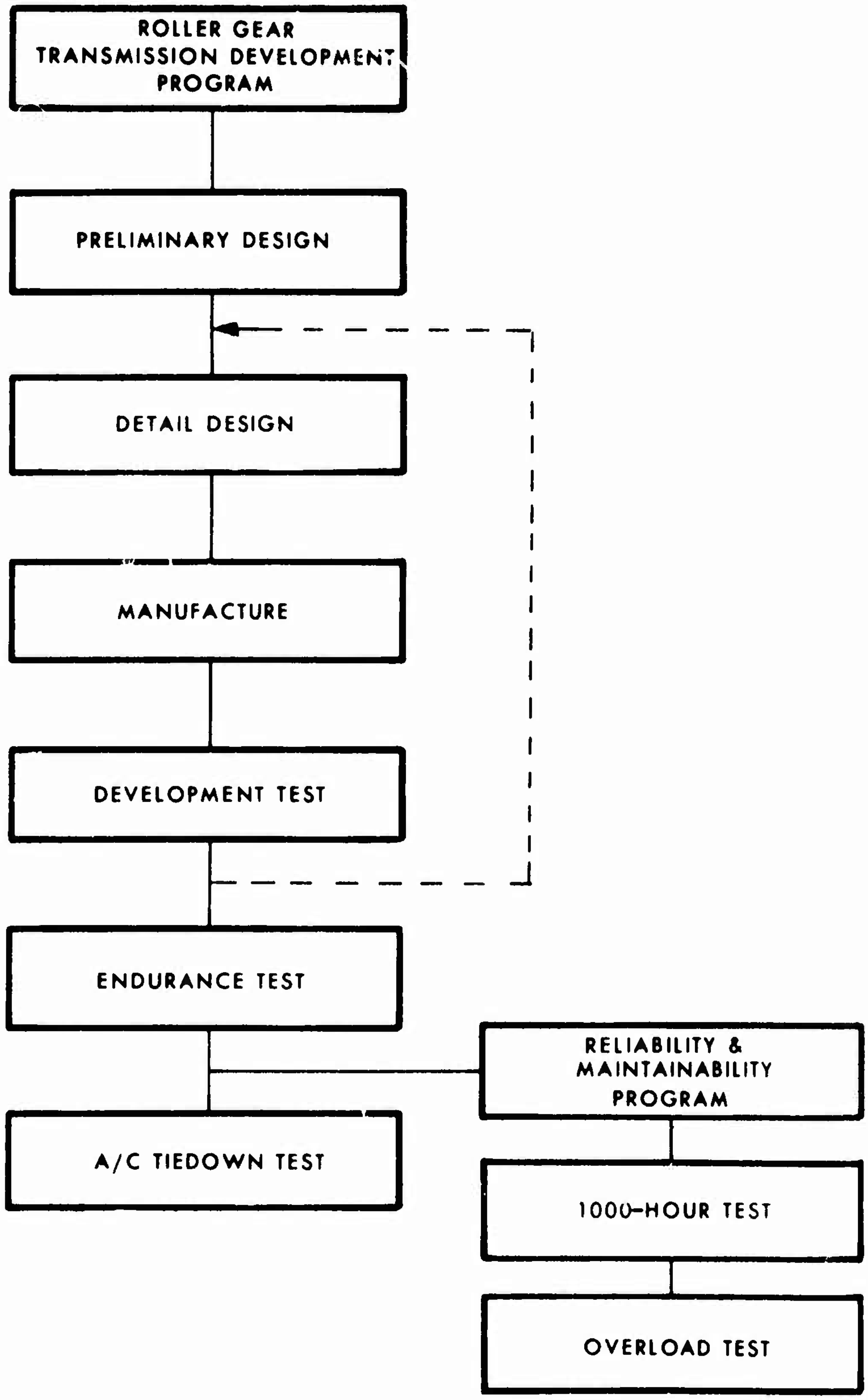

Figure 3. Sikorsky Roller Gear Program.

Because of the complexity of many of the components of a roller gear drive, the examination of manufacturing and inspection procedures is of particular interest. This report summarizes these procedures and their development as they apply to the S-61 Roller Gear Transmission.

ROLLER GEAR TRANSMISSION

The roller gear transmission of this program, shown in Figure 4, was designed for use with a 27,000-pound gross weight growth version of the S-61 helicopter. A schematic diagram, shown in Figure 5, illustrates the transmission's basic arrangement. Power from twin T58-GE-16 engines is fed into the main transmission through two 3.05:1 reduction ratio spiral bevel meshes located on either side of the main transmission. From these meshes, power is fed through the ramp roller clutch type freewheel units to spur gears which mesh with the combining spur gear whose centerline is common with the centerline of the main rotor shaft. A quill shaft attached to the combining spur gear shaft feeds power to the 19.85:1 reduction ratio roller gear unit. Here power is transmitted to the sun gear by splined attachment from the quill shaft. It then passes through the two planetary pinion rows of the roller gear unit out to the rotating ring gear. Power transfer from the ring gear to the main rotor shaft is accomplished with a splined connection at the main rotor shaft. Power to the tail and accessories is transmitted through a spiral bevel mesh located on the shaft between the combining spur gear and the roller gear unit.

The cross-sectional view of Figure 6 shows the detailed assembly of the transmission. Note that the only bearings present in the roller gear portion of the transmission are the spherical roller bearings at the second-row pinions. Conventional combinations of ball and roller bearings are used to support all other gear shafts. The input bevel pinion, because of the input speed of 18,966 rpm from the engine, employs a four ball bearing stack in addition to a roller bearing to provide axial and radial support.

The ramp roller clutch type freewheel unit, shown in Figure 7, is located between the input bevel mesh and the combining spur mesh. This unit is in the driving mode when the engine tends to turn faster than the main rotor shaft. It is in the freewheel mode when the main rotor shaft tends to turn faster than the engine. This clutch permits autorotation and single-engine operation without rotation of the other engine. It also acts as a safety device in the event of engine failure, by permitting safe descent by autorotation.

A cross section of the roller gear drive is presented in Figure 8, while Figure 9 shows the roller gear component arrangement from the top. The sun gear is connected to the quill shaft by a floating spline and is supported in the axial direction by the rollers at the first-row pinions. The first-row pinion contains two outer spur gears which mate with the sun gear and an inner spur gear which mates with the second-row pinion. The first-row pinion is accurately positioned at one point on the inside by the sun gear and at two points on the outside by the

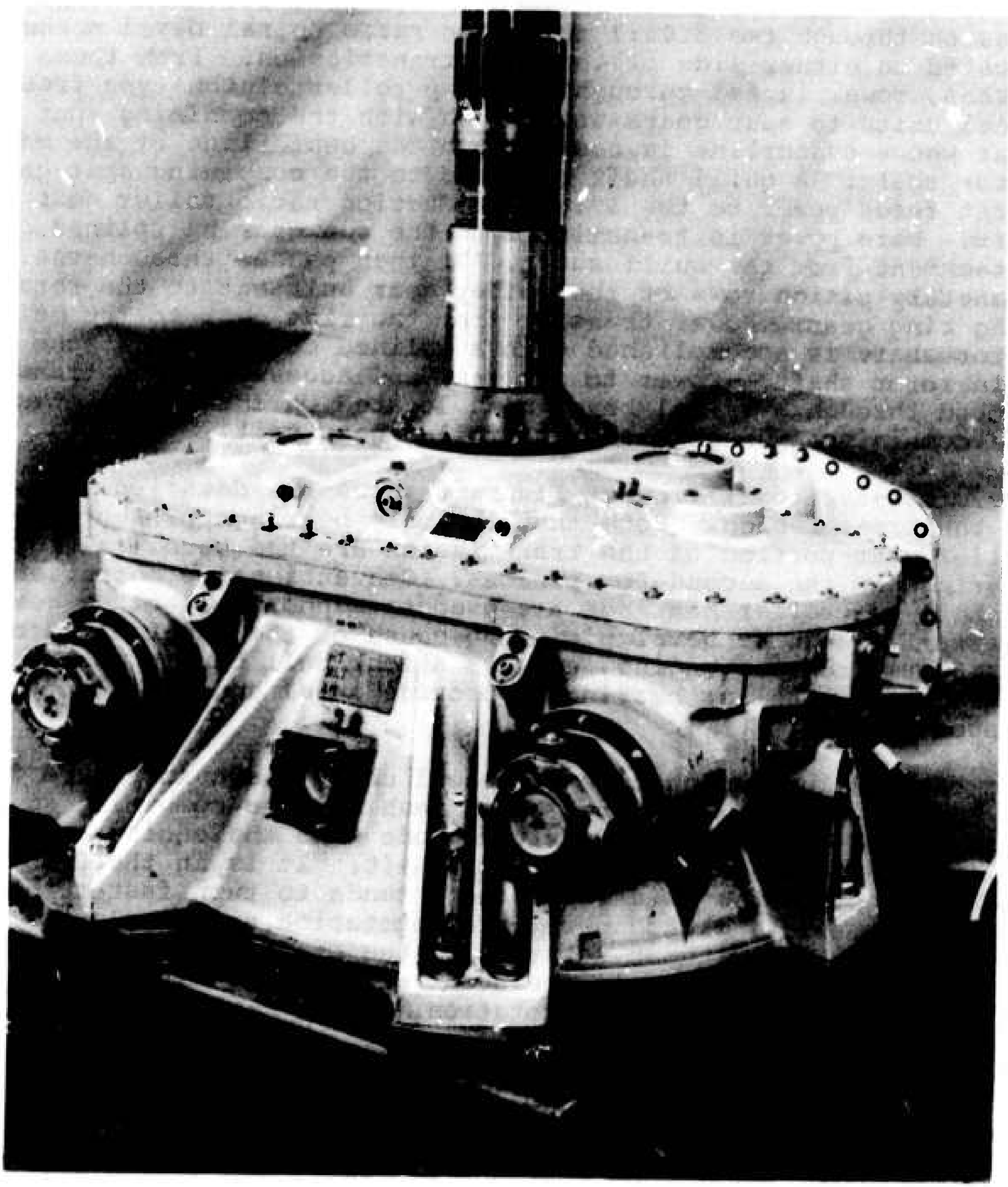

Figure 4. Roller Gear Transmission.

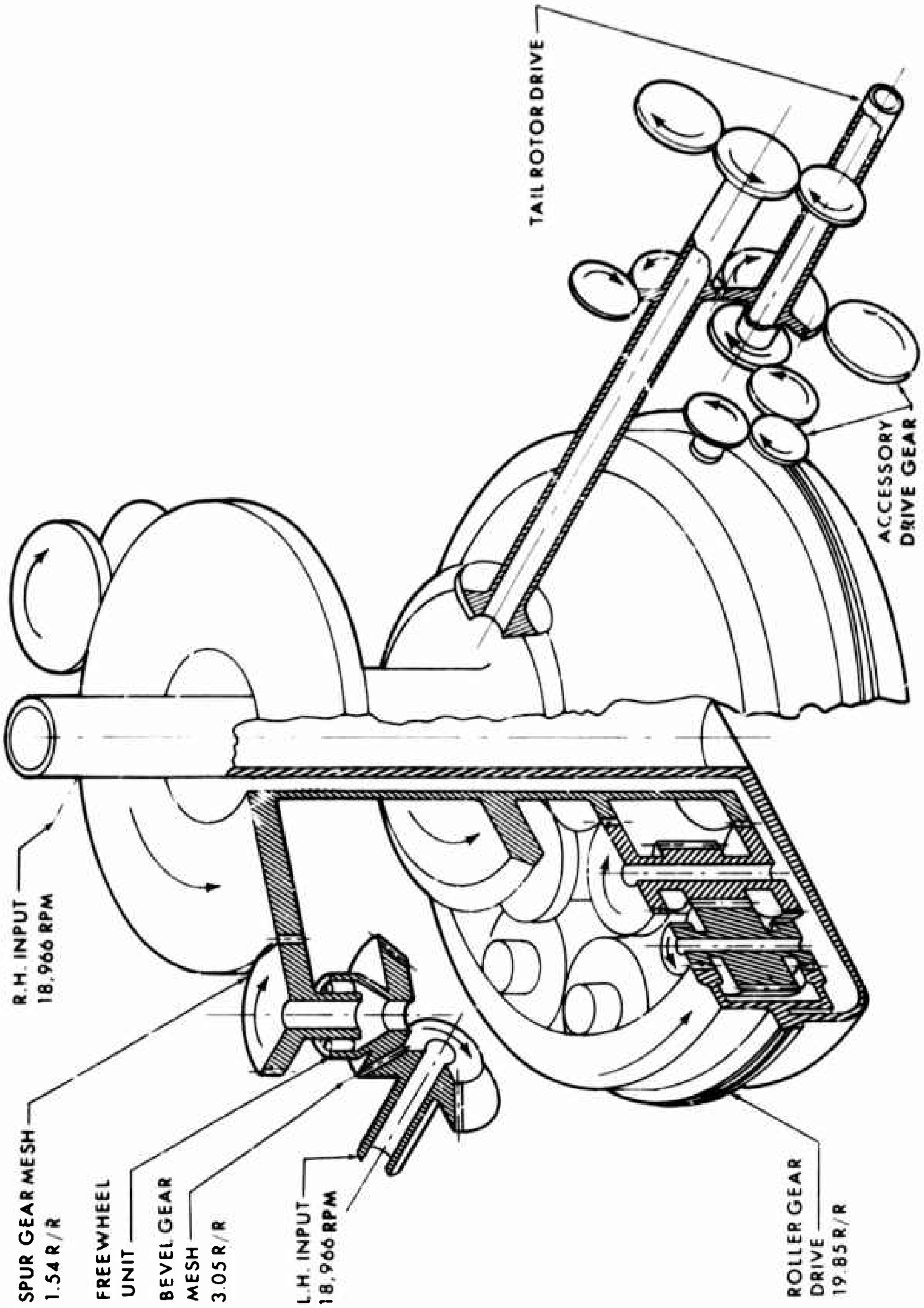

Figure 5. Roller Gear Transmission Schematic.

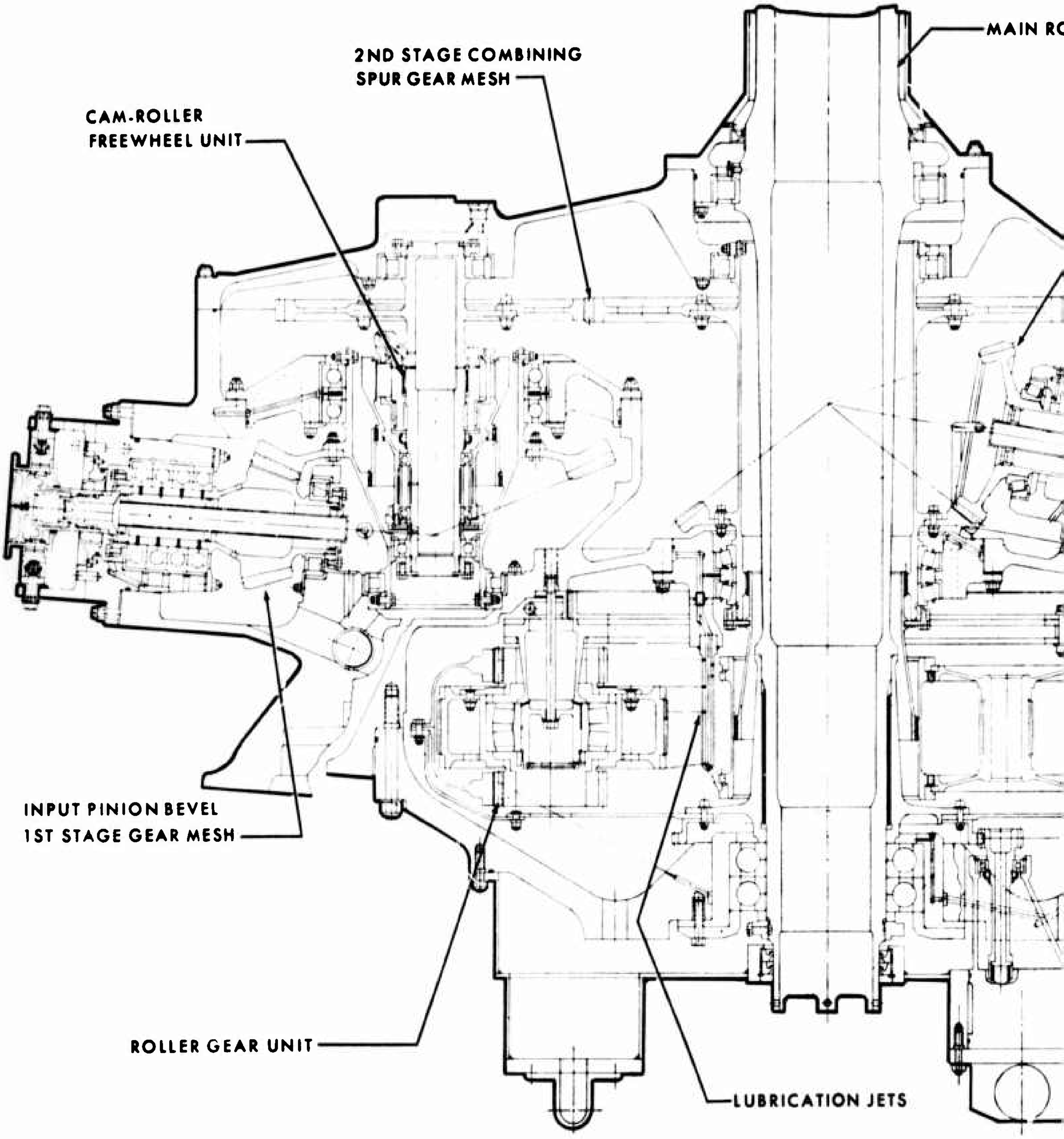

Figure 6. Cross Section of Roller Gear Transmission.

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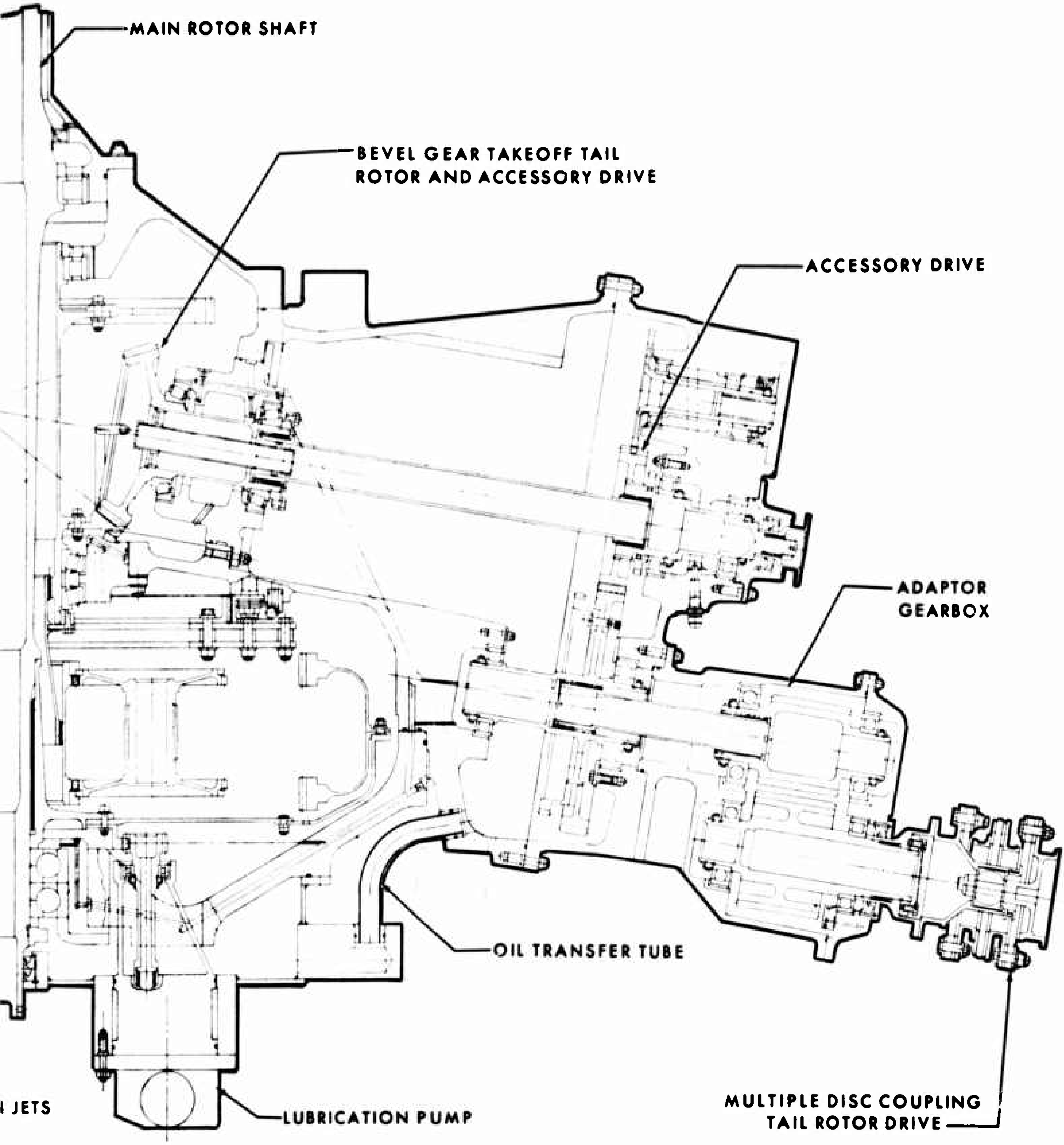


MAIN ROTOR SHAFT
BEVEL GEAR TAKEOFF TAIL ROTOR AND ACCESSORY DRIVE
ACCESSORY DRIVE
ADAPTOR GEARBOX
OIL TRANSFER TUBE
JETS
LUBRICATION PUMP
MULTIPLE DISC COUPLING TAIL ROTOR DRIVE

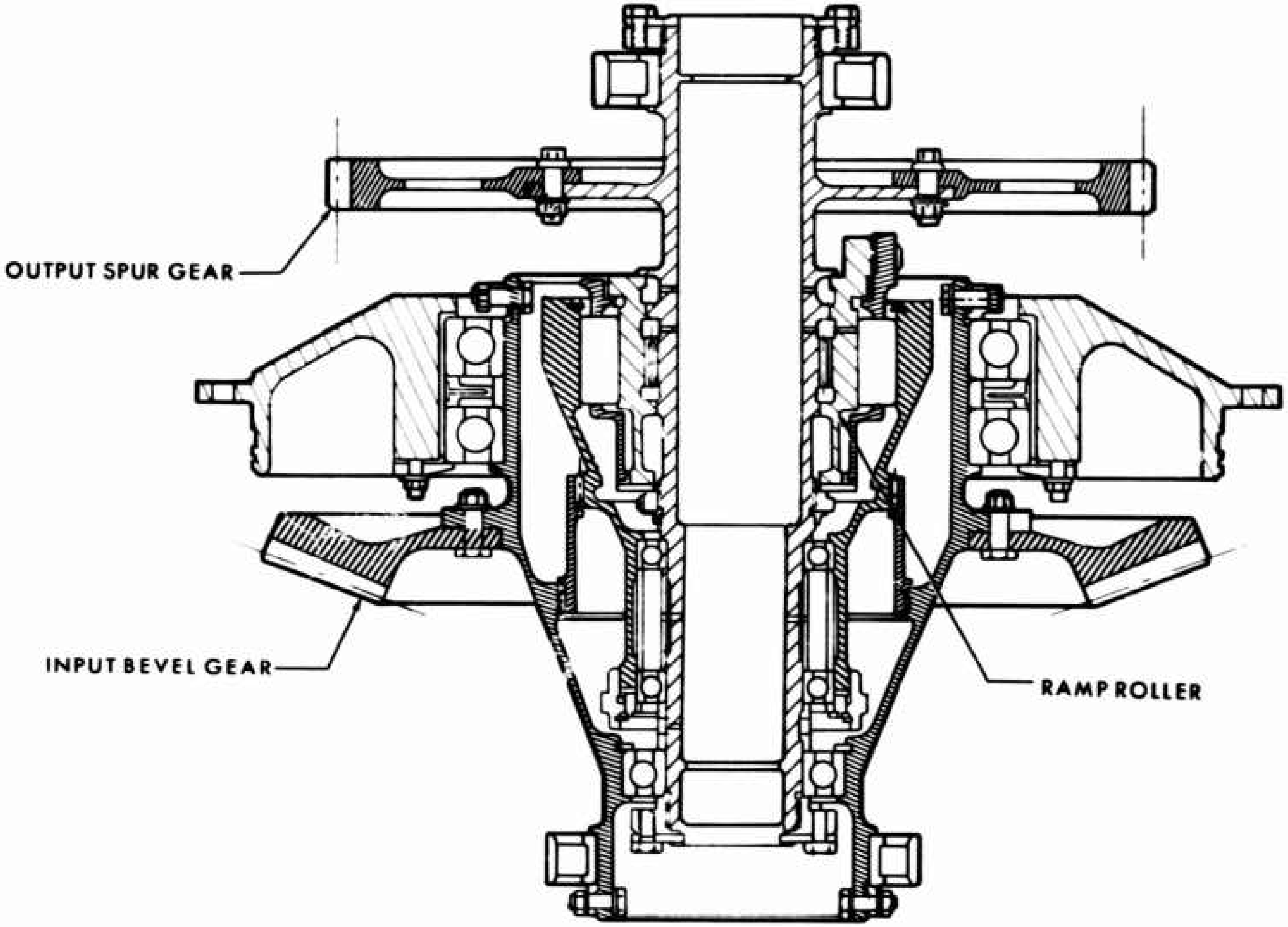


Figure 7. Roller Gear Transmission Freewheel Unit.

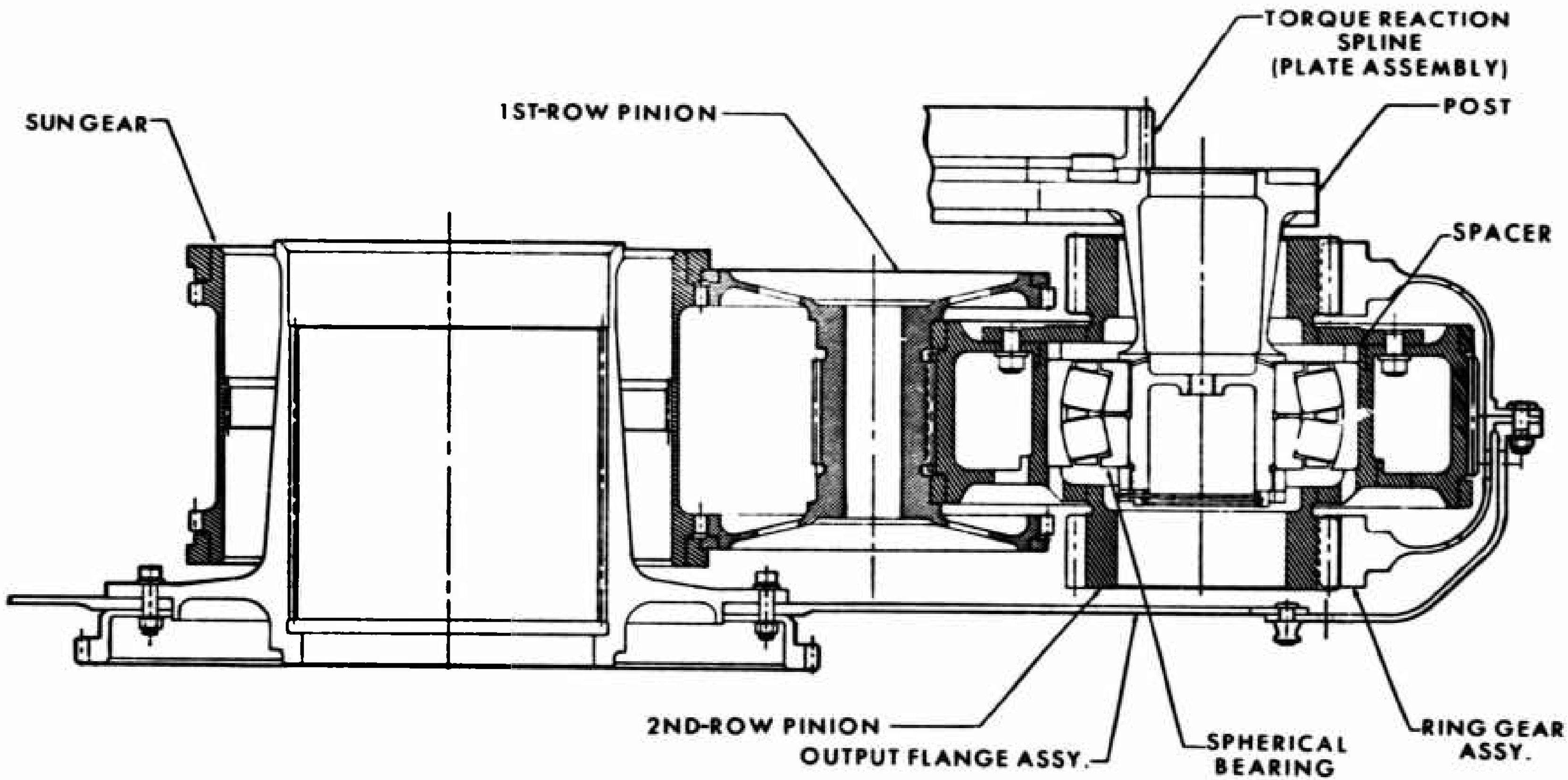


Figure 8. Cross Section of Roller Gear Unit.

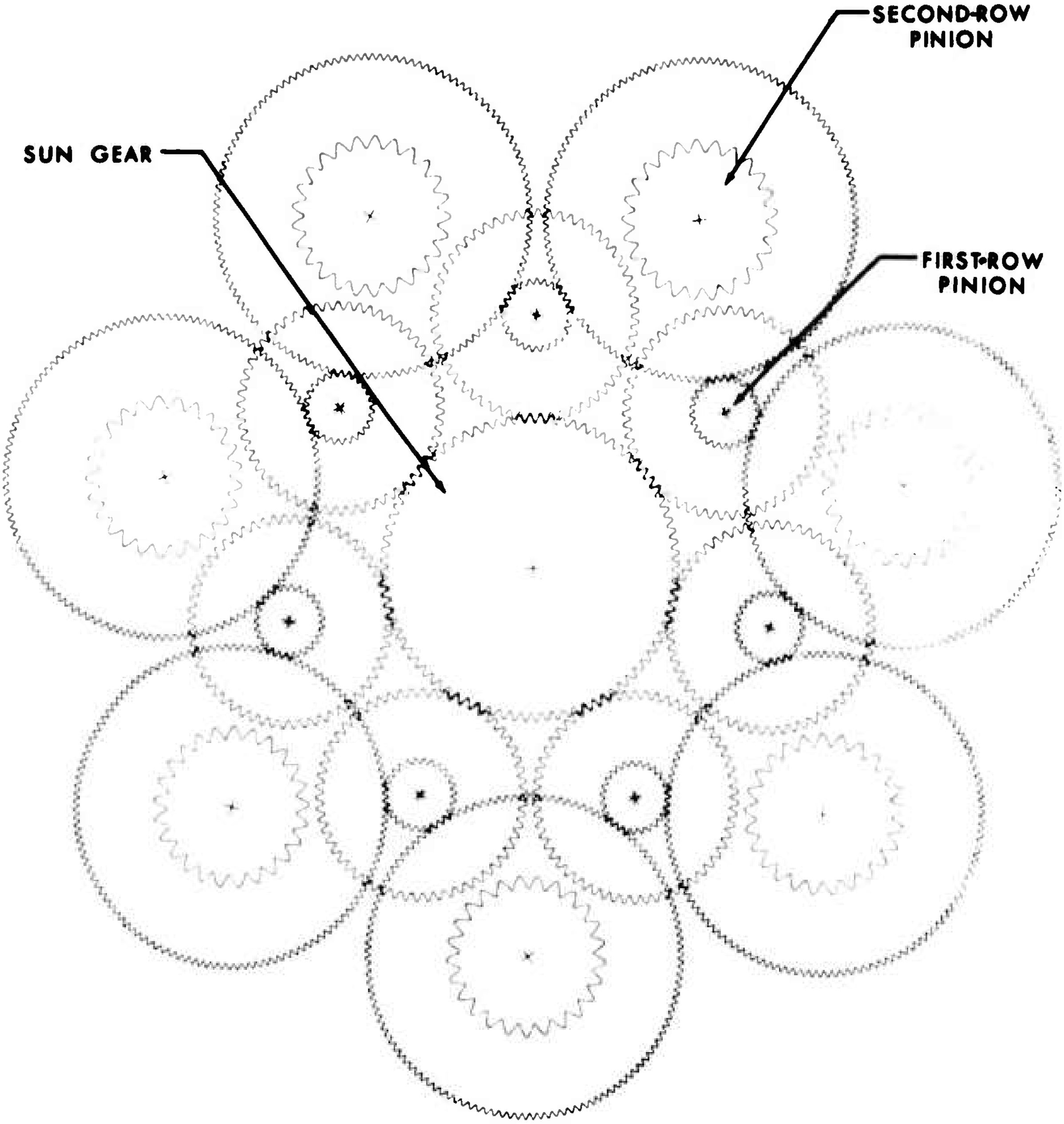


Figure 9. Roller Gear Component Arrangement.

second-row pinions. This three-point support is inherently stable and dispenses with the need for bearing support. The inner rollers of the first-row pinions contain end flanges which constrain these pinions in the axial direction.

The second-row pinions are contacted at two inner points by the first-row pinions, and at one outer point by the ring gear. Spherical bearings are used to hold these pinions in place and to react torque through the gearbox. The internal clearances of these bearings are such that under the worst case of roller tolerances and defections, the bearings cannot react loads in the radial direction. Only tangential loads resulting from the reaction torque of the roller gear unit are reacted by these bearings. The split ring gear has no rollers since the resultant gear mesh load from the ring gear teeth on the second-row pinion teeth is radially inward. Basic data of the roller gear components is presented in Table 1.

TABLE 1. BASIC GEAR DATA OF ROLLER GEAR COMPONENTS

Gear	Number of Teeth	Pitch Diameter (in.)	Pitch	Pressure Angle (deg)
Sun	84	8.89077	9.448	22-1/2
1st Row Outer	58	6.13887	9.448	22-1/2
1st Row Inner	27	2.04282	13.217	25
2nd Row Inner	126	9.53318	13.217	25
2nd Row Outer	25	4.47788	5.583	30
Ring Gear	154	27.58374	5.583	30

To ensure contact and proper location of "free" pinions such as the first-row pinions, earlier roller gear units used loading mechanisms that preloaded the first- and second-row pinions, holding them against one another and the sun gear. In these designs, the initial preload had to be sufficient to overcome the resultant gear loads at the maximum power to be transmitted.

The roller loads in the roller gear drive are a function of gear loads and roller gear geometry. Whenever torque is transmitted in the roller gear drive unit, tangential and radial gear tooth loads are induced. The rollers, which transmit loads normal to the rolling surface, must react the resultant loads from the gear teeth. Depending on the geometry and the gear tooth loads induced, the resultant roller loads may be either positive or negative and are directly proportional to horsepower. A negative roller load has no physical interpretation and indicates that the roller gear unit is unstable and tends to roll out of mesh. In this case, external preloading devices are required. However, by careful choice of roller gear design parameters, the roller reactive loads can be made to be always positive, thereby ensuring stability of the three point support. When the roller gear unit is designed so that all the roller loads are positive, the unit is said to be "self-preloading". This is achieved by using successively higher gear pressure angles for each gear mesh from sun gear to ring gear. The S-61 roller gear unit is a self-preloading unit and has no roller loads when at rest. As soon as power is applied, however, positive roller loads are generated, and all the roller gear members move radially inward to contact each other, thus forming a preloaded assembly. A summary of the preload forces is presented in Figure 10.

The S-61 roller gear drive also features a cantilever mounted bearing post with double plate. The double plate effectively expands the cross section to obtain a higher moment of inertia for less weight. The carrier plate attachment to the main housing is accomplished with a splined connection. The male portion of the spline is attached to the carrier plate while the female member is bolted to the main casting. During operation, the expansion of the magnesium housing with increasing operating temperature has no effect on the carrier plate since the splined connection simply repositions itself. The carrier to housing connection is therefore temperature compensated.

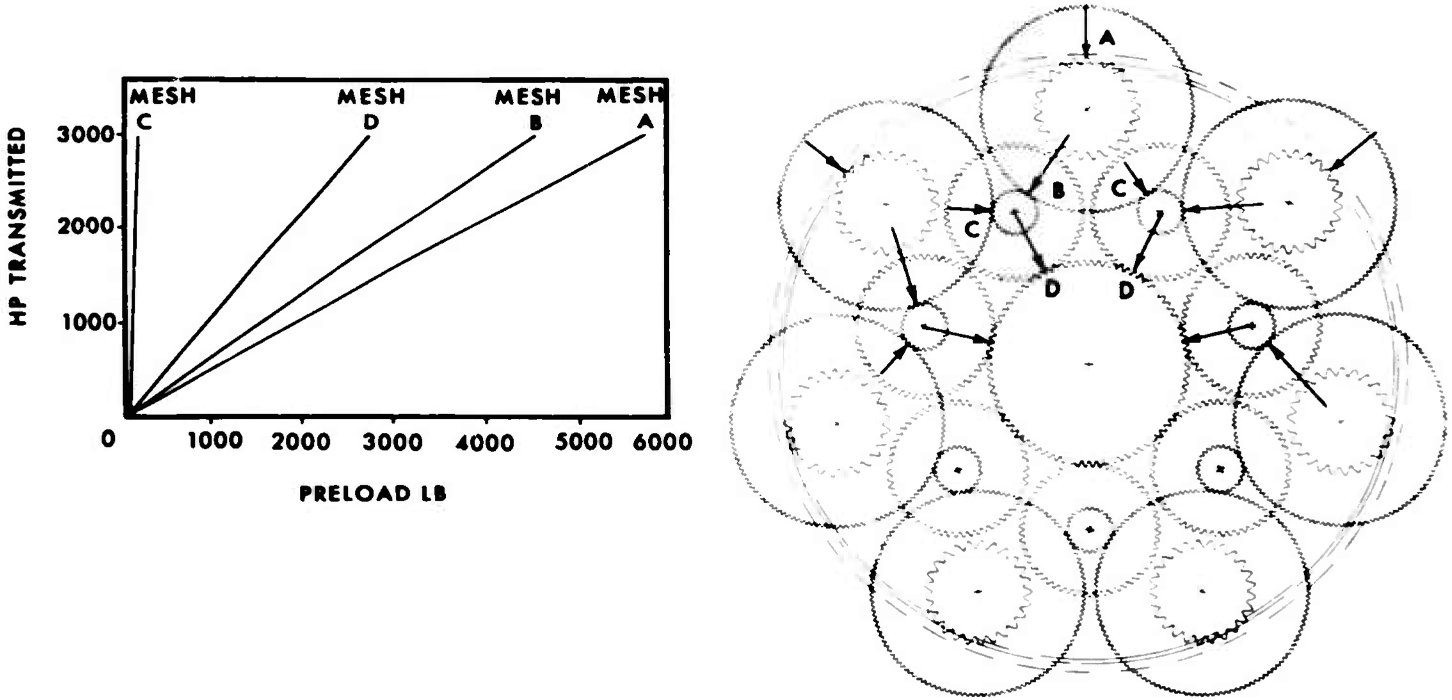


Figure 10. Summary of Roller Preload Forces.

GEAR MANUFACTURE

This chapter presents the manufacturing techniques utilized in the fabrication of the gears in the roller gear transmission. Manufacturing processes are applicable to bevel gears, external and internal spur gears, and the spur gear assemblies of the roller gear drive.

MATERIAL PROPERTIES

All primary gears in the transmission are manufactured from SAE 9310 steel procured to AMS 6265 specification. This carburizing steel is a premium quality consumable electrode vacuum melt (CEVM) material which offers higher impact properties than the air melt AMS 6260 from which the accessory drive gears were fabricated. The material for gear blanking was supplied in forgings which were metallurgically inspected for composition. Table 2 shows the chemical compositions of SAE 9310 to AMS 6260/6265 specification.

TABLE 2. AMS 6260/6265 COMPOSITION

Element	Percent Min.	Percent Max.
Carbon	0.07	0.13
Chromium	1.00	1.40
Manganese	0.40	0.70
Molybdenum	0.08	0.15
Nickel	2.95	3.55
Silicon	0.20	0.35
Phosphorus	-	0.025
Sulfur	-	0.025
Iron	Balance	

MANUFACTURING PROCESS

The fabrication of all gears, whether bevel or spur, followed the same basic process. Upon receipt of the forgings, the blanks are inspected for dimensional size and chemical composition.

Hardness surveys are conducted, the grain size is checked to ASTMA standards and a Ternkontoret rating conducted for micro inclusions. Finally the forging is subject to magnaflux inspection to determine the inclusion content.

The manufacturing process from the gear forging to the finished gear is depicted in Figure 11.

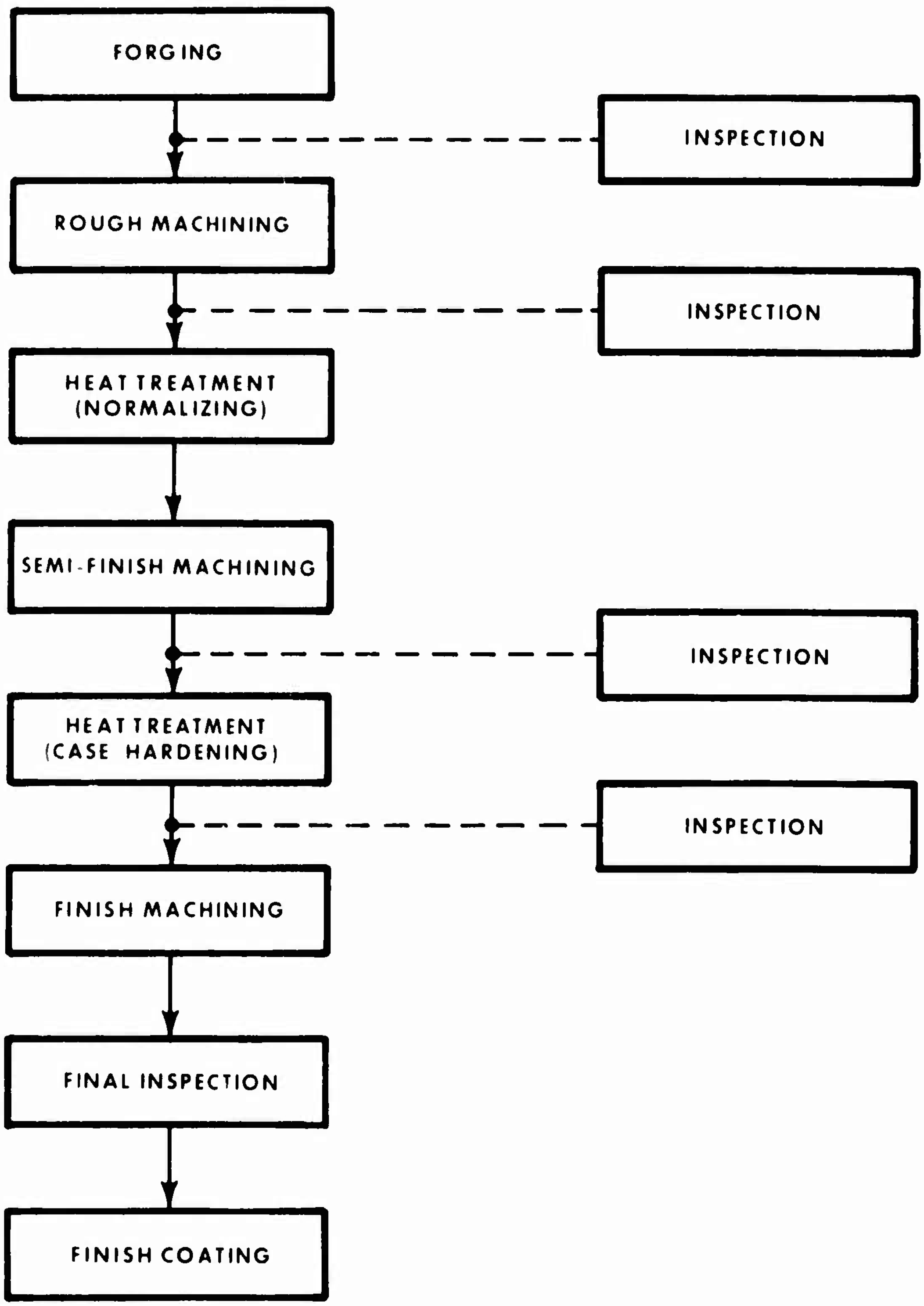


Figure 11. Basic Gear Manufacturing Process.

Rough Machining

All gear forgings are machined to allow 0.062 inch stock allowance on the gear contour. If an internal bore is greater than 1.0 inch in diameter, this is also rough machined.

Heat Treatment, Normalizing

The purpose of normalizing is to refine the grain structures that have been coarsened in the forging process. More homogeneous structures result and machinability is improved. In this process the gear blanks are heated to 1600°-1700°F and allowed to air cool. The machined properties obtained are given in Table 3.

TABLE 3. AMS 6260/6265 NORMALIZED PROPERTIES

Ultimate Tensile Strength	125,250 psi
Yield Strength	81,750 psi
Elongation	19.5%
Reduction of Area	61.7%
Hardness	255 BHN

Semi-Finish Machining

The rough machined and normalized gear blanks are now subjected to further machining operations. Where areas of the gear are carburized, the stock has to be removed to within 0.010 inch of the finished dimensions to allow the carburizing gases to penetrate the required finish case depth. This therefore requires machining of the gear teeth and free floating splines which are all carburized and ground. All bearing journals are also carburized to minimize the damage to the bearing seat should the bearing race skid due to bearing seizure.

Heat Treatment - Case Hardening

Case-hardening treatment provides for the addition of carbon to the surface of the gears in order to provide a definite depth of hardened layer, or case, upon completion of the subsequent hardening operations. The various processes which may be used to infuse carbon into the steel include molten cyanide mixtures, activated cyanides, dry cyaniding, nitriding, oil or gas carburizing and pack carburizing with activated solid material such as charcoal or coke. The roller gear transmission gears were all gas carburized in furnaces. Both temperature and time are important factors in the carburizing process. The case depth progresses with time but not in direct proportion to it. Roller gear components were carburized at 1600° to 1775°F with the gas atmosphere capable of producing a .65 to .95 percent case carbon content.

Since carburization of many surfaces was undesirable, it was necessary to mask those surfaces with copper plating to prevent penetration of the carburizing gases into the steel.

Copper plating for selective hardening is accomplished in a cyanide copper bath. The sections of the gear to be carburized are protected from the action of the plating bath by a coating of wax. The cyanide copper bath then readily deposits a dense fine-grained protective layer of copper directly on the remainder of the part.

The ultimate combinations of strength and ductility are achieved by heat treatments that yield a refined microstructure. Effective heat treatment involves not only critical heating rates and temperatures, but also critical cooling rates and temperatures both depending primarily upon section size and carbon content. For optimum results, it is necessary for the quench bath to extract heat uniformly from all surfaces of the part being quenched so that uniformity in hardening is achieved. The roller transmission gears are quenched in an agitated oil bath. The bevel gears and large spur gears are held in presses to prevent distortion during the quenching process. Figure 12 illustrates the quenching press used for the input bevel gear.

After quenching but before complete cooling, the gears are subjected to a cold treatment in which the gears are cooled to -110°F for an hour. This treatment serves to ensure the complete transformation of the austenite to martensite. This produces a harder steel while minimizing distortion.

After cold treatment the gears are tempered to restore somewhat the ductility and impact resistance lost in the quenching process. The tempering is done within 2 hours after removal from the cold box by heating the parts to 375°F for 2 hours.

Finish Machining

The final machining operations bring the gears into blueprint tolerance.

Final Inspection

Throughout the various processes of manufacture, inspection of the component is continually occurring. The final inspection verifies that the part conforms to drawing requirements.

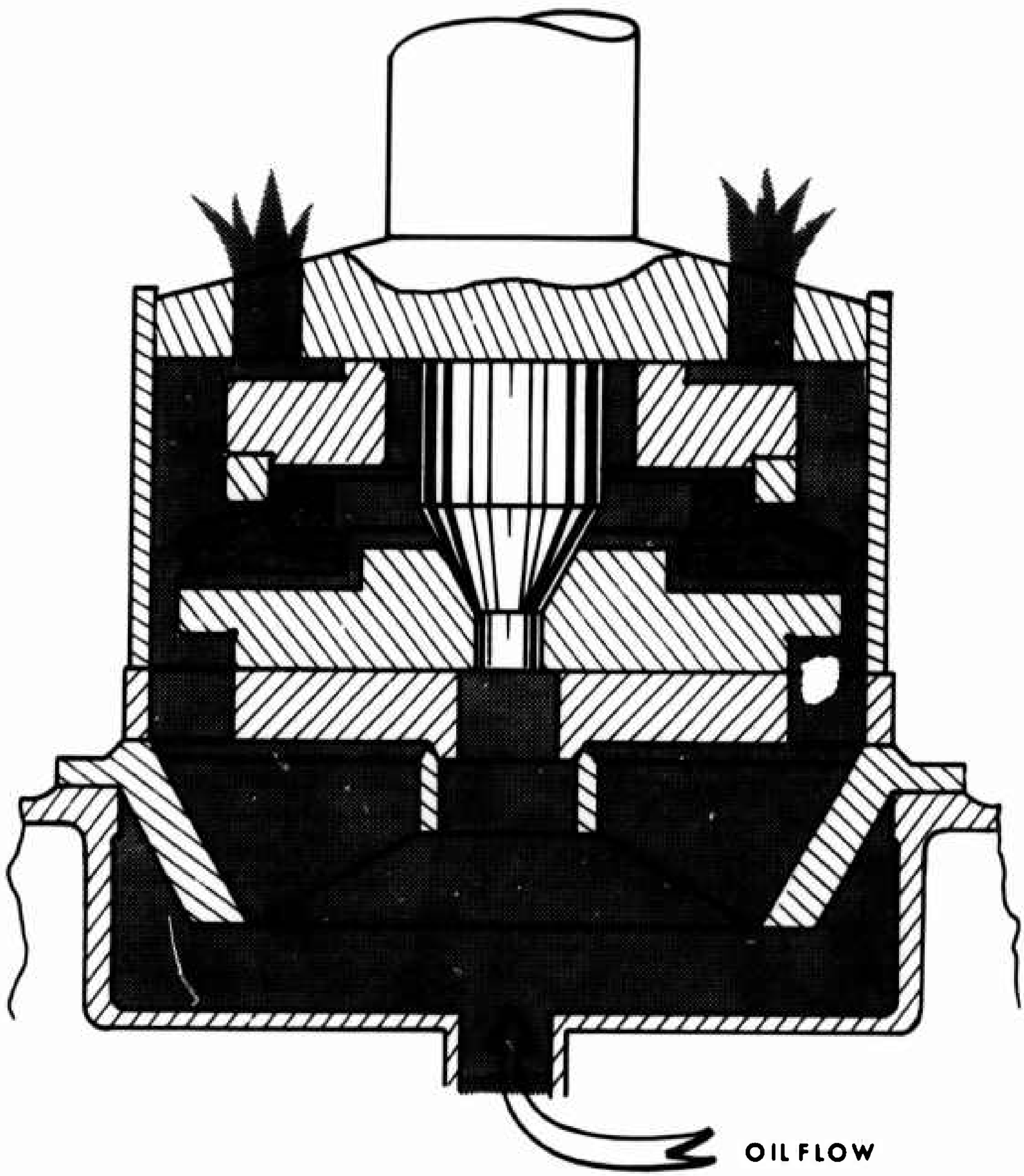


Figure 12. Input Bevel Gear Quench Press.

Coating - Finish

Gears are lastly subjected to either a phosphate coating or a black oxide treatment. Usually the pinion teeth will be of one treatment and the gear teeth the other. Both treatments give only slight corrosion protection under mildly corrosive conditions.

SPIRAL BEVEL GEARS

There are four spiral bevel gears among the primary power-train components of the roller gear transmission. These are the input bevel pinion and gear, Figure 13, and the tail takeoff pinion and gear. Tables 4 and 5 summarize the dimensions of the input bevel set and tail takeoff bevel set, respectively.

TABLE 4. INPUT BEVEL SET GEOMETRY

	Pinion	Gear
Number of Teeth	21	64
Diametral Pitch	4.193	4.193
Face Width (in.)	2.100	2.100
Pressure Angle (deg)	20	20
Shaft Angle (deg)	86	-
Pitch Diameter (in.)	5.008	15.264
Addendum (in.)	.284	.122
Dedendum (in.)	.166	.329

TABLE 5. TAIL TAKEOFF BEVEL SET GEOMETRY

	Pinion	Gear
Number of Teeth	42	73
Diametral Pitch	5.660	5.660
Face Width (in.)	1.400	1.400
Pressure Angle (deg)	20	20
Shaft Angle	80° 15'	-
Pitch Diameter (in.)	7.420	12.898
Addendum (in.)	.192	.108
Dedendum (in.)	.141	.225
Mean Spiral Angle (deg)	35	35
Backlash with Mate (in.)	.005/.007	-

Figures 14 and 15 depict the gears of the input bevel set dimensionally, while Figure 16 depicts the tail takeoff set.

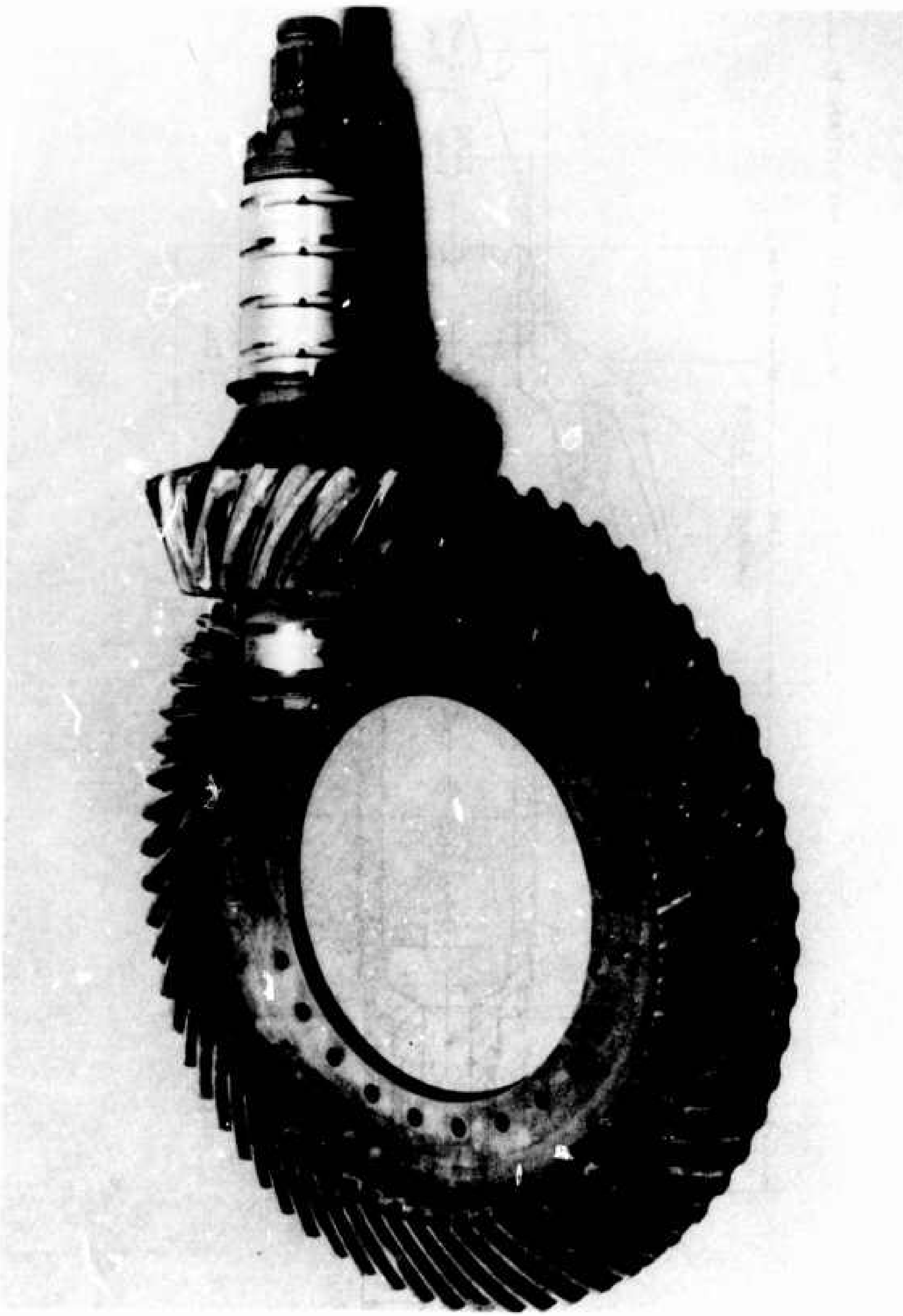


Figure 13. Input Bevel Set.

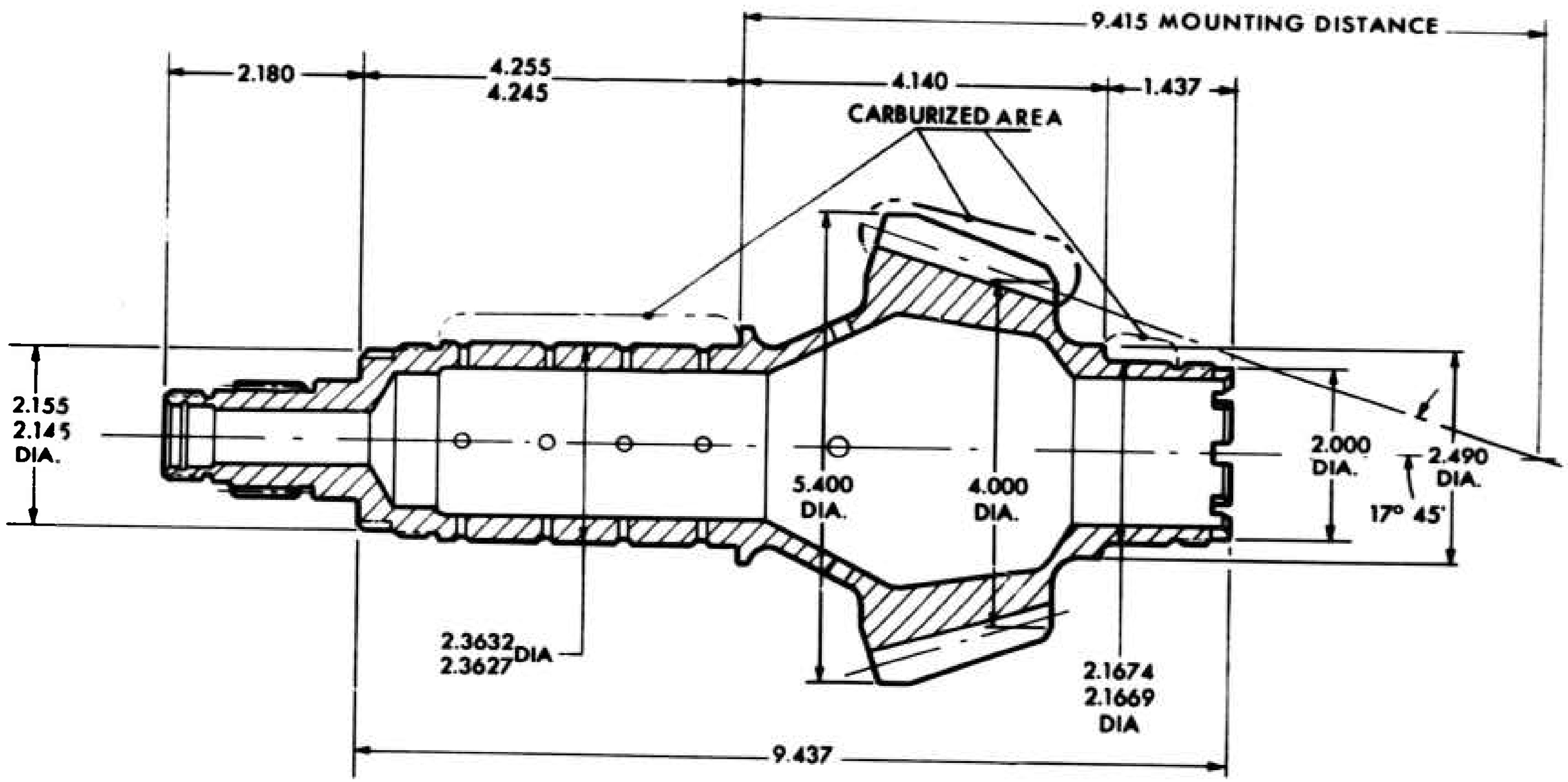


Figure 14. Dimensions, Input Bevel Pinion.

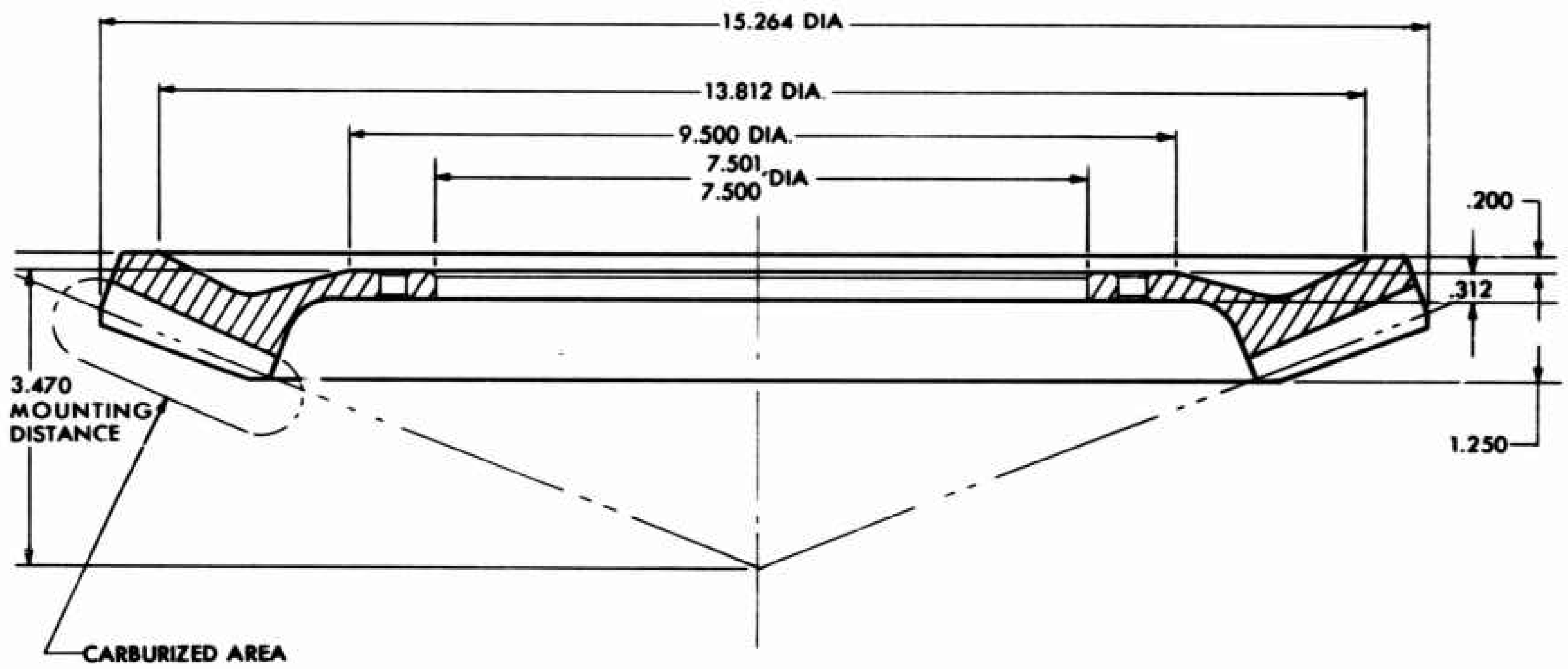
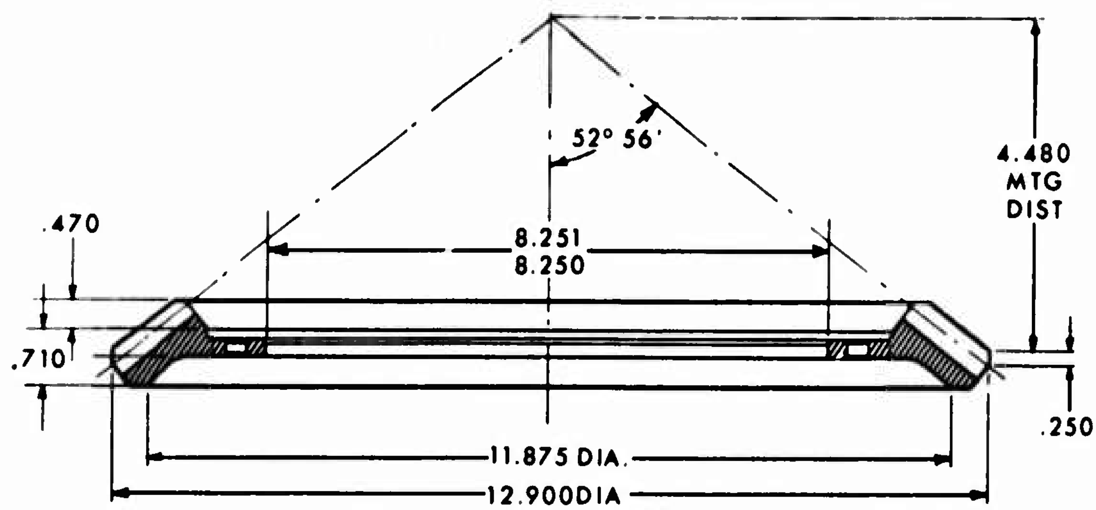


Figure 15. Dimensions, Input Bevel Gear.



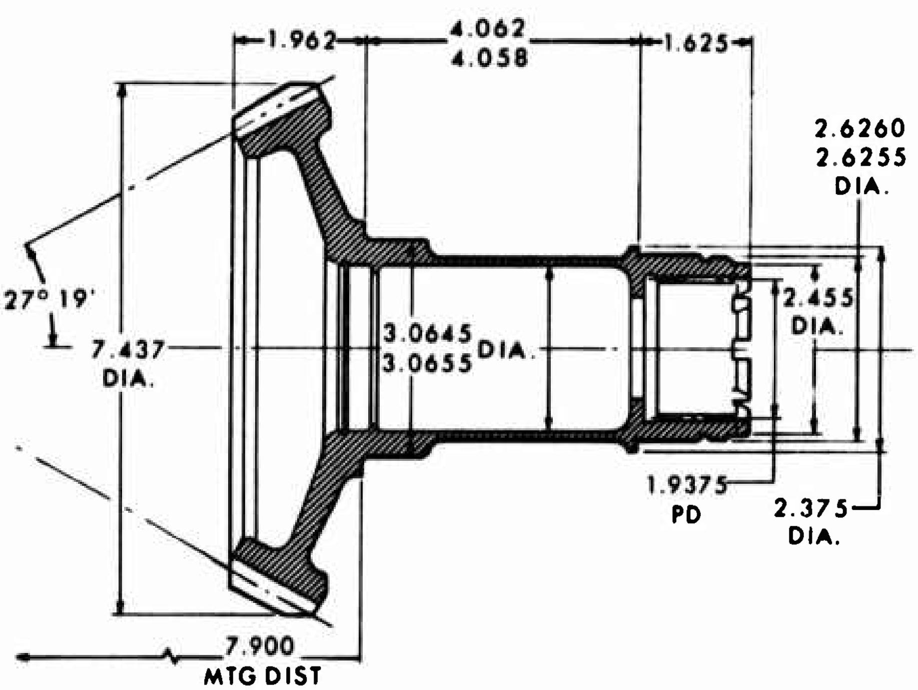


Figure 16. Dimensions, Tail Takeoff Bevel Set.

All four of these gears were roughed on a Gleason Model 26 and finished on a Gleason Model 27 gear generator using standard depth cutters. The gears were generated using the spread blade method in which the gear is produced by alternate inside and outside cutting blades which finish both sides of a tooth space in one operation. The pinions were generated using the fixed-setting method. This method finishes one side of a tooth at a time; hence, either all inside or all outside cutting blades are used depending on the side of the tooth being finished.

Cutter specifications for the generation of the input bevel set are presented in Table 6, while Table 7 presents the cutter specifications for the tail takeoff bevel set.

TABLE 6. INPUT BEVEL SET CUTTER SPECIFICATIONS

	Pinion	Gear
Cutting Method	Fixed Setting	Spread Blade
Cutter Radius (in.)	6.000	-
Gear Finishing Point Width (in.)	-	.160
Roughing Point Width (in.)	.060	.150
Outer Slot Width (in.)	.085	.160
Mean Slot Width (in.)	.098	.160
Inner Slot Width (in.)	.089	.160
Finishing Cutter Blade Point (in.)	.040	.065
Stock Allowance (in.)	.025	.010
Cutter Edge Radius (in.)	.040	.070
Cutter Number	3	6
Cutter Blade Type	STD	STD

TABLE 7. TAIL TAKEOFF BEVEL SET CUTTER SPECIFICATIONS

	Pinion	Gear
Cutting Method	Fixed Setting	Spread Blade
Cutter Radius (in.)	6.000	-
Gear Finishing Point Width (in.)	-	.100
Roughing Point Width (in.)	.040	.090
Outer Slot Width (in.)	.067	.100
Mean Slot Width (in.)	.077	.100
Inner Slot Width (in.)	.079	.100
Finishing Cutter Blade Point (in.)	.040	.065
Stock Allowance (in.)	.027	.010
Cutter Edge Radius (in.)	.020	.040
Cutter Number	3	5
Cutter Blade Type	STD	STD

After cutting, the bevel gears were carburized to produce a .035 inch to .050 inch depth of case in the finished part and heat treated to produce a case hardness of Rockwell C58 with a core hardness of Rockwell C30-45. After the heat treat, the gear teeth were finish ground to a surface roughness of 16 micro-inches rms. The finish grinding was followed by a stress relieving cycle in which the gears were heated to 320°F ±25°F for 1 hour and oven cooled. This treatment minimizes the possibility of cracking due to residual stresses.

A final hardness inspection was performed by means of a surface temper etch. This inspection is performed to detect the presence of any surface tempering which may have occurred in the finish grinding or stress relief cycle. Surface tempering is not acceptable on the working profile of the gear teeth or on the fillet radii.

After completion of the heat treatment process, these gears were finish ground to within blueprint tolerances. The next step in the manufacturing cycle for these gears was the gear bearing development test. Performed on a Gleason No. 519 tester, this test was performed to assure optimum loading of the gear teeth under full load. The first step in this test was the production of a master set, pinion and gear, with the desired tooth bearing pattern. All gears manufactured thereafter were tested and matched with the master set. Corrections were then made to these gears so that their patterns match as closely as possible the patterns of the master set. The grinding corrections were usually made only to the pinion. Figure 17 shows the results of a gear bearing development test for an input spiral bevel set. Additional dimensional checks such as tooth spacing were also made at this time before the gears were subjected to a final stress relief heat treatment. A magnetic particle inspection, discussed in detail in a later section of this report, was performed as the final step of the spiral bevel manufacturing process.

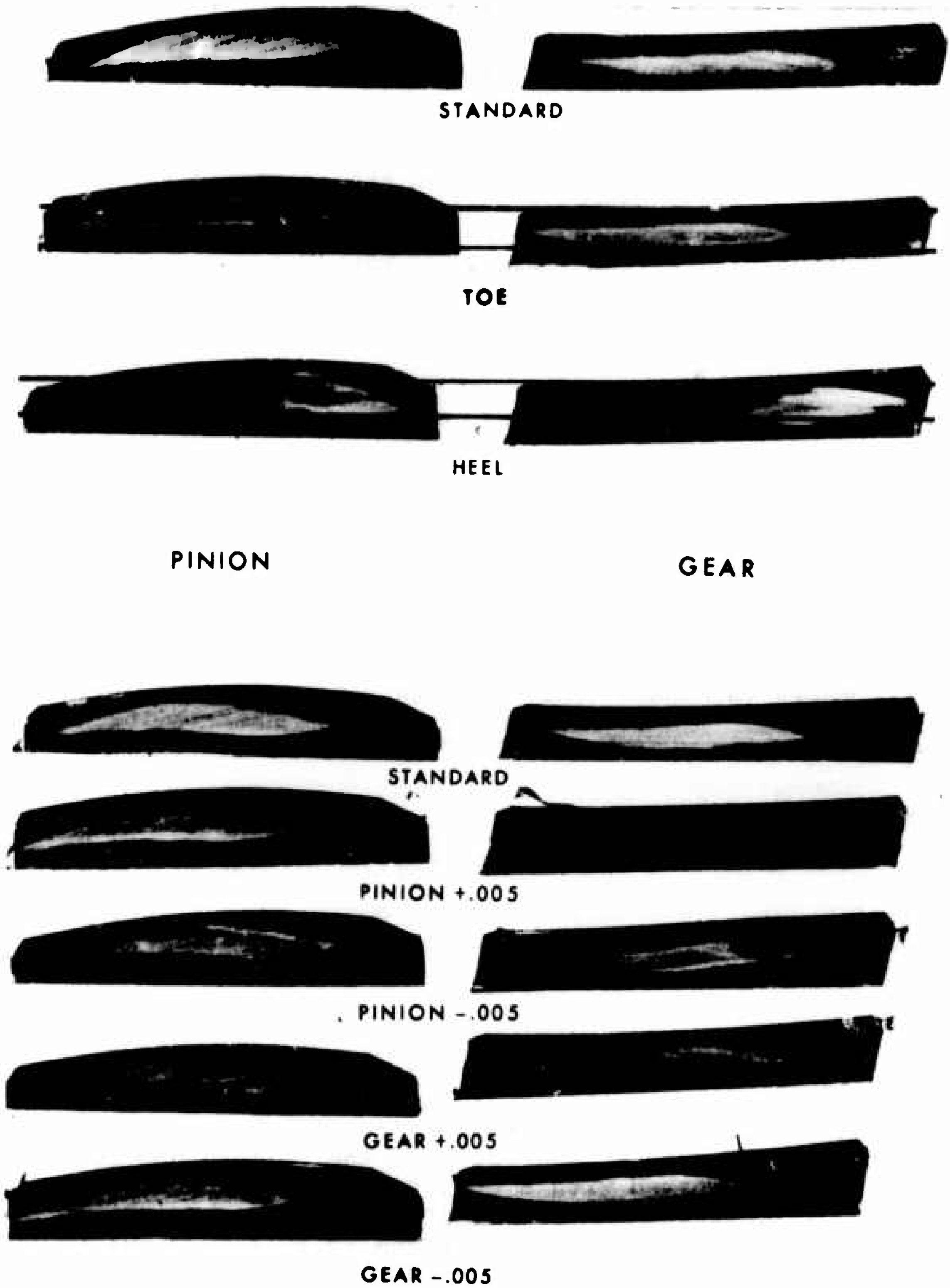


Figure 17. Bearing Patterns of Input Spiral Bevel Set.

SPUR GEARS

The only spur gears included in the primary drive train outside of the roller gear unit are those associated with the 1.54 reduction ratio combining spur gear mesh, shown in Figure 18. The basic data for both the pinion and gear of this mesh is presented in Table 8. These gears were roughed on a Fellows Model 36 vertical gear shaper. Heat treatment and carburizing of these gears followed the same basic procedure as for the spiral bevel gears. Finish machining of these gears was done in a Reishauer No. 27 gear grinder. The same surface finish was applied to the spur gears as was applied to the bevel gears. Stress relief also was the same as for the bevel gears.

TABLE 8. BASIC DATA, COMBINING SPUR GEAR SET

	Pinion	Gear
Number of Teeth	78	120
Diametral Pitch	6	6
Pressure Angle (deg)	22-1/2	22-1/2
Pitch Diameter (in.)	13.0000	20.0000
Base Circle Diameter (in.)	12.0104	19.4776
Outside Diameter (in.)	13.330	20.330
Root Diameter (in.)	12.585	19.585
Chordal Tooth Thickness (in.)	.2580	.2580
Backlash (in.)	.005/.008	.005/.008

Roller Gear Unit Spur Gears

The manufacture of the spur gears for the roller gear unit presented special manufacturing problems because of their compound nature. Not only did these gears contain multiple geared surfaces, but they also incorporated multiple roller surfaces used to support the gears at their pitch diameters.

Sun Gear

The sun gear, shown in Figures 19, 20, and 21, is composed of three elements: two rollers and the main body containing the geared surfaces. The rollers were first rough machined before the carburizing process. Surfaces of the rollers not being carburized were masked with a copper plate of approximately 0.001 inch. This was done to insure that no carburization would occur on the weld surface, since carburized steel cannot be electron beam welded. The copper plate was removed after carburization. After heat treating and cold treating, the rollers were tempered. The rollers were then machined to their finished dimensions except for the outside diameter of the roller surface which was finish machined after the electron

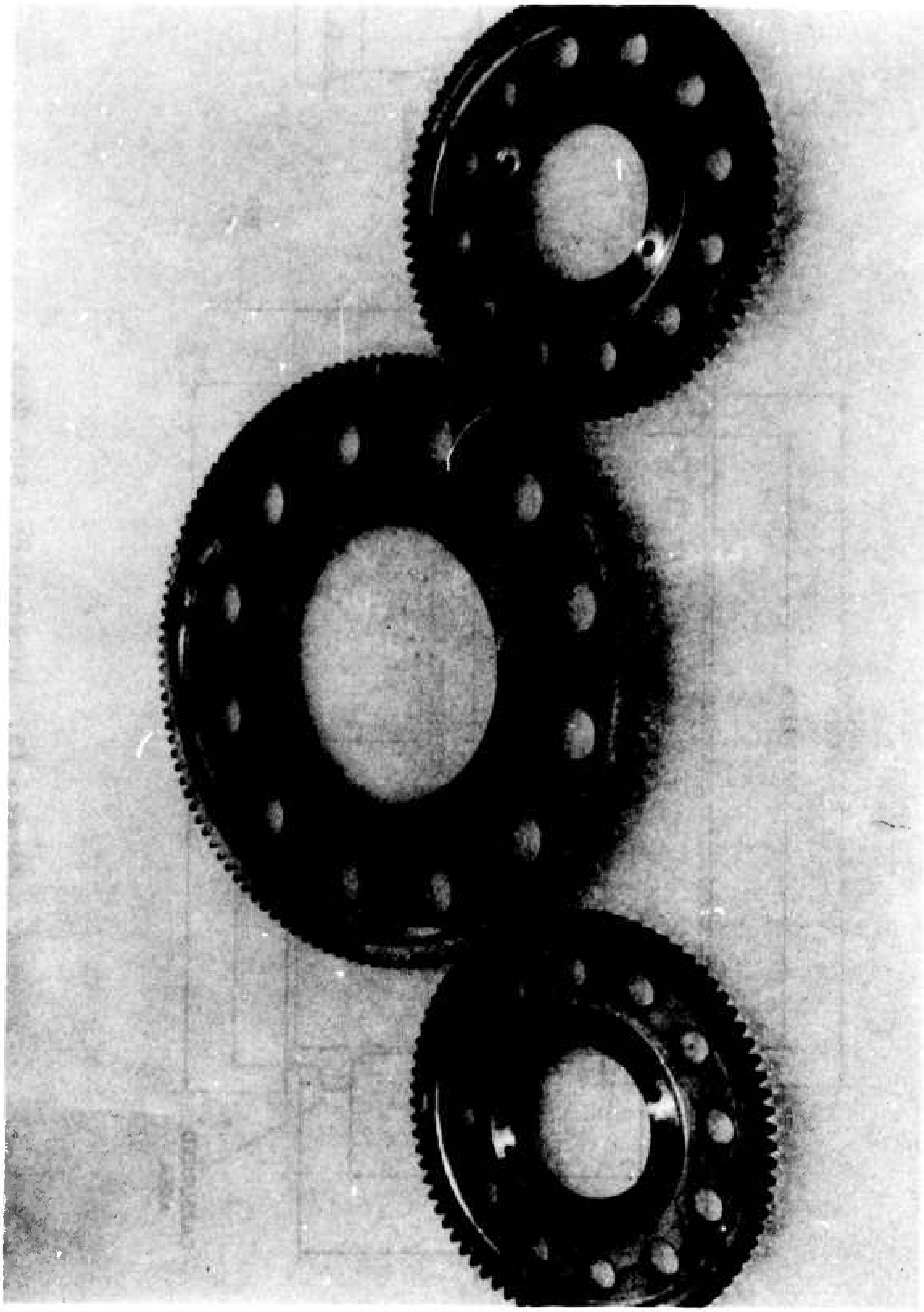


Figure 18. Combining Spur Gears.

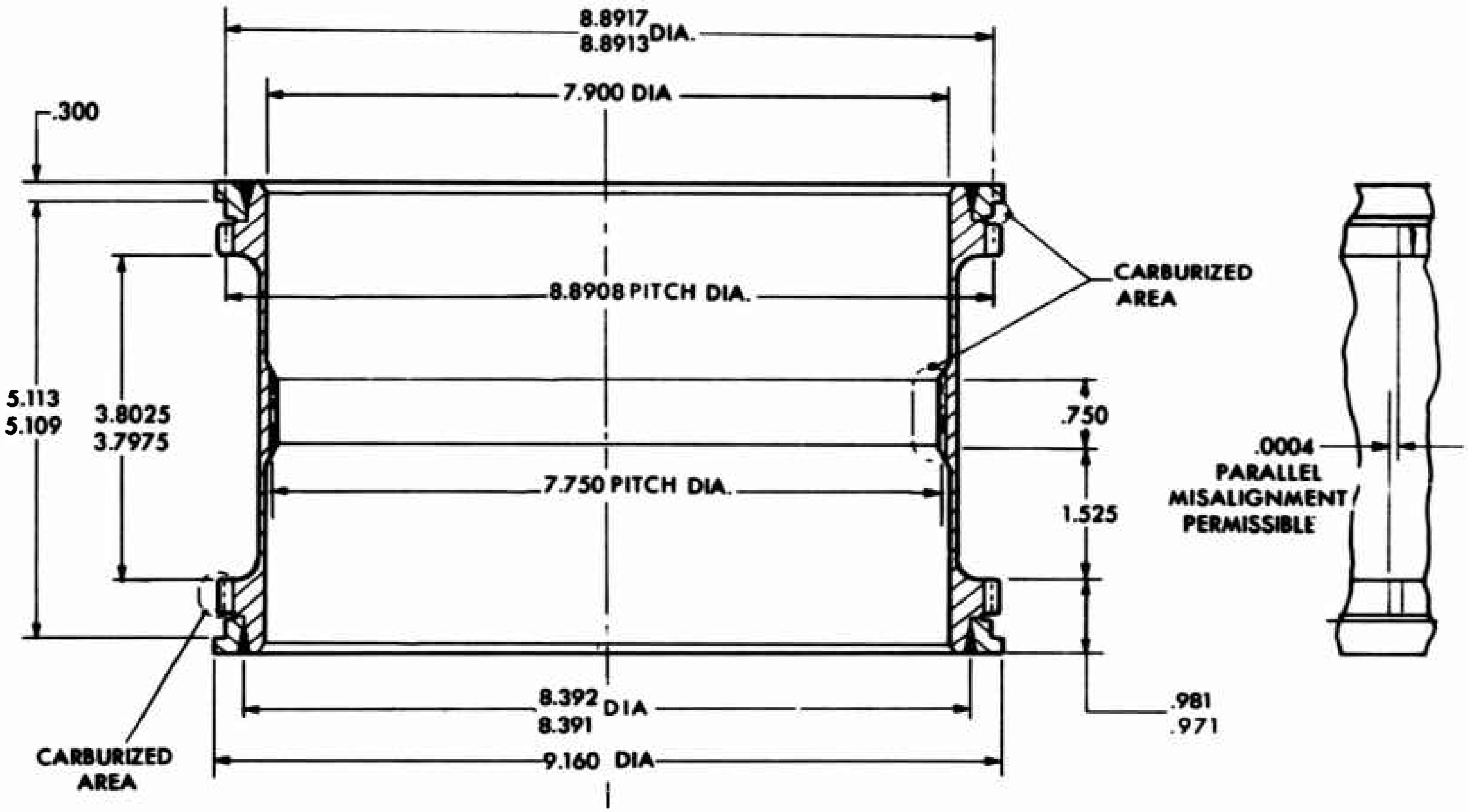


Figure 19. Dimensions, Sun Gear.

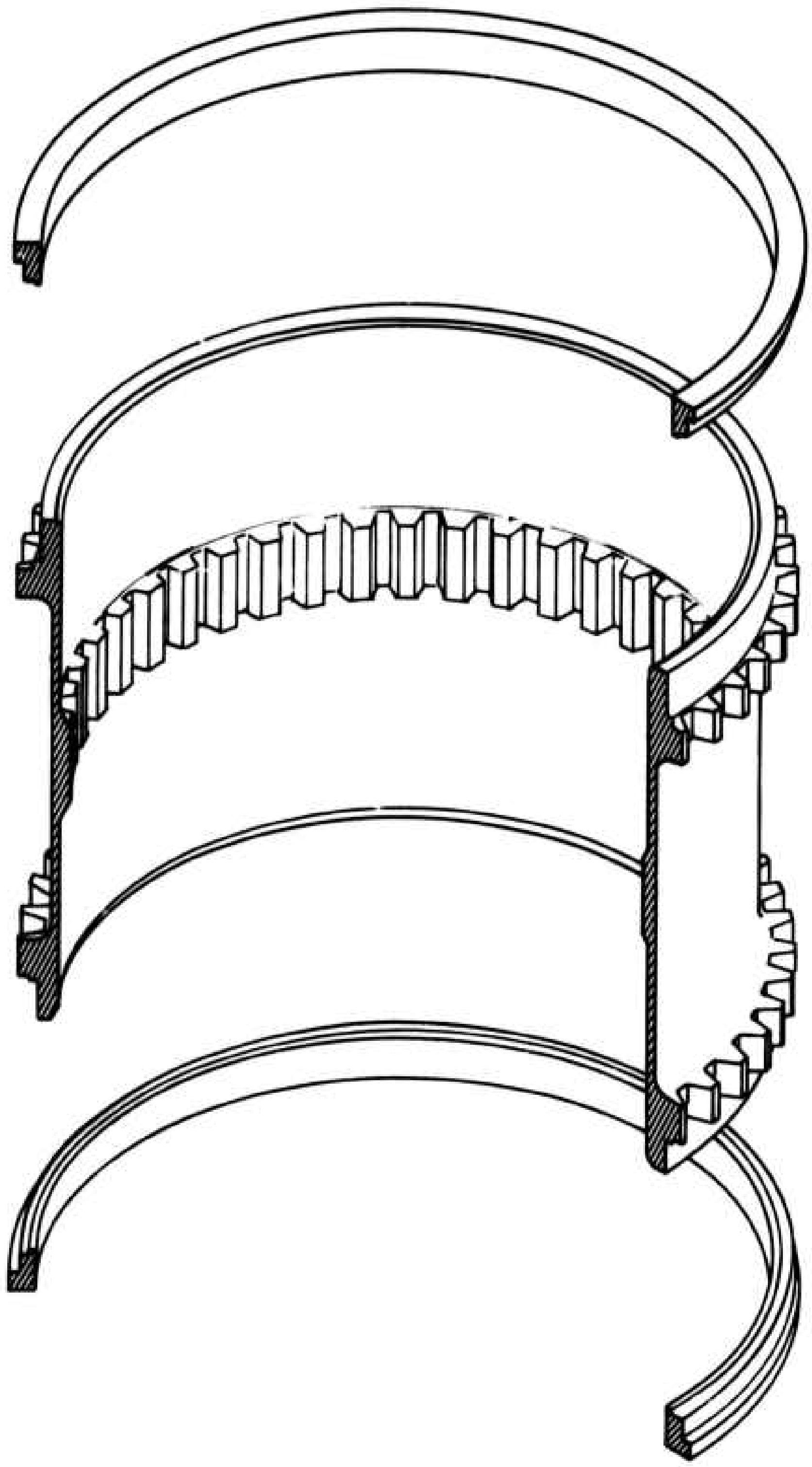


Figure 20. Sun Gear, Exploded View.

Figure 21. Roller Gear Drive Sun Gear.

beam welding process. This procedure applies to all rollers in the roller gear unit.

The spur gear portion of the sun gear was hobbed on a Barber-Coleman #16 and finished ground on a Detroit #36. These same machines were used for all roller gear components except for the ring gear.

The permissible parallel misalignment between the spur gears on the sun gear as shown in Figure 20 is 0.0004 inch. This tolerance is maintained by finish grinding both sets of gears simultaneously in single long passes. After grinding, the rollers are electron beam welded to the sun gears. The roller end faces are then machined to remove the weld beam, and the outside diameters are finish ground to blueprint dimensions with an 8AA (Arithmetic Average) finish. The finished sun gear is shown in Figure 21.

First-Row Pinion

The first-row pinion presented the greatest manufacturing problem. As shown by the dimensional view of Figure 22 and the exploded view of Figure 23, the first-row pinion is composed of five elements: two large diameter rollers, two large diameter gear and web segments, and the small diameter gear. Except for the roller surfaces and outer gear teeth, the elements are completely finished before they are welded together. The large diameter gears require timing to the small diameter gear. This is critical to the proper operation of the roller gear unit. In fact, without proper timing of these gears, the roller gear unit would be impossible to assemble. The timing of the first-row pinion large diameter gears to the small diameter gear is illustrated in Figure 24. An index tooth on the small diameter gear is selected and labeled "Z". After one of the larger diameter gears is welded onto it, the "X" dimension shown in Figure 24 is measured. This dimension must be equal to within ±0.0002 inch for all seven first-row pinions within a set. In addition, the teeth on the two larger diameter gears must line up to within ±0.0002 inch relative to each other. Although these tolerances were controlled as closely as possible during the electron beam welding process, the gear members tended to move as much as 0.002 inch relative to each other during this operation. This was corrected during the finish grinding of the larger diameter gears after welding. The final steps in the assembly of the first-row pinion are the welding of the larger diameter rollers to the assembly and the finish machining of these rollers. This procedure is also closely controlled since the rollers must be concentric to the larger gears to within 0.0005 inch TIR (total indicator reading). The finished gear is shown in Figure 25.

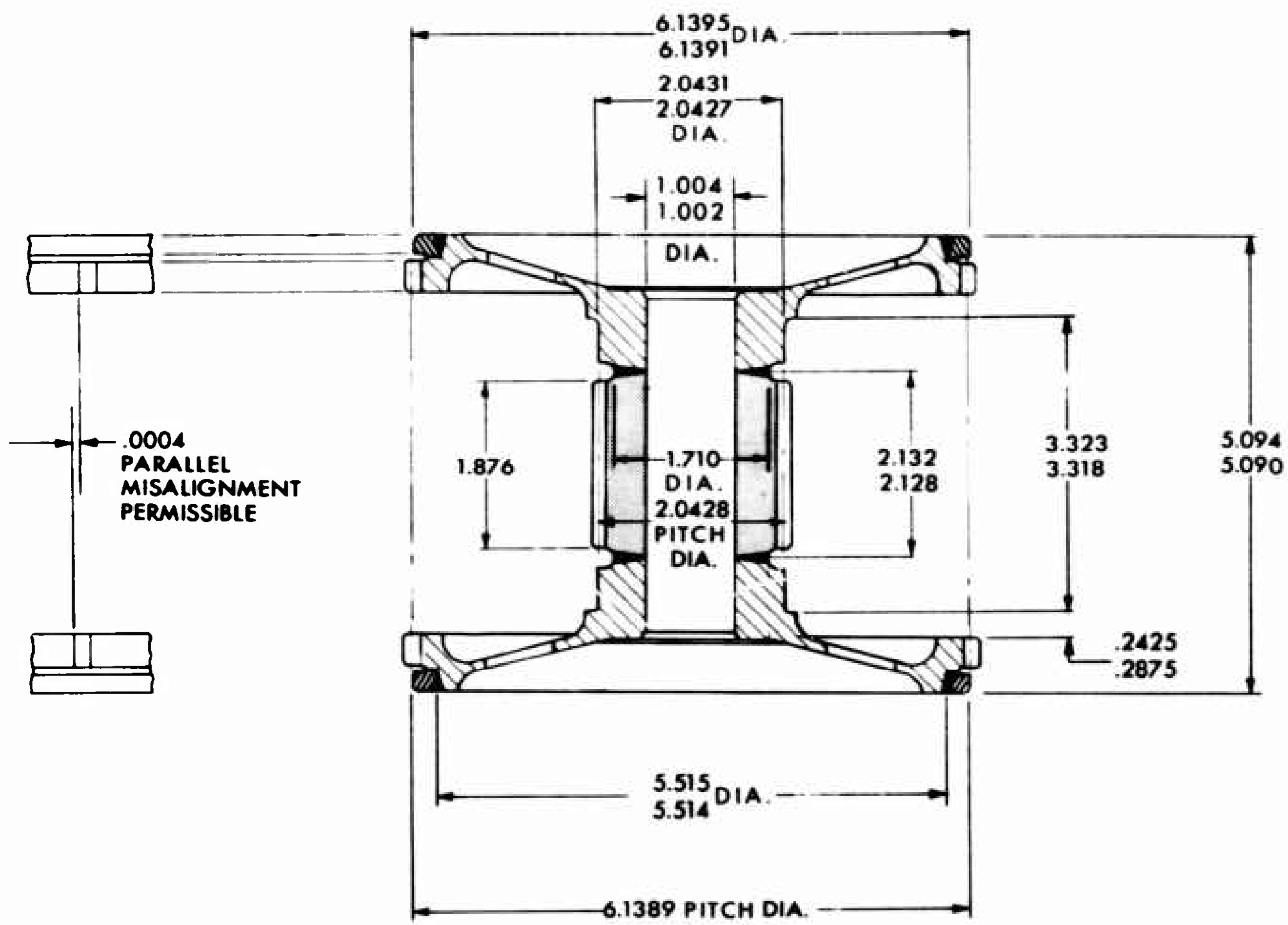


Figure 22. Dimensions, First-Row Pinion.

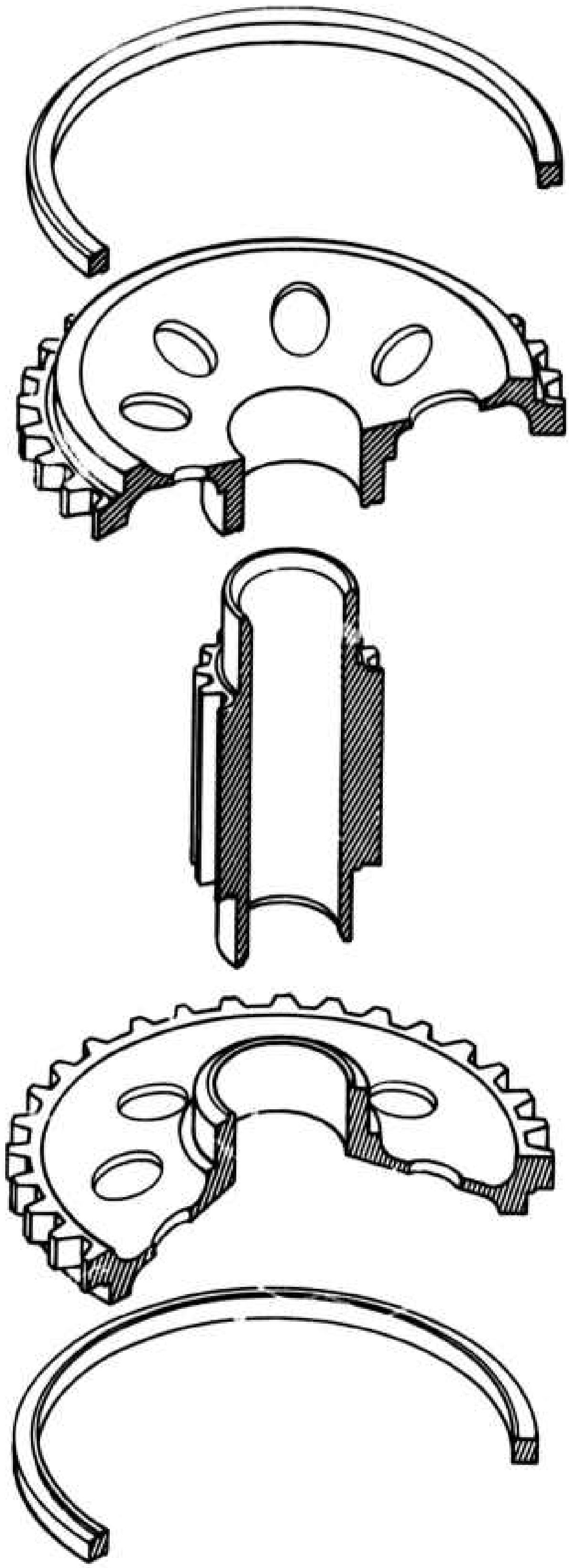


Figure 23. First-Row Pinion, Exploded View.

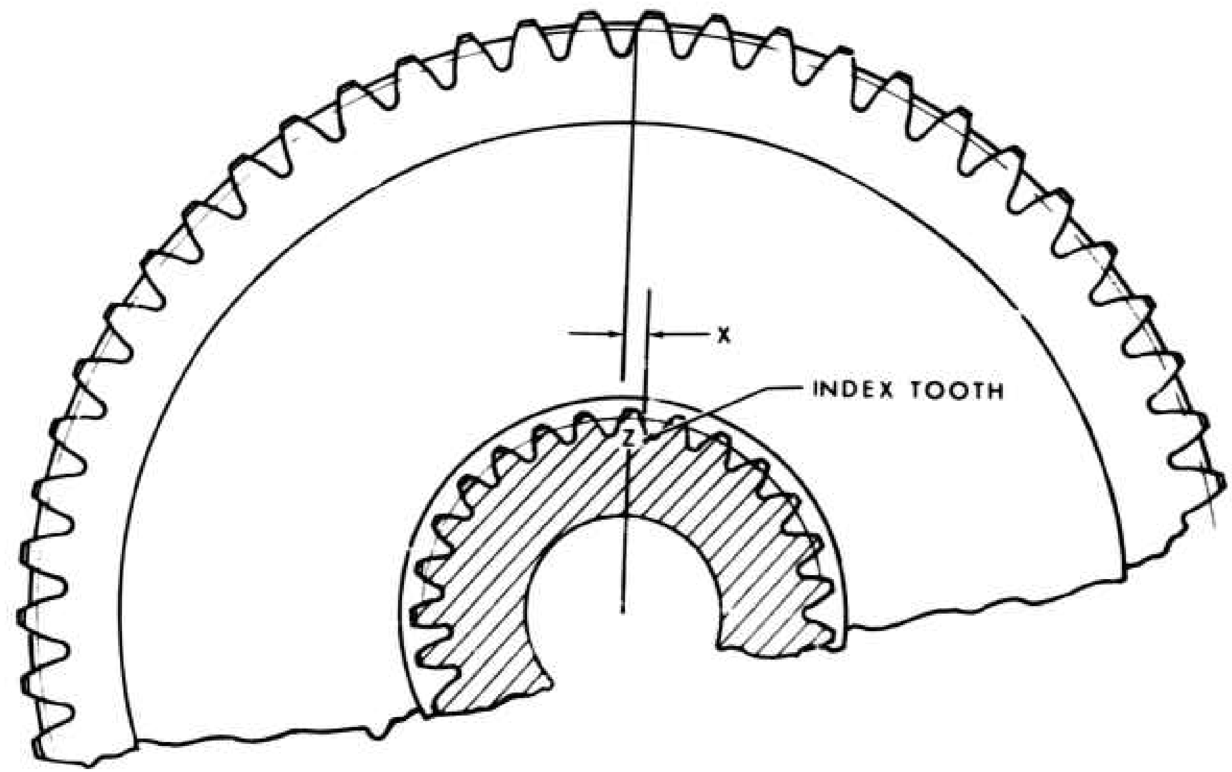


Figure 24. Timing of First-Row Pinion, Sectional View.

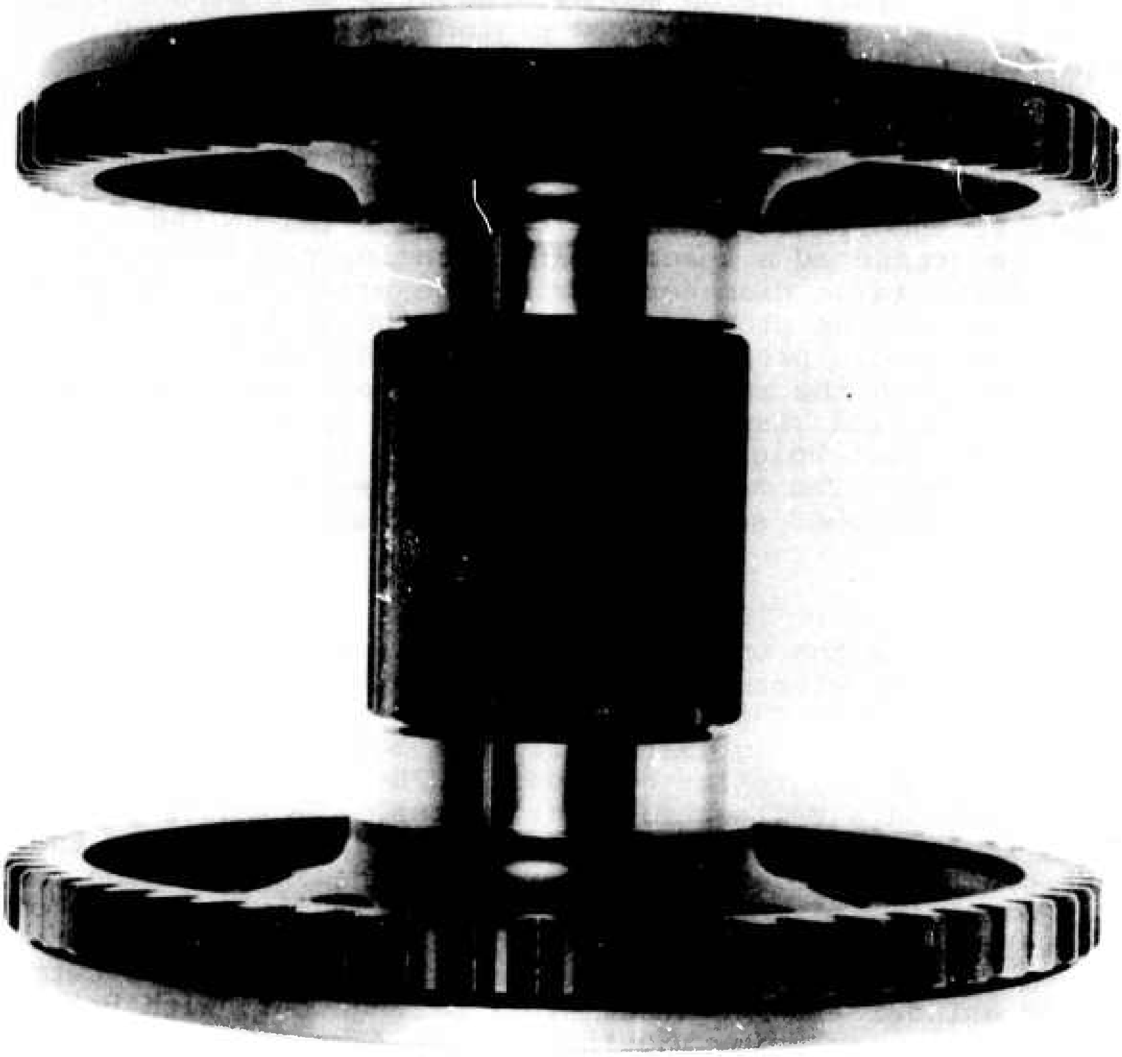


Figure 25. Roller Gear Drive, First-Row Pinion.

Second-Row Pinion

The finished dimensions of the second-row pinion are shown in Figure 26. An exploded view of the second-row pinion is shown in Figure 27. This pinion was manufactured in a manner very similar to that of the first-row pinion. Except for top flange, large diameter gears, and rollers, all of the components of the second row were completely finished prior to electron beam welding. As can be seen from Figure 27, the second-row pinion has a bolted connection in addition to the welded connections. This was incorporated in order to permit assembly of the spherical roller bearings. The bolted connection presented a special manufacturing problem since timing of the large diameter gear to the small diameter gears was critical to the proper operation of the roller gear drive. In order to ensure proper positioning of the top flange and gear assembly on the main assembly, the small diameter gear of the top flange and gear assembly was lined up and clamped in position. A pilot hole was drilled and the positions of the gears were rechecked. The holes were then drilled for the locking bolts. The finished second-row pinion is shown in Figure 28.

Ring Gear

The ring gear is the only gear in the roller gear drive that was not assembled by electron beam welding. This gear is shown in Figures 29 and 30. This gear is composed of two nearly identical internal ring gears which are bolted together during the assembly of the roller gear unit. The internal spur gears were roughed on a Fellows #36 gear shaper. Timing of the upper half to the lower half of this gear is critical to the importance of this factor, a special arrangement was made for the finish machining of this gear. The upper and lower halves of the gear were bolted together and mounted on a special fixture as shown in Figure 31. This unit was then mounted on a Detroit #36 gear grinder and machined. This arrangement, with both halves of the gear being machined at the same time, insured proper timing of upper and lower halves.

GEAR INSPECTION

All gears were subjected to detailed inspection with respect to tooth spacing, involute profile, lead errors, crown and eccentricity. These inspections were especially critical for the roller gear unit elements because of the rigid timing tolerances required for the gears of this unit.

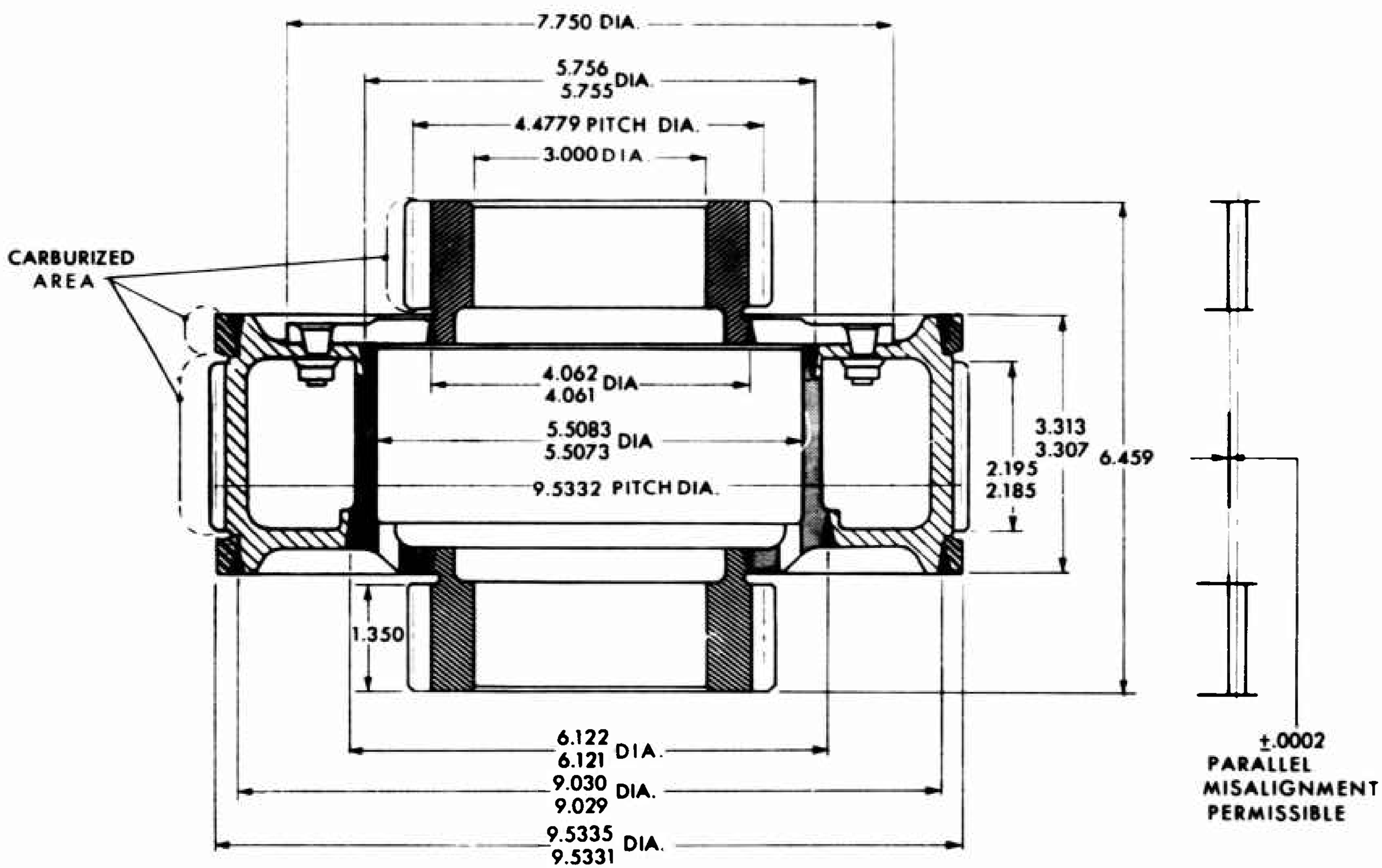


Figure 26. Dimensions, Second-Row Pinion.

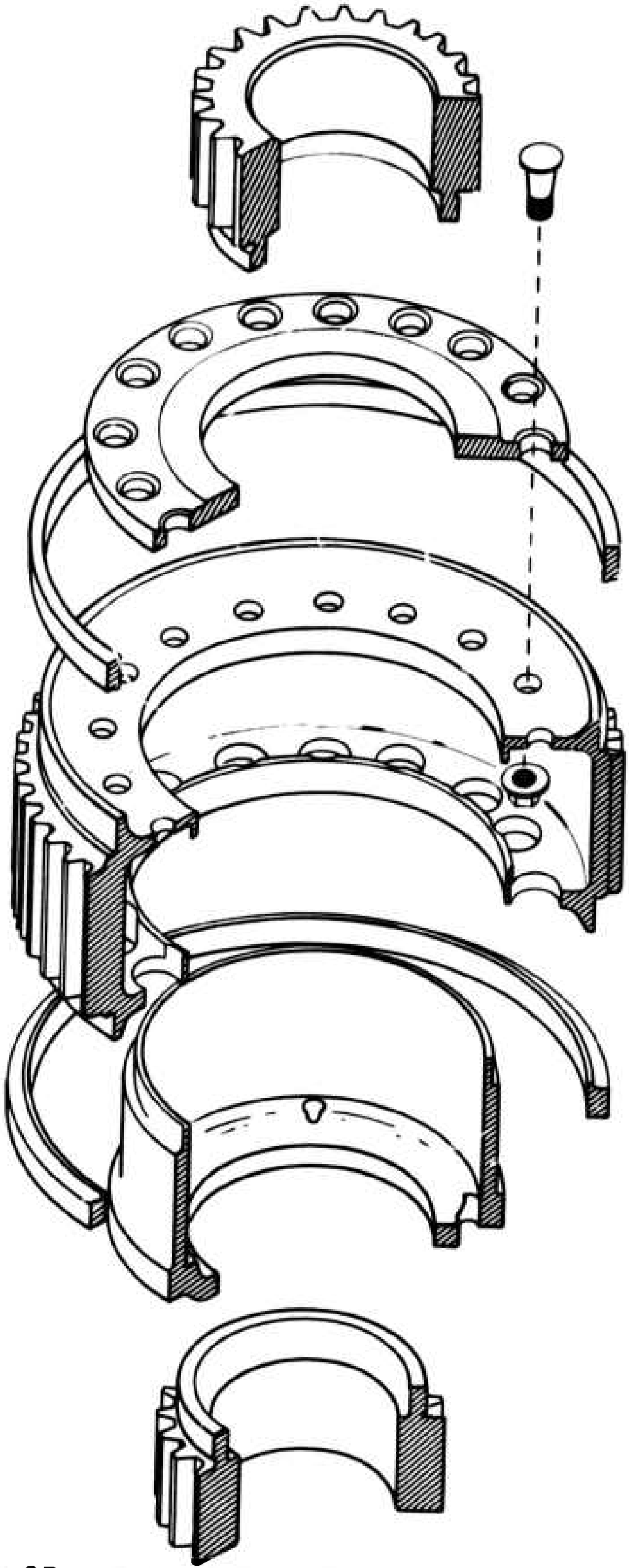


Figure 27. Second-Row Pinion, Exploded View.

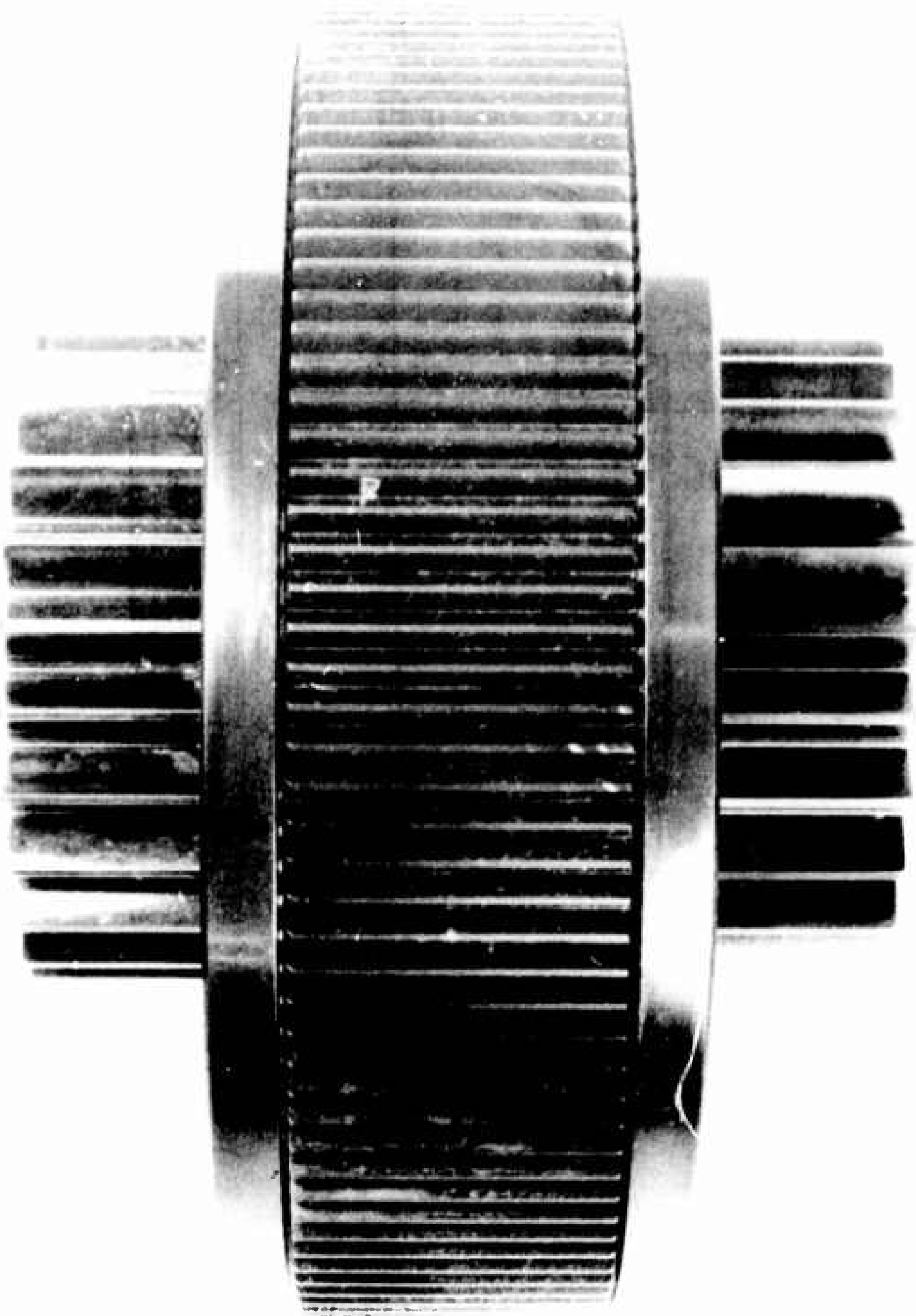


Figure 28. Roller Gear Drive Second-Row Pinion.

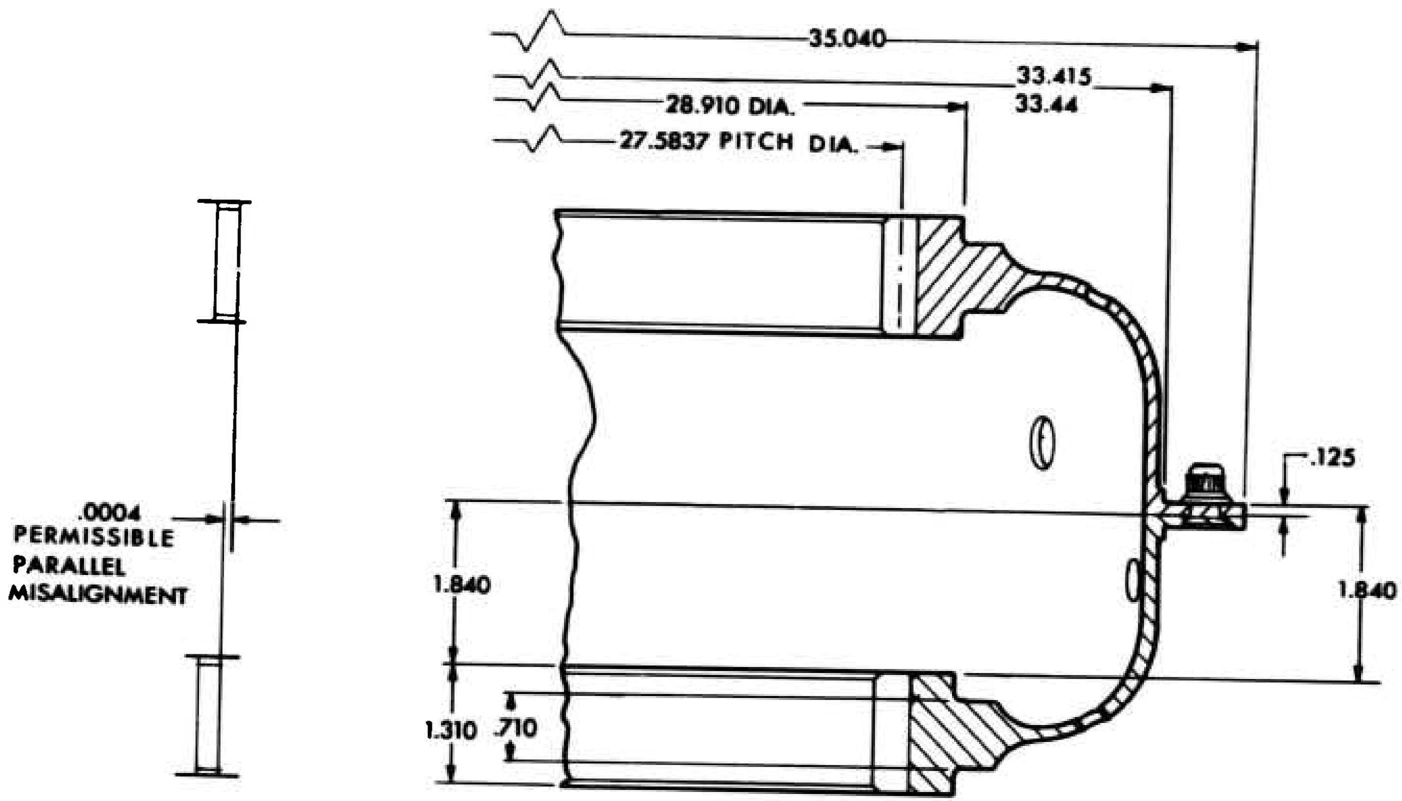


Figure 29. Dimensions, Ring Gear.

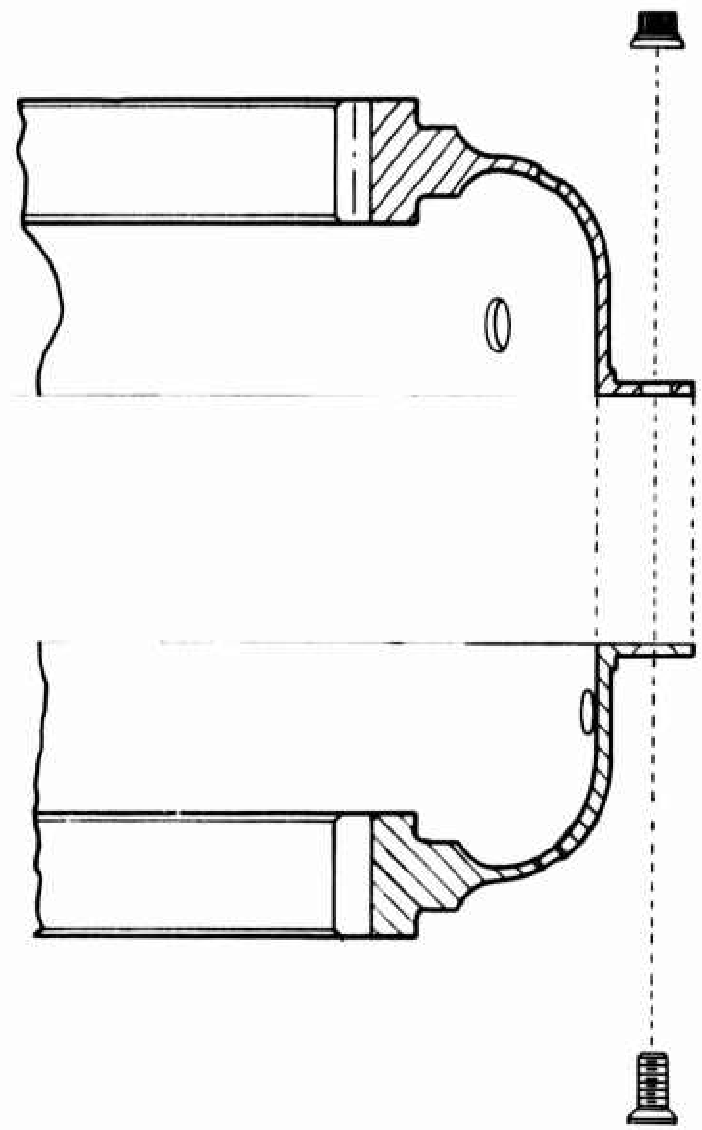


Figure 30. Ring Gear, Exploded View.

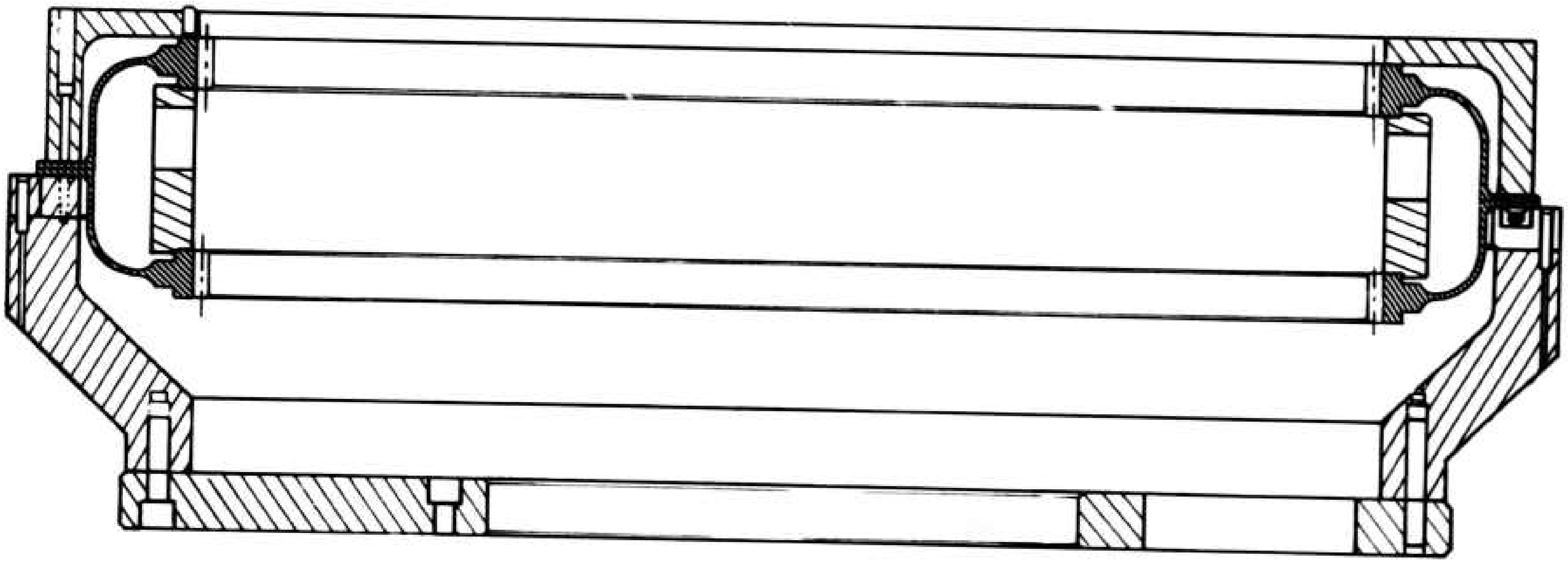


Figure 31. Ring Gear Mounted in Special Machining Fixture.

Figure 32 shows an example of an index chart produced on a Fellows No. 8 tooth index measuring instrument for one of the large diameter first-row pinion gears. If this gear had been perfect with respect to indexing, the resulting chart would have been a perfectly straight line. As can be seen from the chart, this gear has a maximum tooth-to-tooth spacing error of 0.0002 inch and a maximum accumulated tooth spacing error of 0.0005 inch. For the gears associated with the roller gear unit, a maximum tooth-to-tooth spacing error of 0.0002 inch was allowed, while a maximum accumulated spacing error of 0.0008 inch was allowed. Maximum allowable spacing errors for other spur gears not in the roller gear unit were 0.00035 inch and 0.0015 inch for tooth-to-tooth and accumulated errors, respectively.

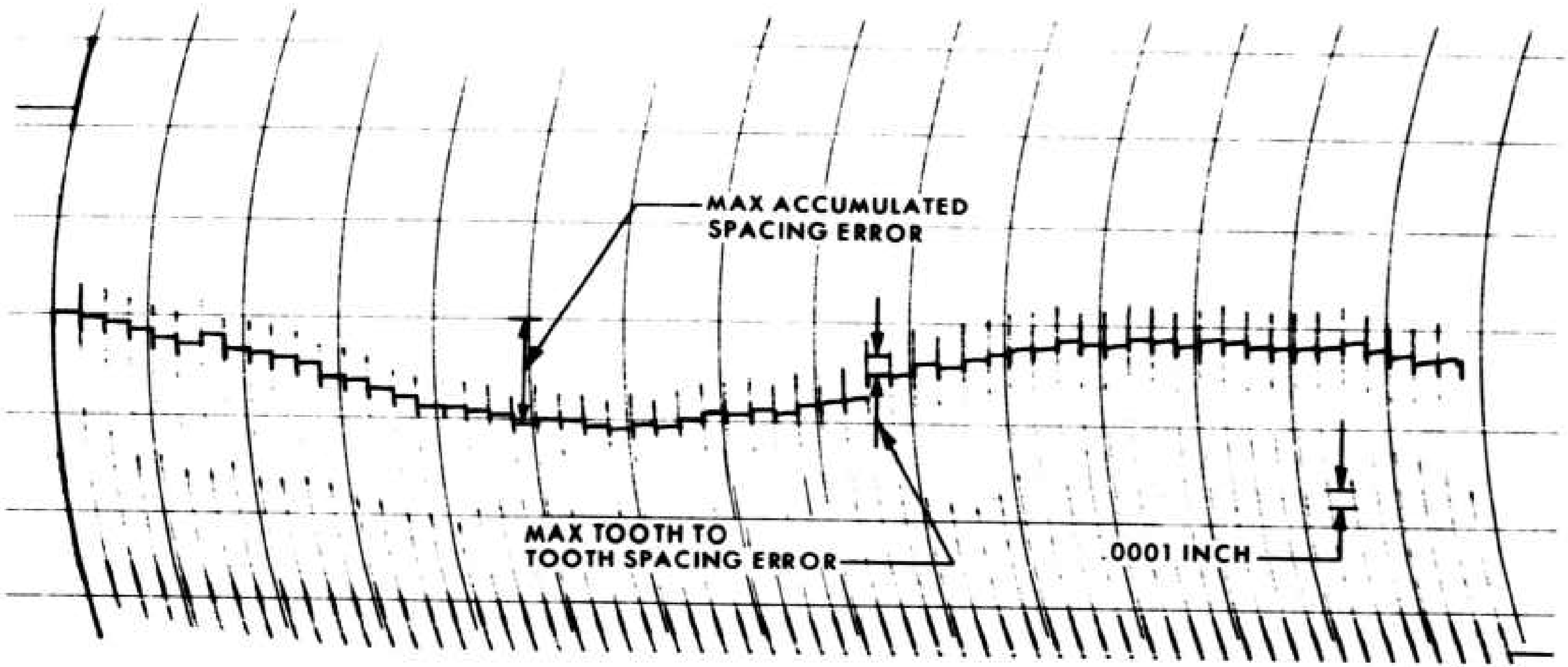


Figure 32. Tooth Spacing Error Chart, Large Diameter First-Row Pinion Gear.

Figure 33 shows an involute profile chart for four teeth of a first-row pinion large diameter gear. A reference line representing a perfect involute profile for the No. 1 gear tooth has been added to the chart. As can be seen from this chart, the No. 1 tooth has a tip relief of 0.0007 inch and a TIF (True Involute Form) relief of 0.0002 inch. Specifications for profile modification varied somewhat among the various spur gears of the roller gear transmission, but the range of tip relief was from 0.0007 to 0.0011 inch, while for TIF relief it was 0 to 0.0006 inch.

Figure 34 shows a typical lead chart for a large diameter gear of the first-row pinion. A reference line has been added to the chart to show what a zero lead error chart would look like for one of the teeth shown. As can be seen from the chart, these teeth all have lead errors of about 0.0001 inch. All spur gears in the roller gear transmission were required to have a lead error of no more than 0.0002 inch per inch of face width.

Crown is checked in exactly the same way lead error is checked. Figure 35 shows a typical chart of four teeth of the large diameter gear of the second-row pinion. These teeth were manufactured with a crown of 0.0003 inch to 0.0007 inch. Crowning was incorporated on both large and small diameter gears of the second-row pinion. This accounts for crowning of one member of both first-row pinion/second-row pinion and second-row pinion/ring gear meshes. Crowning was not incorporated in either member of the sun gear/second-row pinion mesh because of the narrow face widths involved.

Eccentricity was checked on a checking machine with a dial indicator readout. Eccentricity was limited to 0.0005 inch TIR (Total Indicator Reading) for the critical roller gear unit diameters, while 0.001 inch was allowed for most other diameters in the roller gear transmission.

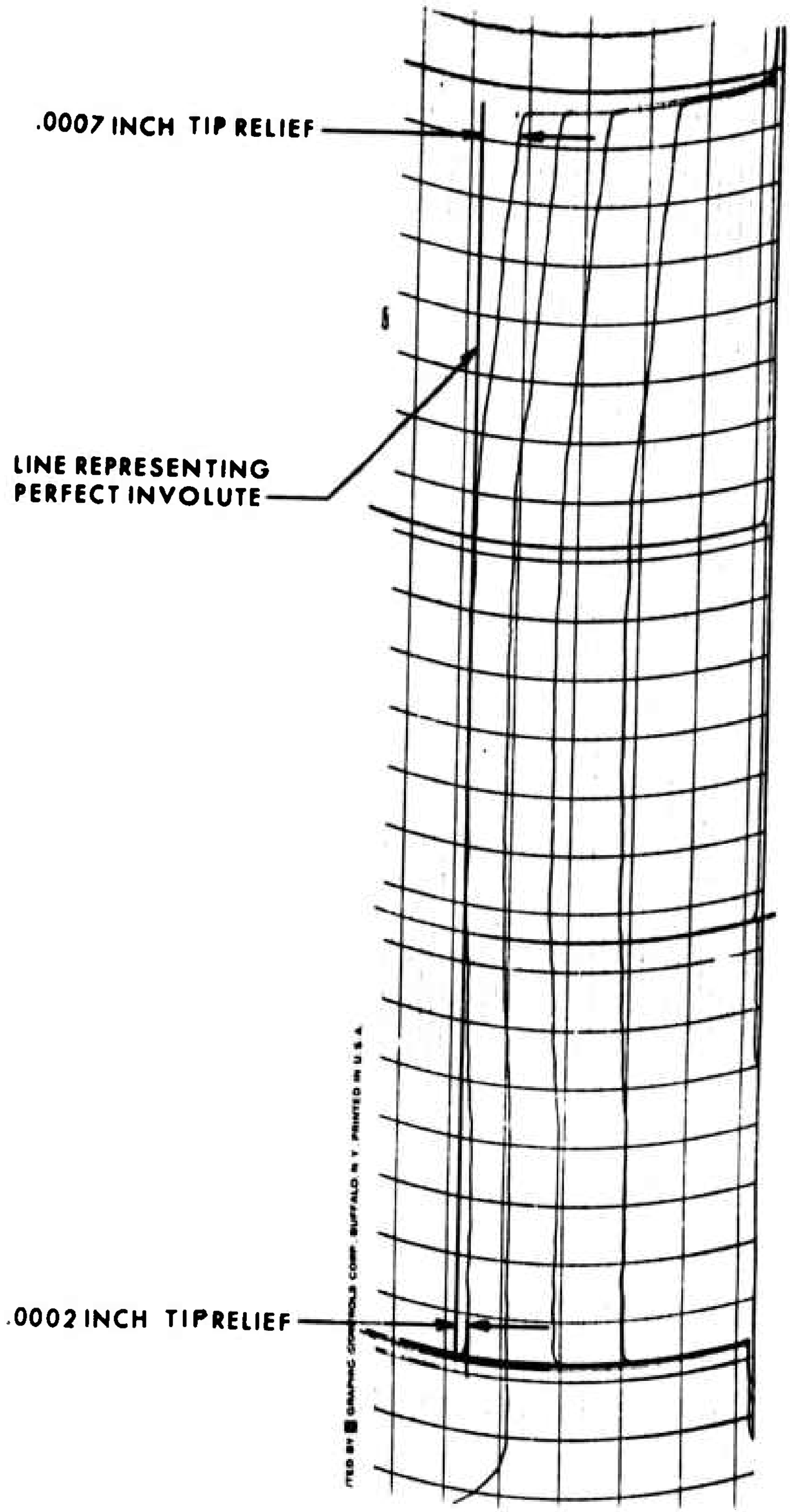


Figure 33. Involute Profile Inspection Chart,
First-Row Pinion Large Diameter Gear Teeth

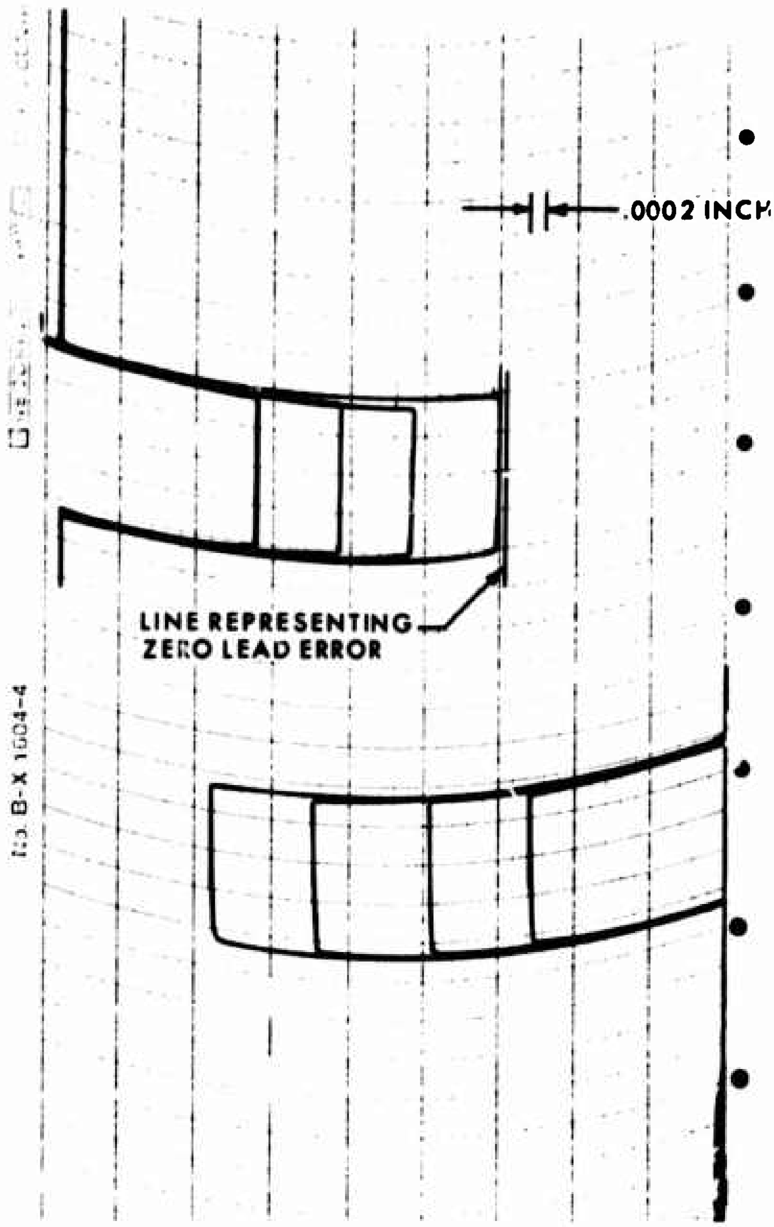


Figure 34. Lead Inspection Chart for First-Row Pinion Large Diameter Gear.

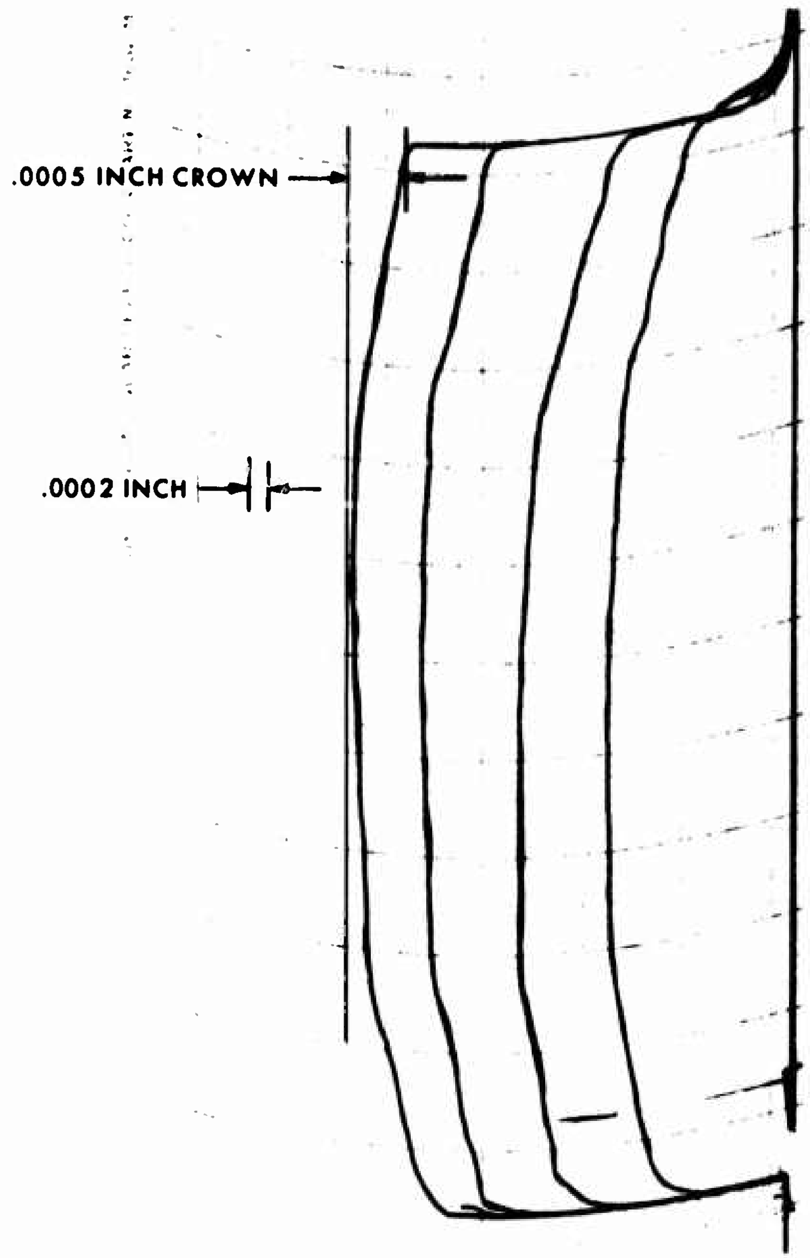


Figure 35. Crown Inspection Chart for Second-Row Pinion Large Diameter Gear.

ELECTRON BEAM WELDING

Of primary importance to the manufacture of the roller gear components in this program is electron beam welding. Electron beam welding is one of the more recently developed types of fusion weld processes and produces extremely clean welds at very high depth to width ratios. The basic principle behind electron beam welding is very simple, and is illustrated in Figure 36. Electrons are released from the surface of a low voltage, high current cathode by thermionic emission. The electrons are then accelerated toward the target material by a high voltage anode. The electrons are focused into a narrow intense beam by passing through coils of successively higher potential which act on the electrons in much the same way a lens acts on a beam of light. Upon impingement on the work piece, the kinetic energy of the electrons is converted into thermal energy causing localized melting and fusion of the part. The entire process is accomplished in a vacuum chamber evacuated to a pressure of 1 x 10-4 mm Hg or less. This exposes the molten metal to less than 2 parts per million of external contaminant and eliminates the problem of interstitial gases which tend to weaken a weld.

The decision to use electron beam welding in the manufacture of the roller gear components was precipitated by the complexity of the components and the accuracy to which they had to be manufactured for proper functioning of the roller gear unit. The first-row pinion, for example, contains three geared surfaces and four roller surfaces, all of which must be held within very close tolerances of each other. Alternate methods of assembly such as locknuts, splines and shrink fits were considered, but were rejected on the basis of low reliability and difficulty of holding assembly tolerances.

Although there are many advantages to electron beam welding, including weld integrity and speed, the most important considerations in choosing electron beam welding for roller gear manufacture were its minimal heat effect and its high depth-to-width ratio. The fusion process occurs so rapidly with electron beam welding that very little heating occurs in the surrounding metal. This means that there is very little, if any, distortion of the welded part, a necessary condition for the close tolerances required by the roller gear components. In addition, the size of the heat affected zone, where the structure of the metal might be altered, is minimized. The extremely small working area in the fabrication of the roller gear components necessitated a welding process with a high depth-to-width ratio. Figure 37 shows a comparison of this parameter for electron beam and a typical tungsten inert gas (TIG) arc weld. In most of the welds in the roller gear components there is a working width of less than 1/10 inch between the stressed surfaces of roller and gear which would tolerate little heating from the welding process. As will be seen later in this

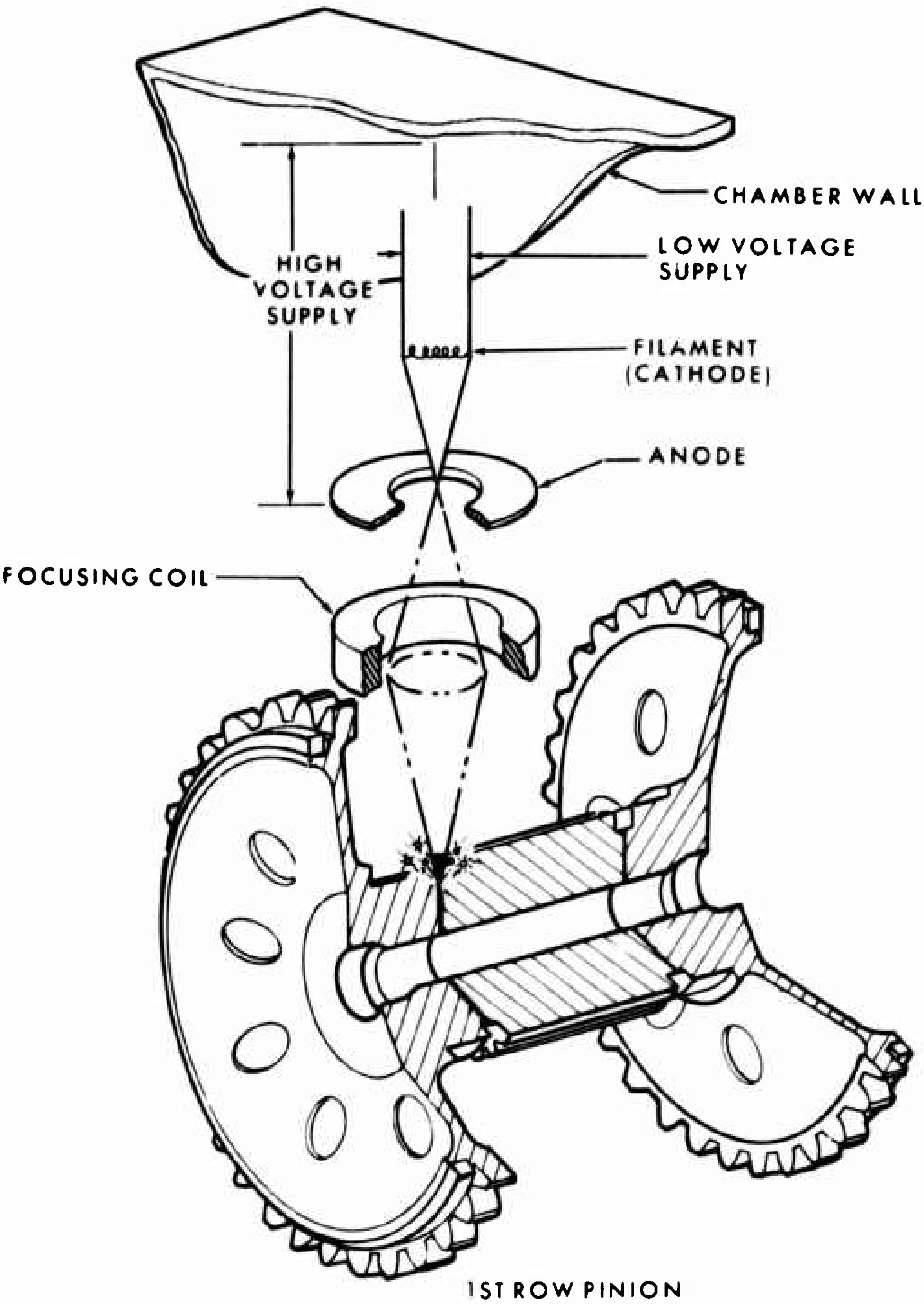


Figure 36. Electron Beam Welding Process, Schematic.

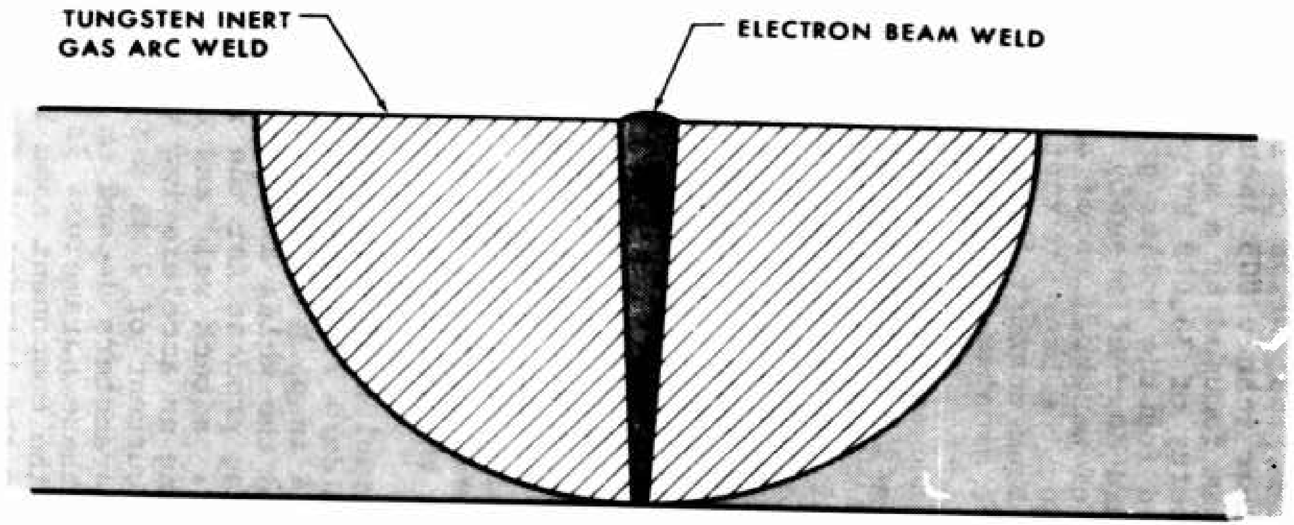


Figure 37. Comparison of Depth-to-Width Ratios of TIG and Electron Beam Welding.

section, problems were nevertheless encountered by even the minimal heat effects of the electron beam welds which led to several design changes in the roller gear components.

A Hamilton Standard W2-0 welder was used to weld the components of the roller gear drive. The electron gun system of this weld operates at a maximum voltage of 150 KV and a maximum beam current of 40 MA. This represents a maximum power output of 6 KW. With a focused beam, spot sizes of less than 0.015 inch at maximum power and of less than 0.005 inch at lower power can be obtained. The 6 KW beam focused to a spot size of 0.015 inch represents a power density of 36,000 KW per square inch. A rotary fixture was used for the roller gear component welds. Rotation of this fixture is continuously variable from .12 rpm to 50 rpm. The depth of penetration of an electron beam weld is determined by varying the beam current and the speed of the weld. The higher the beam current the greater the penetration; the lower the speed the greater the penetration.

Before manufacture of the actual roller gear components, a series of proof tests and hardness tests was performed on sample welds to determine the optimum weld parameters for roller gear manufacture. The proof tests consisted of performing constant strain rate tests to failure on weld samples of various cross-sectional areas. Figure 38 shows a typical stress-strain curve derived from these tests. Although electron beam welding has no filler material in the weld, the weld does not exhibit a well defined yield point because of the variation in micro-structure through the weld zone. For these tests, the standard 0.2 percent offset from the elastic region is taken for determination of the weld yield strength. The hardness tests were taken to determine the extent of the hardness loss resulting from the heat generated during the weld. Figure 39 is an example of these hardness readings taken through the various weld configurations of the roller gear components.

The roller gear transmission of this program contains a total of 72 electron beam welds: 2 in the sun gear, 4 in each of the 7 first-row pinions and 6 in each of the 7 second-row pinions. Assembled views showing the welds are presented in Figures 40 through 43. The welding process for the roller gear components consisted of two welds: a tack weld and a final weld. The tack weld was performed using an accelerating voltage of 140 KV with a relatively low beam current of 2 MA and a weld speed of 40 ipm. The final weld parameters depend on the components being welded. A summary of these parameters is presented in Table 9. The letters following the component name refer to the weld locations and correspond to the letters of Figures 40 through 43. Figures 44 through 52 illustrate the various holding fixtures used for the welding of the roller gear components. The unlabeled arrows point to the weld associated with the holding fixture. The copper chill dies shown in these figures are

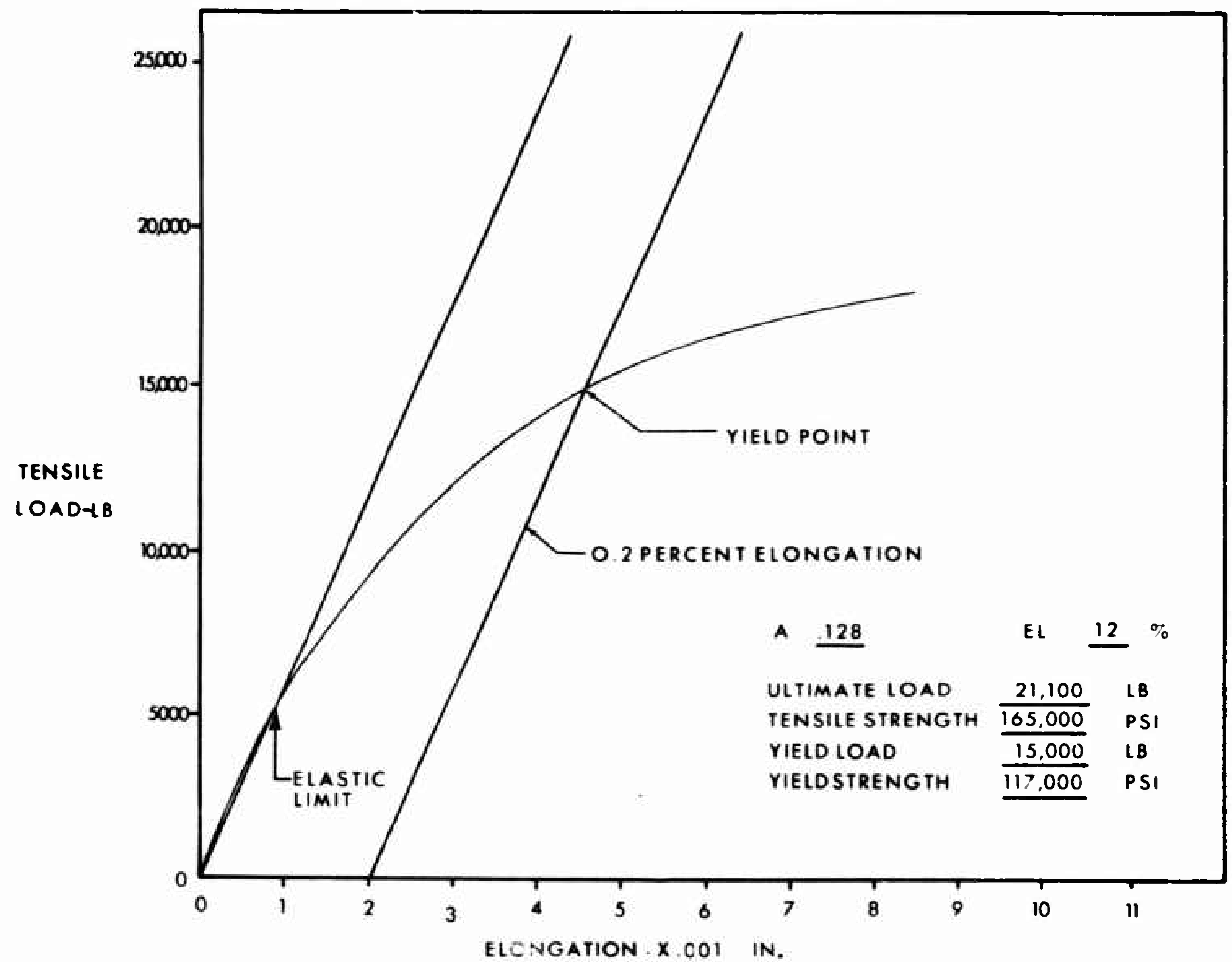


Figure 38. Typical Electron Beam Weld Proof Test.

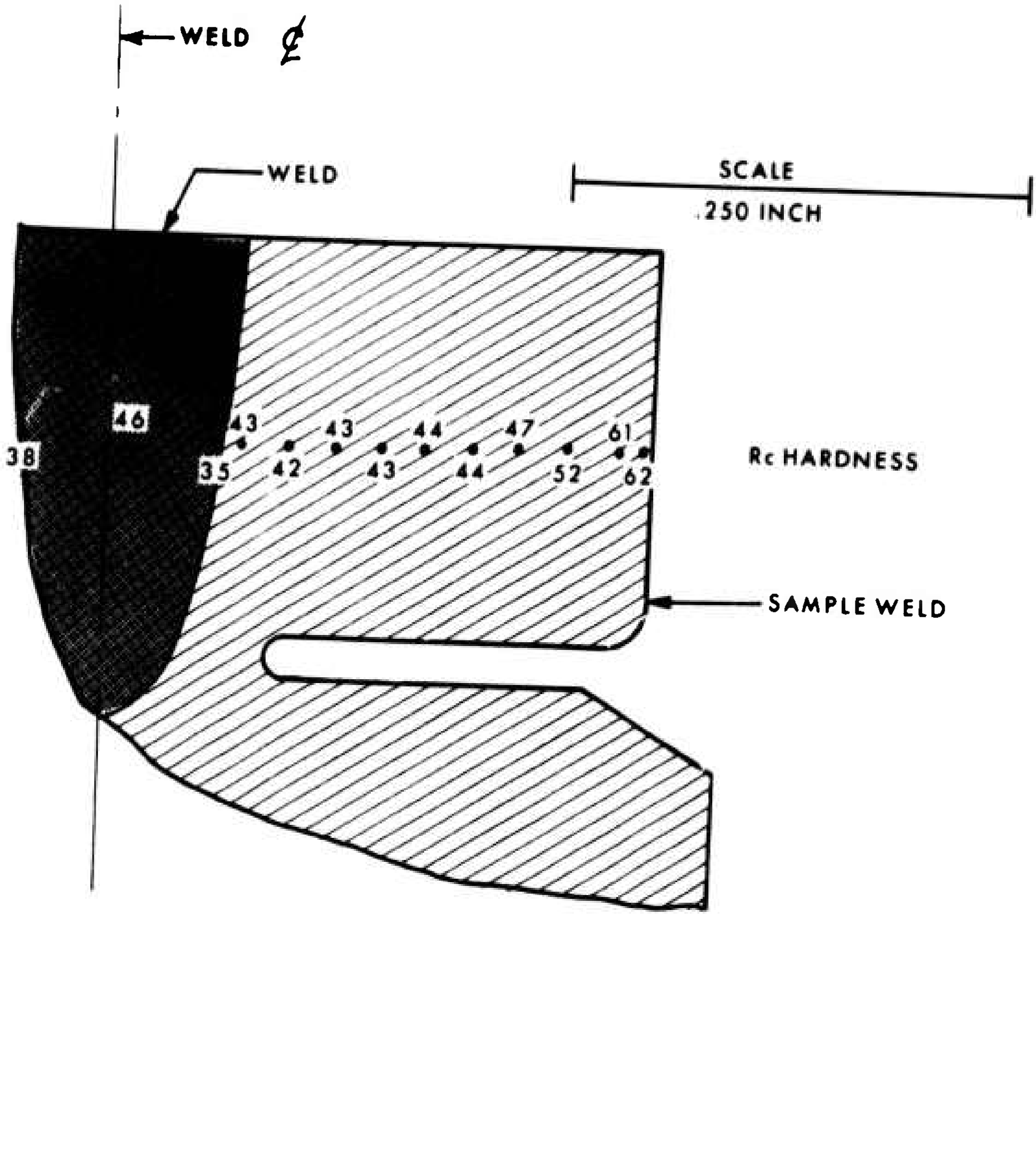


Figure 39. Typical Hardness Test of Electron Beam Weld Showing Effects of Heat on Steel hardness.

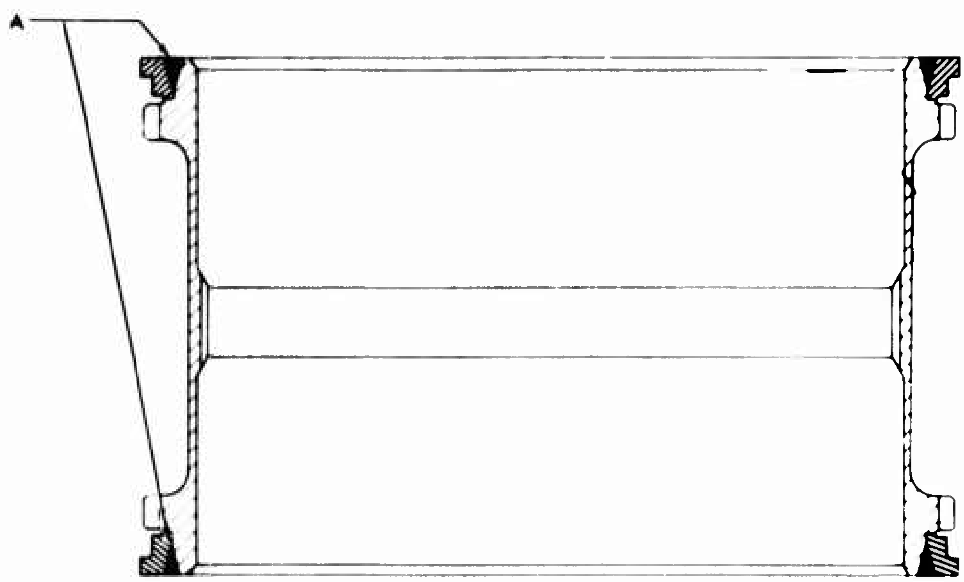


Figure 40. Assembled View of Sun Gear Showing Electron Beam Welds.

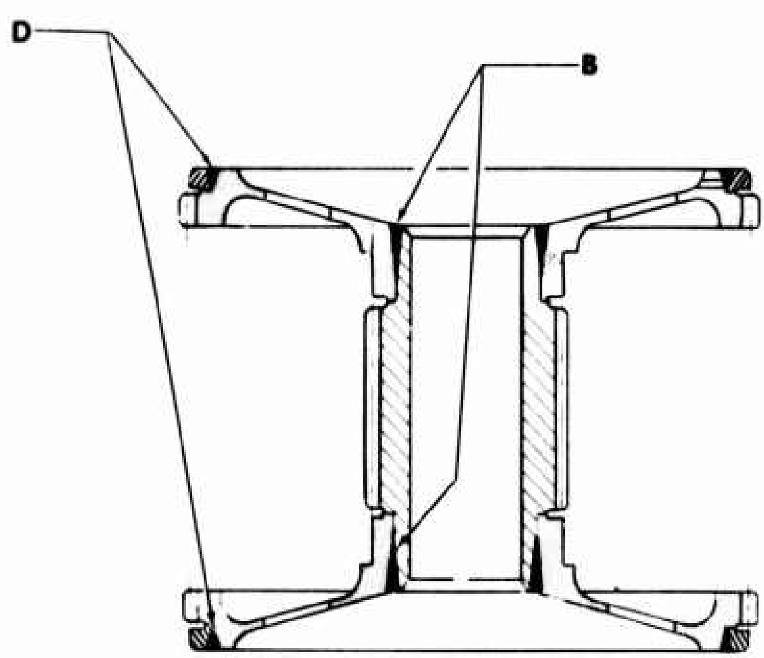


Figure 41. Assembled View of First-Row Pinion Showing Electron Beam Welds (Original Configuration).

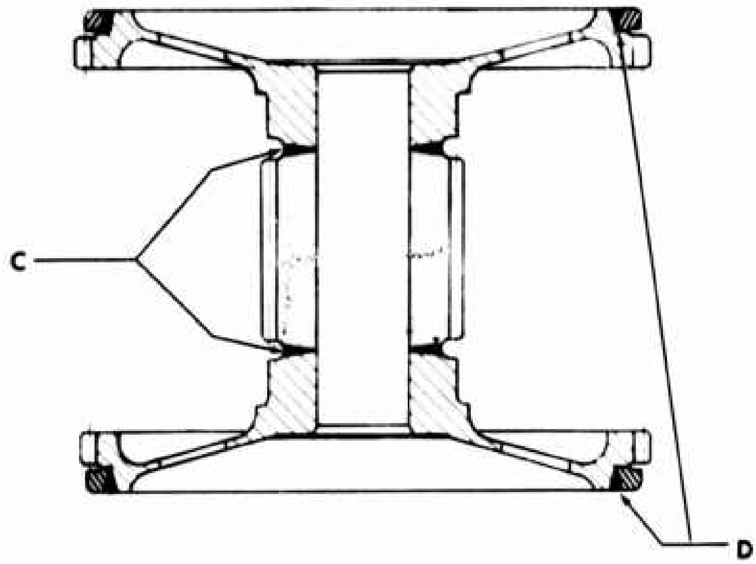


Figure 42. Assembled View of First-Row Pinion Showing Electron Beam Welds (Butt Weld Configuration).

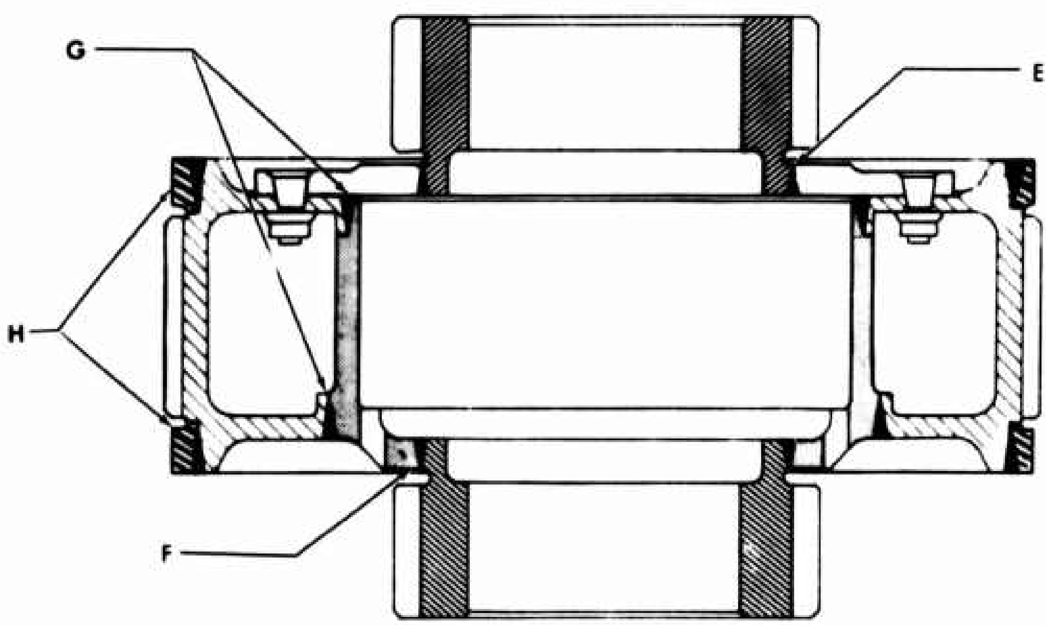


Figure 43. Assembled View of Second-Row Pinion Showing Electron Beam Welds.

TABLE 9. SUMMARY OF ROLLER GEAR COMPONENT WELD PARAMETERS

Component	Location Reference	Accelerating Voltage (KV)	Beam Current (MA)	Speed (RPM)	Maximum Penetration	Focus
Sun Gear	A	140	40	60	.480	Flush
First-Row Pinion (Original)	B	140	40	40	.640	Flush
First-Row Pinion (Modified)	C	140	27	30	.600	.3 Inch Below
First-Row Pinion	D	140	14	60	.160	.25 Inch Below
Second-Row Pinion (Original)	E	140	22	60	.310	Flush
Second-Row Pinion (Modified)	E	140	26	60	.310	Flush
Second-Row Pinion	F	140	32	60	.463	Flush
Second-Row Pinion	G	140	34	60	.390	.25 Inch Above
Second-Row Pinion	H	140	38	60	.460	Flush

*Letters correspond to the letters on Figures 40 through 43.

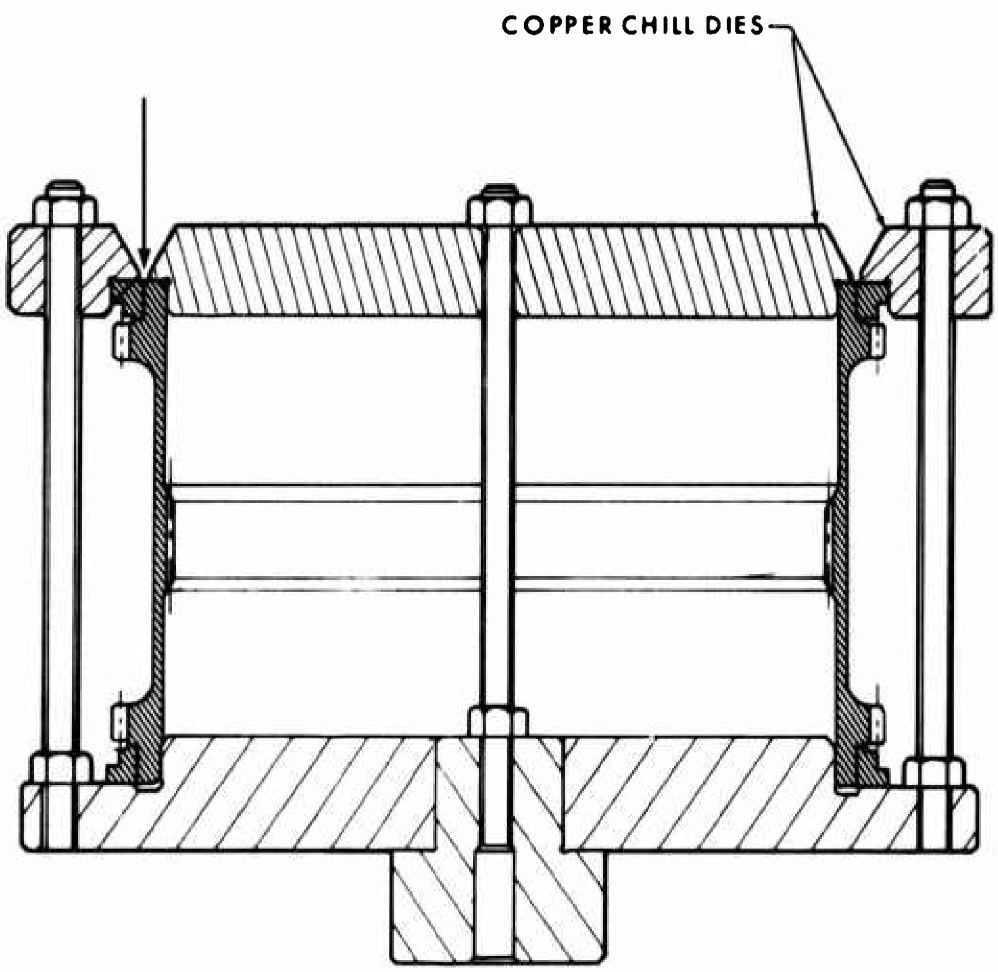


Figure 44. Welding Fixture for Sun Gear Roller Welds.

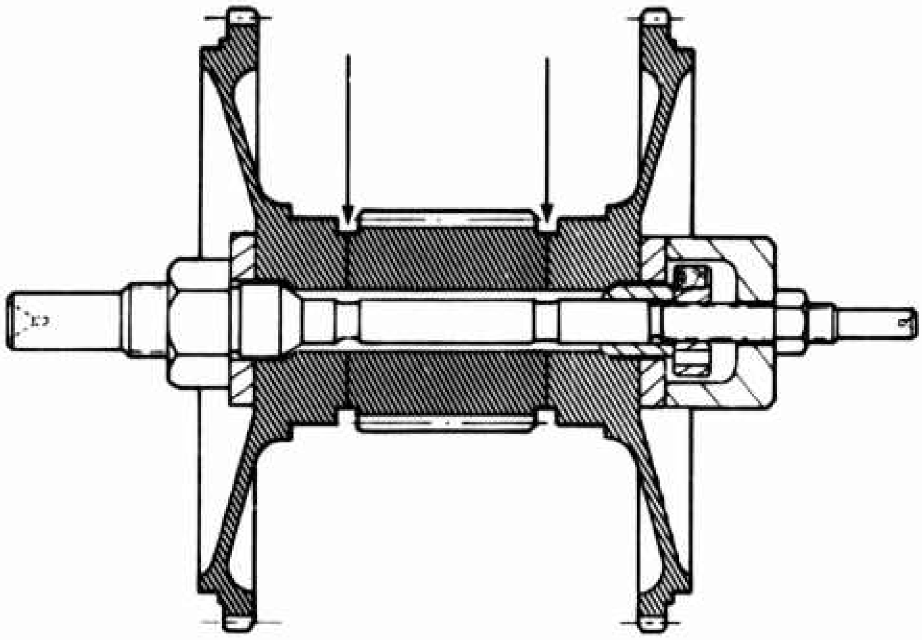


Figure 45. Welding Fixture for First-Row Pinion Butt Weld.

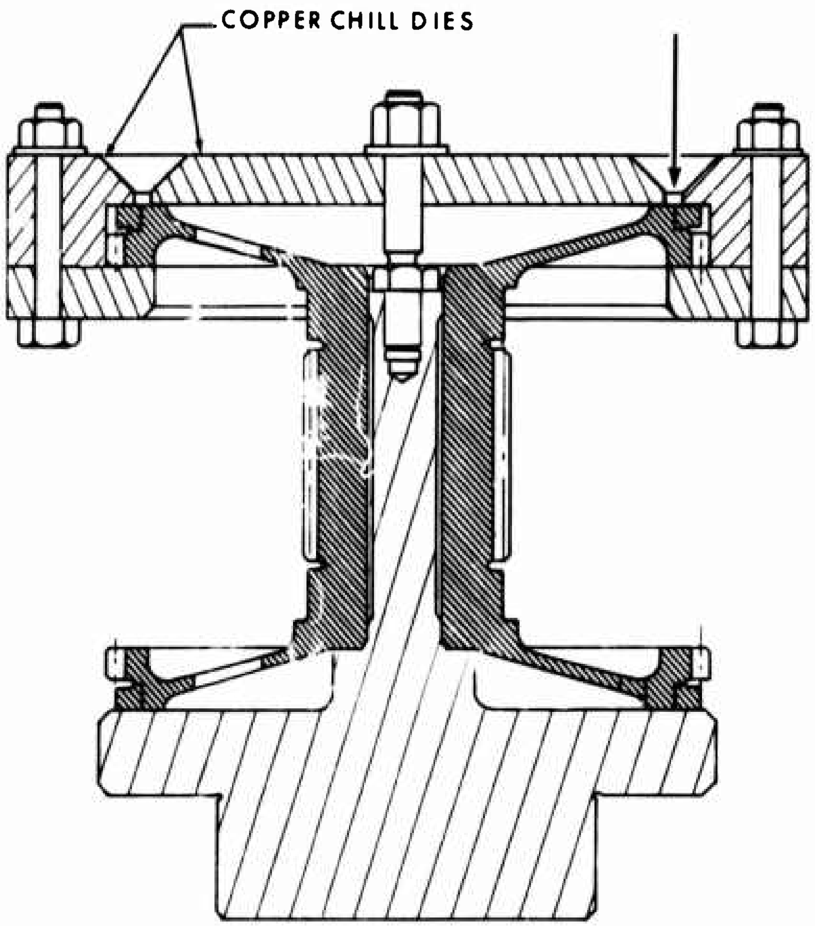


Figure 46. Welding Fixture for First-Row Pinion Roller Weld.

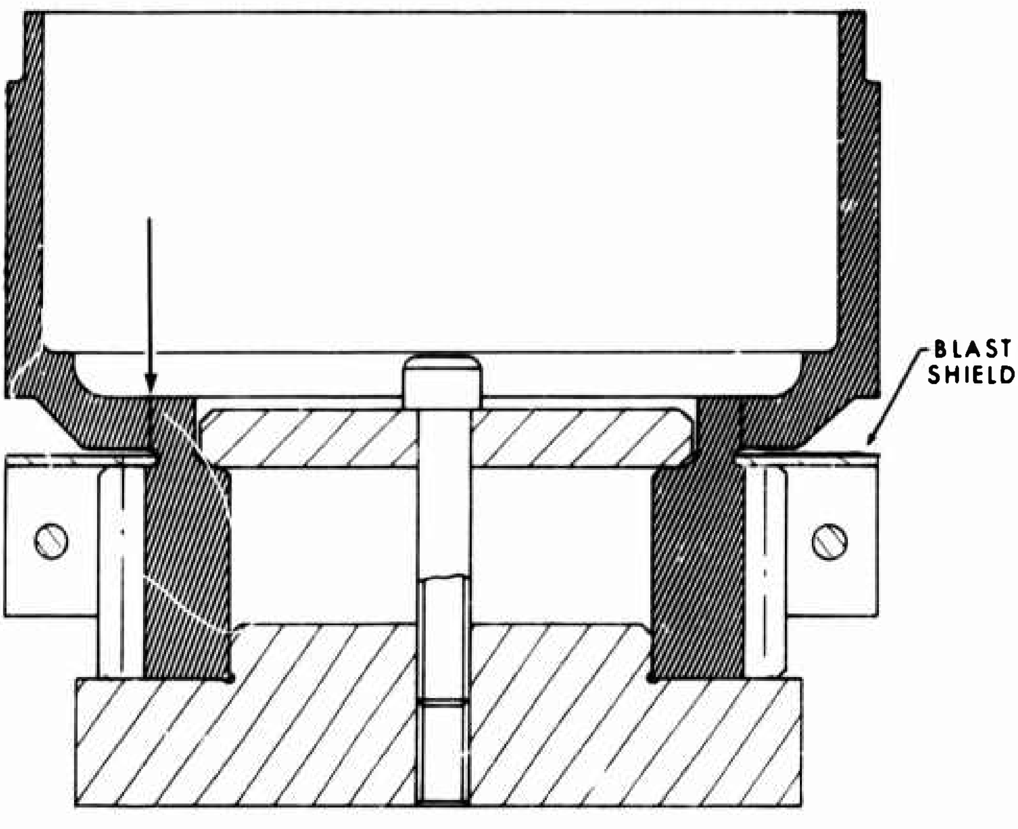


Figure 47. Welding Fixture for Second-Row Pinion Small Gear to Shaft Weld.

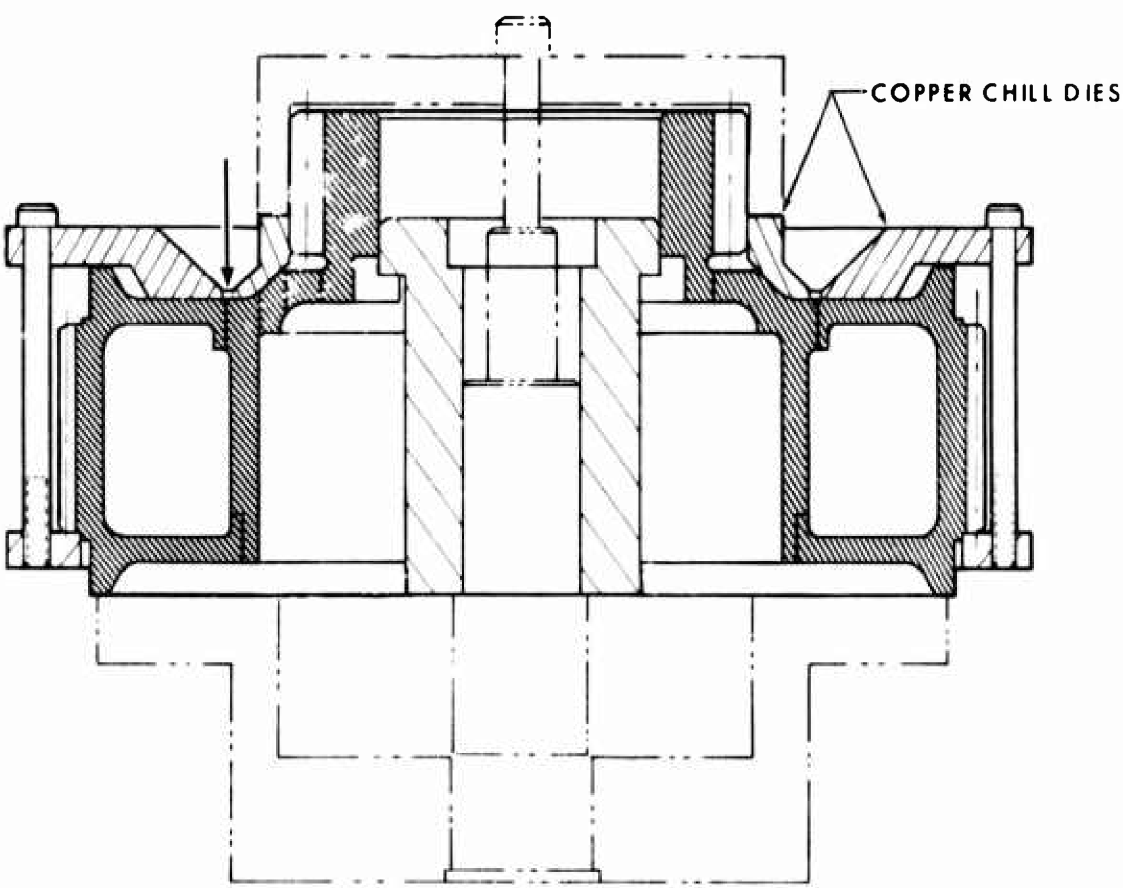


Figure 48. Welding Fixture for Second-Row Pinion Large Gear to Shaft Lower Weld.

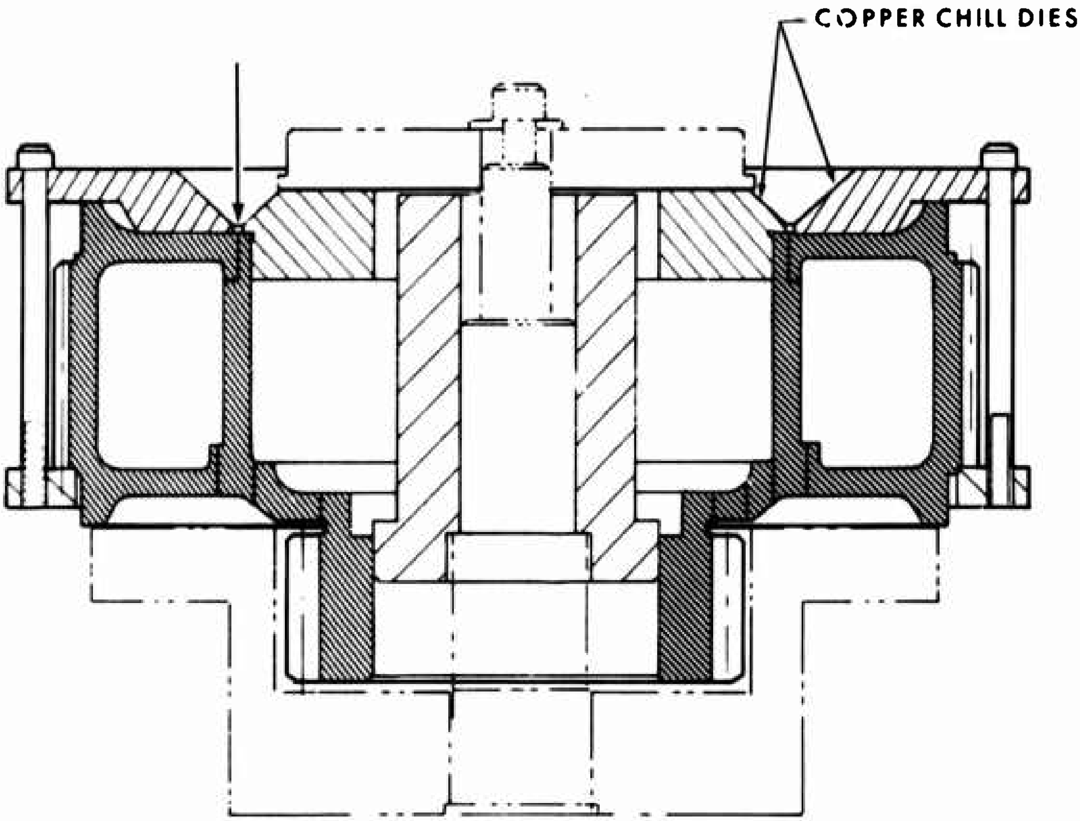


Figure 49. Welding Fixture for Second-Row Pinion
Large Gear to Shaft Upper Weld.

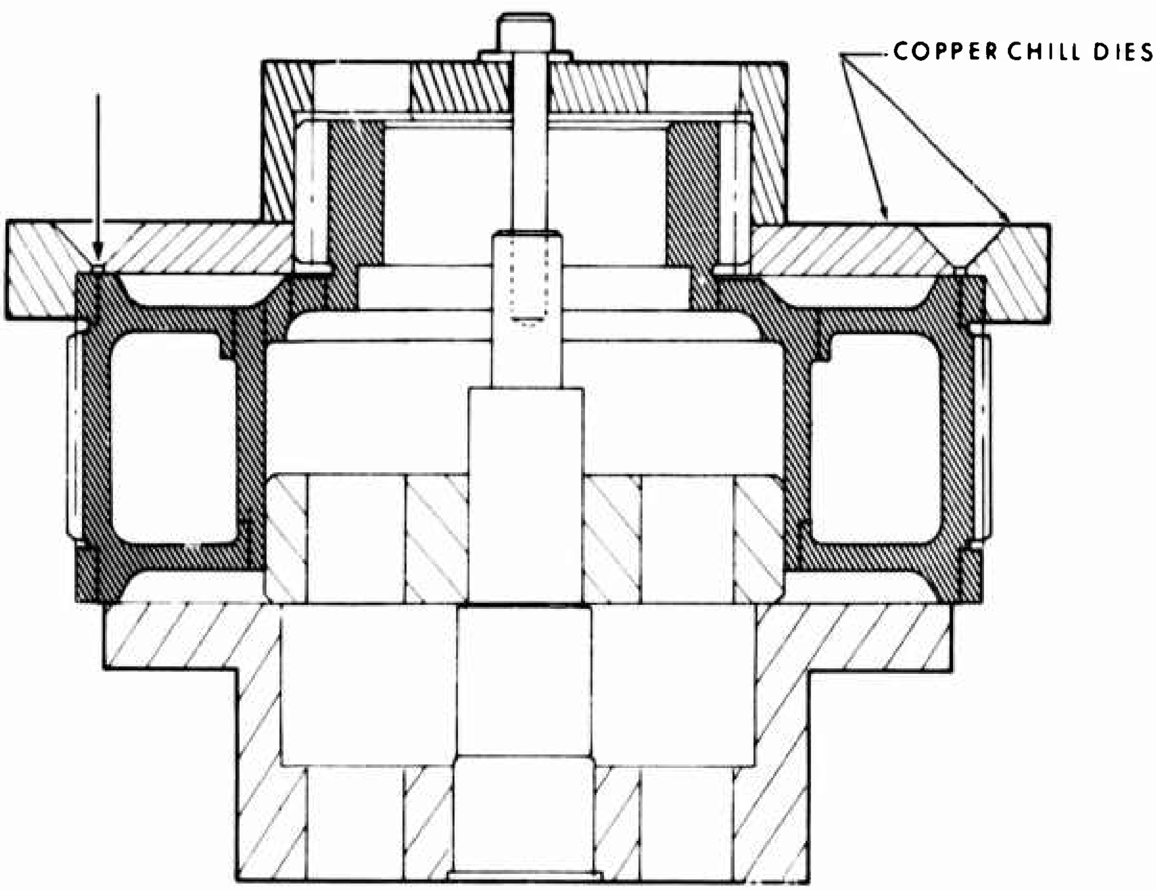


Figure 50. Welding Fixture for Second-Row Pinion Lower Roller Weld.

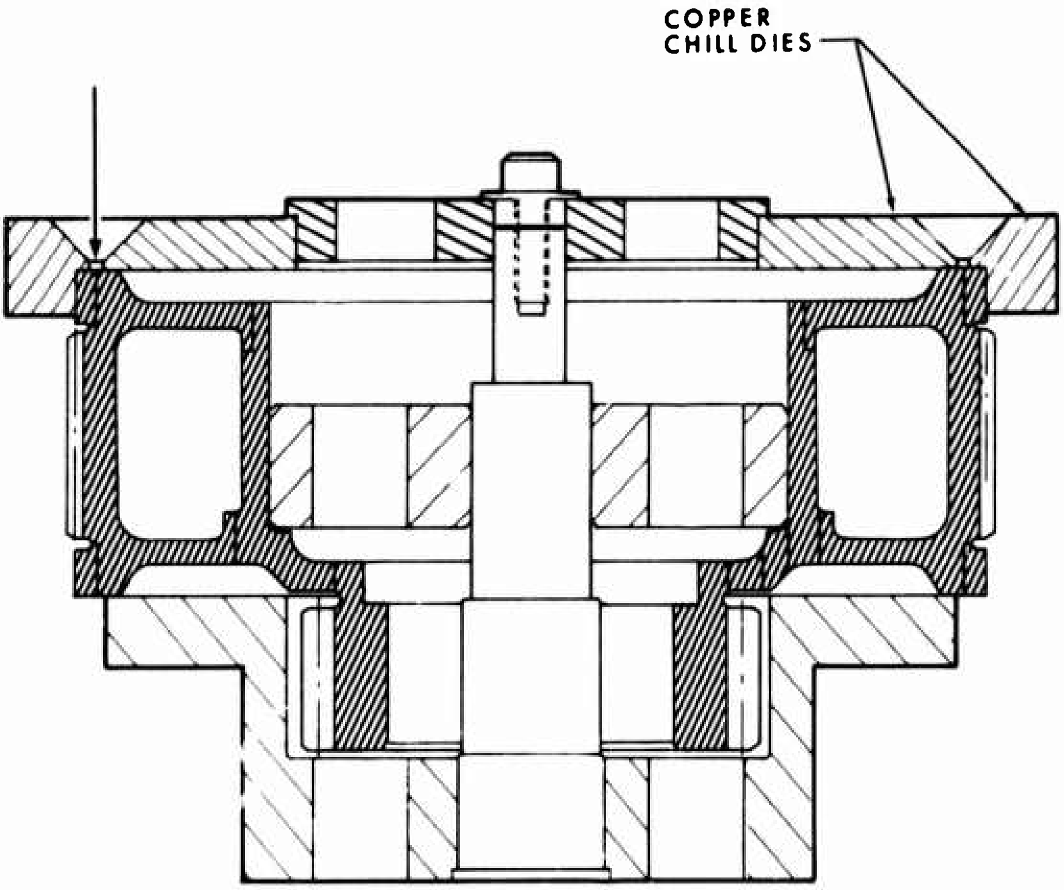


Figure 51. Welding Fixture for Second-Row Pinion Upper Roller Weld.

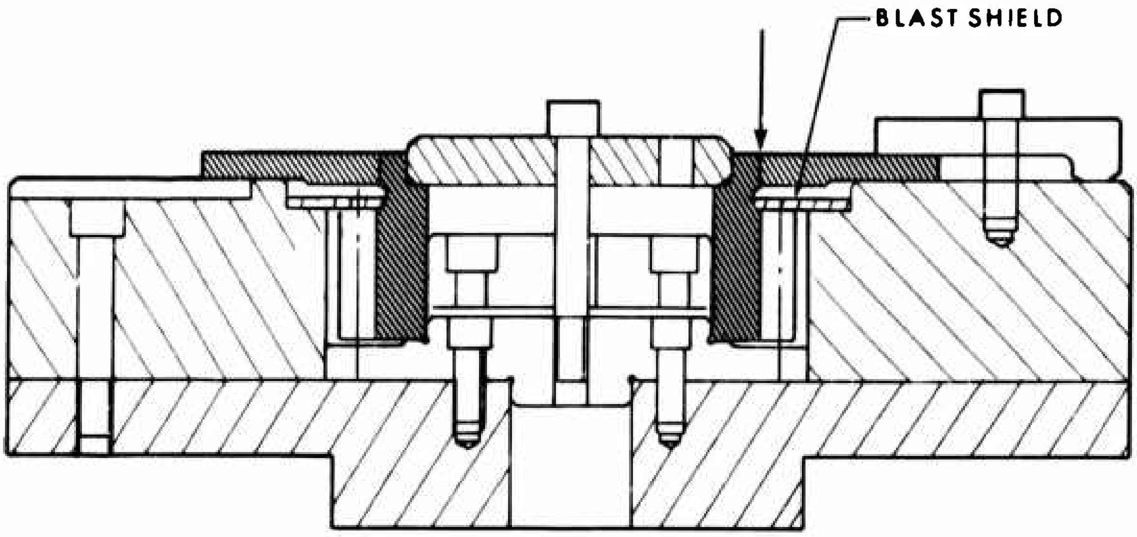


Figure 52. Welding Fixture for Second-Row Pinion Upper Gear to Plate Weld.

used to conduct heat away from the weld area. It should be noted that two of the welds of Table 9 show weld parameters for both an original and a revised version. These changes, among others to be discussed here, are the direct result of the initial development test segment of the roller gear bench test program. One of the primary purposes of this test was the evaluation of electron beam weld geometry and parameters. The test was designed to detect any shortcomings in these areas by subjecting the welded components to high loads in the actual transmission environment and to make any necessary changes prior to the start of the 200-hour endurance test.

The initial development test was performed in a back-to-back regenerative test stand capable of subjecting the gearboxes to an equivalent of 3500 HP. Only those aspects of the initial development test relating directly to electron beam welding development are discussed below. Figure 53 shows the bench test schedule, including both initial development test and endurance test, to which the roller gear transmission was subjected (Reference 5). At 26 hours 28 minutes into the initial development test, the rollers adjacent to the small diameter gear of the first-row pinions showed severe spalling (Figure 54).

Microscopic examination of a failed first-row pinion revealed that spalling of the small diameter gear's lower roller was caused by fatigue cracking originating below the surface and propagating to the surface. A cross-sectional sample taken in an unspalled area immediately adjacent to the spalling revealed a subsurface crack extending through the electron beam weld zone as shown in Figure 55. There was no evidence of this crack at the surface. Metallographic examination revealed a series of voids along the weld line as shown in Figure 56. Cracks were evident extending from one of these voids. Examination revealed a desired case microstructure of martensite and tempered austenite with no evidence of carbide network.

Microscopic examination of the spalling on the roller revealed fatigue cracking of the surface with no evidence of subsurface origins. A metallurgical specimen taken adjacent to the spalling did not exhibit subsurface cracking in this area. Voids in the weld zone, similar to those evident in the weld in the opposite roller, were evident. Spalling of this surface may have been a result of load transfer occurring from a loss of contact area when the lower roller spalled.

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5. Gardner, G. F., and Haven, R. E., LABORATORY BENCH TEST 3000 HP ROLLER GEAR TRANSMISSION DEVELOPMENT PROGRAM, Sikorsky Engineering Report SER-611622, Sikorsky Aircraft, Stratford, Connecticut, August 1973.

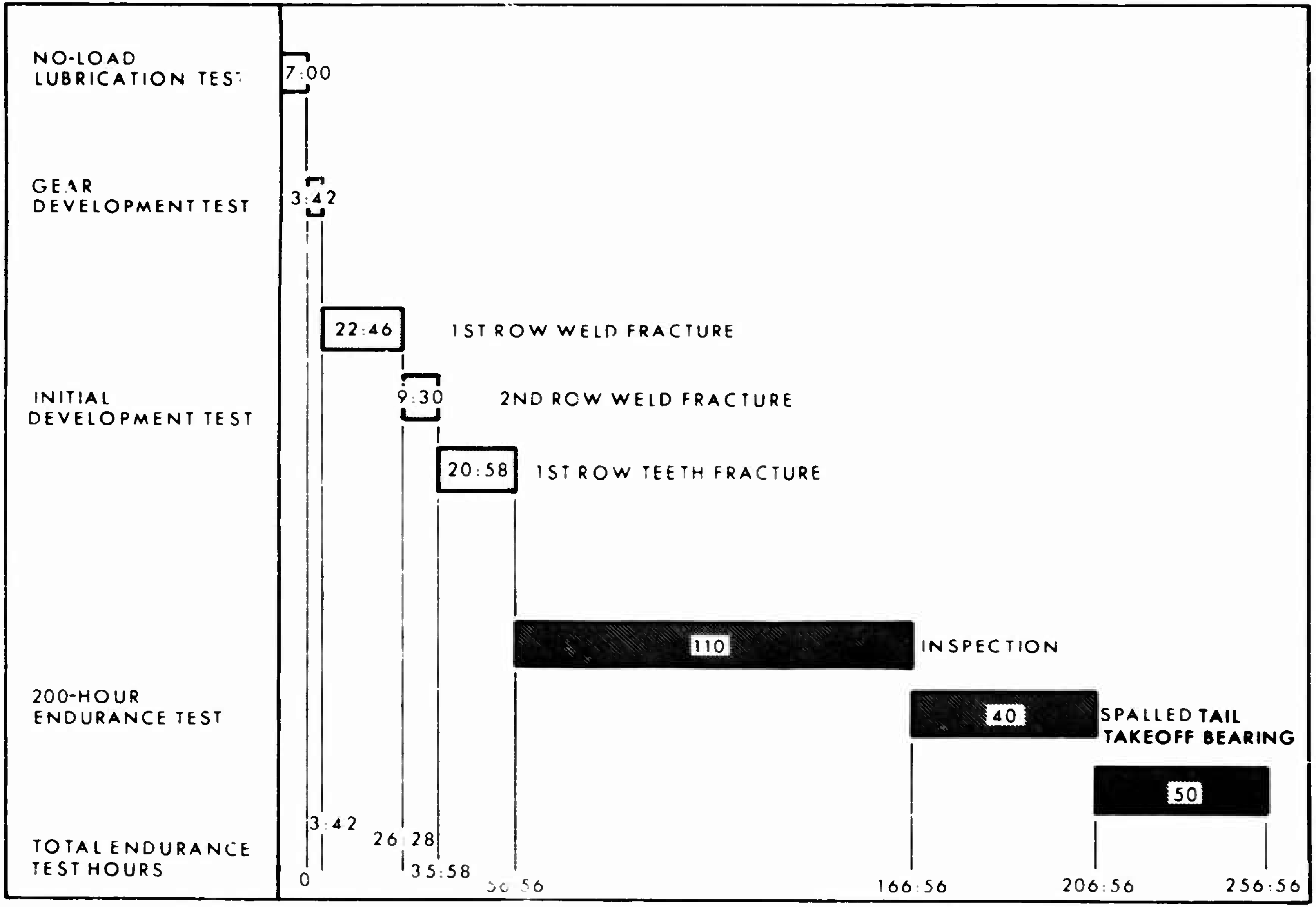


Figure 53. Bench Test Schedule.

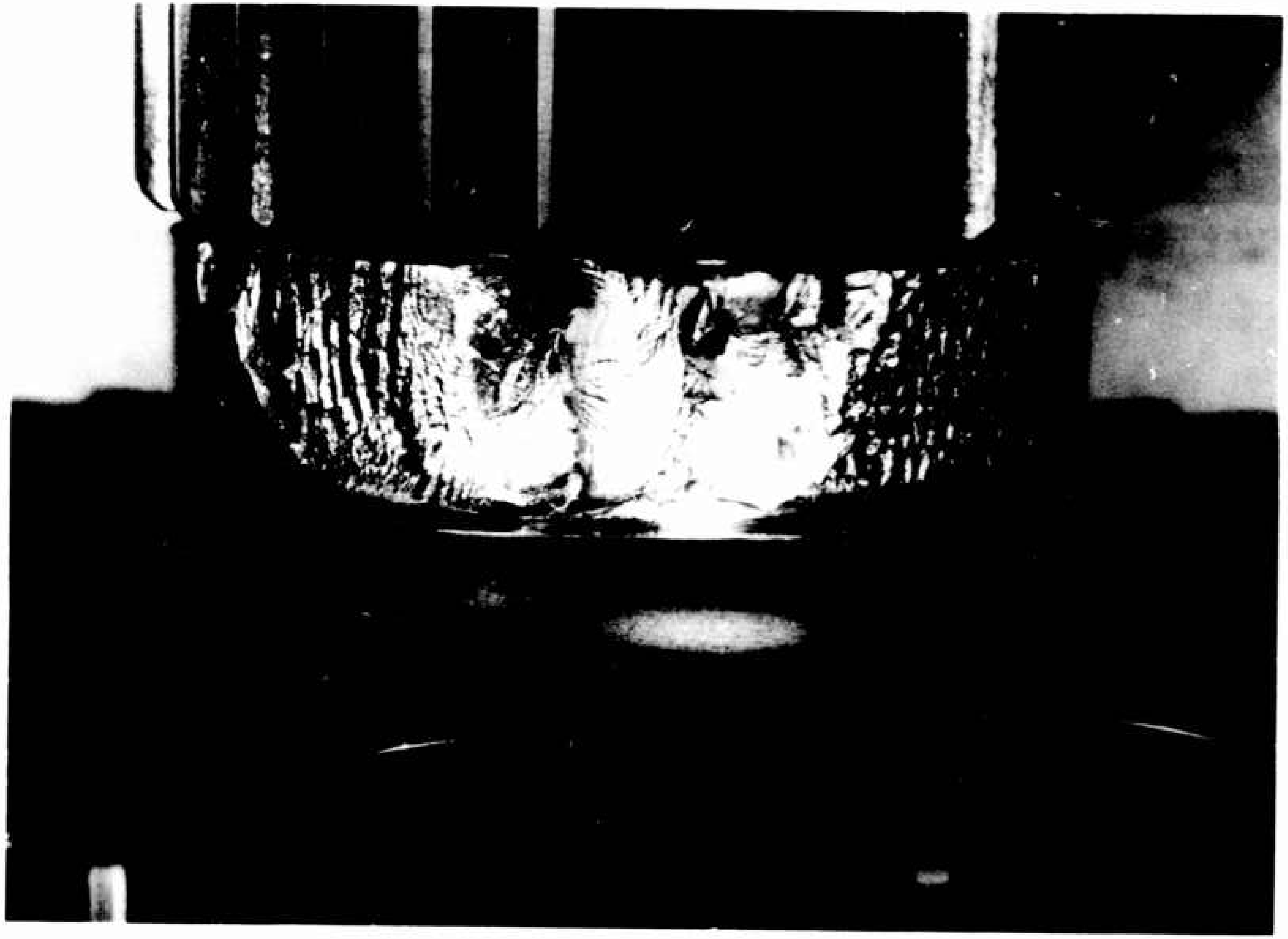


Figure 54. First-Row Pinion Small Diameter Roller Spalling.

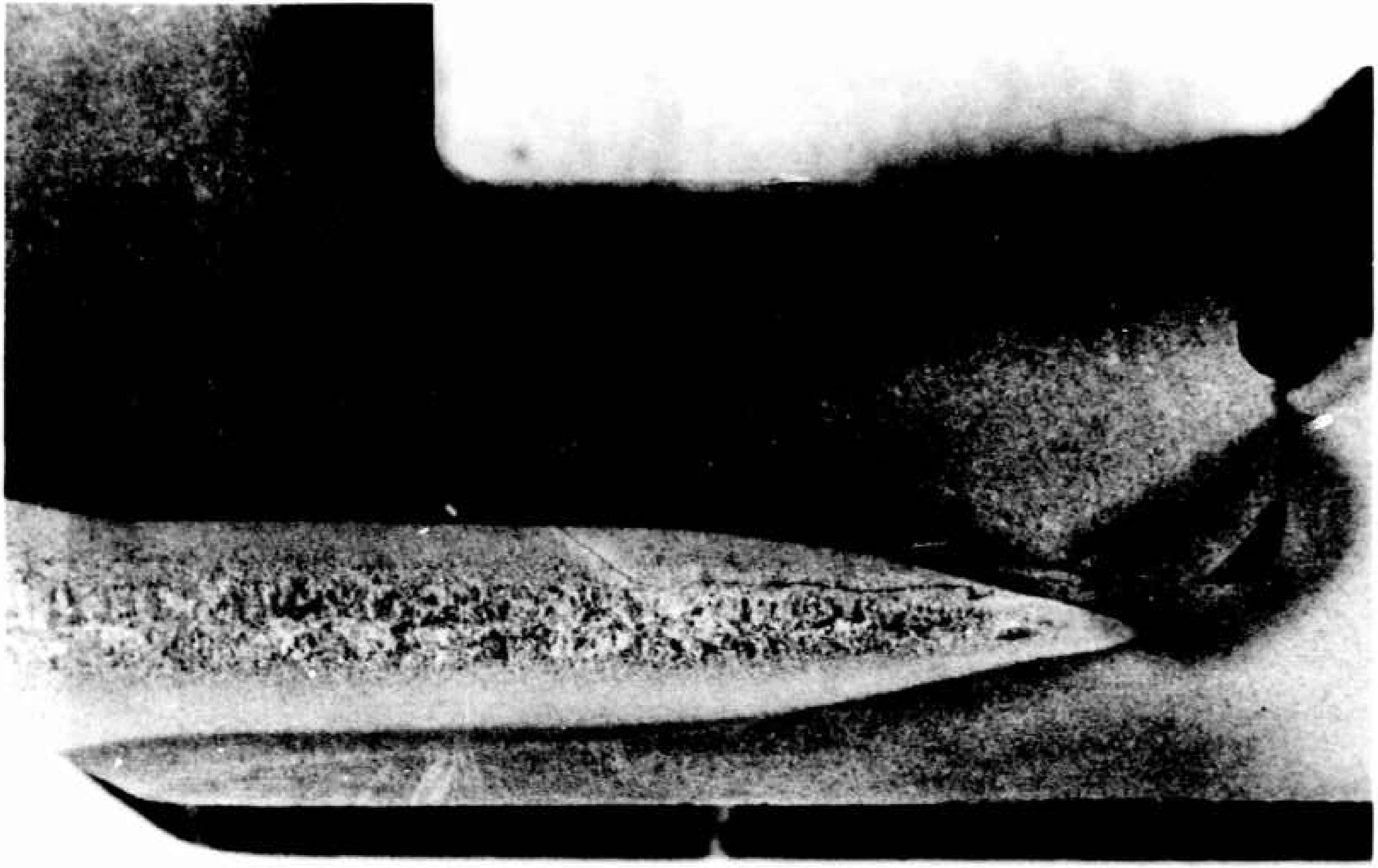


Figure 55. Cross-Sectional Sample Through First-Row Pinion Spalled Roller.

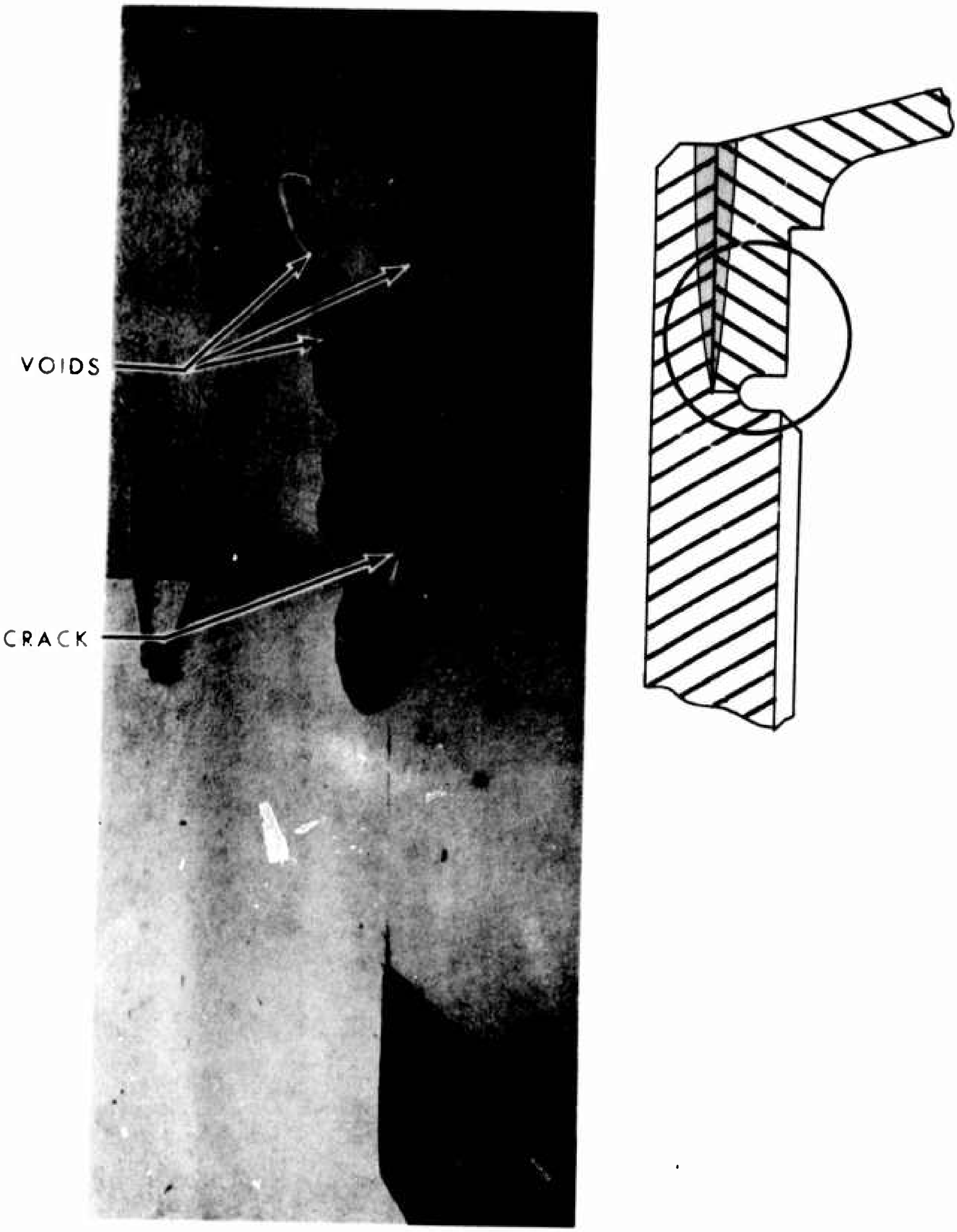


Figure 56. Metallographic Inspection of First-Row Pinions Revealing Voids at Weld Line.

A microhardness traverse through the core, in a direction normal to the surface, showed a slight reduction in hardness and effective case depth on both top and lower rollers. This plot is shown in Figure 57. This reduction is explained by the removal of stock during the final roller grinding operation and probably also the result of high temperatures generated during electron beam welding. The microhardness survey reveals a smooth transition from case to core with effective case depth measured at Rc 50. The low case hardness and depth were not considered factors in the spalling, since the cracking originated subsurface at voids in the weld.

It was concluded that the fracture initiated from voids in the area of the electron beam weld.

Ultrasonic testing was conducted on the small diameter rollers of the first-row pinions to determine if detection of subsurface cracking was possible. A Krautkramer ultrasonic flaw detector was used in conjunction with a dual transducer utilizing longitudinal waves. Acoustic contact between the transducer and the roller surface was by glycerine. A 0.25-inch-thick steel reference block was used for calibration of the ultrasonic equipment, this being representative of the distance from the roller surface to the weld. A first-row pinion showing no external indications of failure exhibited a sonic indication of an abnormality. Laboratory sectioning through the groove between the small gear and adjacent roller revealed subsurface cracking extending for approximately half the circumference. A series of voids was apparent around the entire circumference, as shown in Figure 58. Separation of the crack interface revealed multiple fatigue zones originating at voids in the weld zone, shown typically in Figure 59.

In order to alleviate the problems described above, the first-row pinion was redesigned to include a butt weld instead of the original longitudinal weld. This weld configuration would require a decreased depth of penetration, thereby decreasing the chance of voids. Secondly, the weld would pass completely through the section of the pinion instead of ending in a blind. Visual inspection could then detect completeness of the weld which was impossible in the original configuration. In addition, the inherent stress concentration caused by the inner gear-roller interface, Figure 60, would be removed. The butt weld configuration would also have the advantage of being further removed from the compressively stressed material of the inner roller surface.

The next welding related failure of a roller gear component occurred after 35 hours 58 minutes of testing with the fracture of a second-row pinion as shown in Figure 61. Inspection of the fractured second-row pinion revealed a machined surface

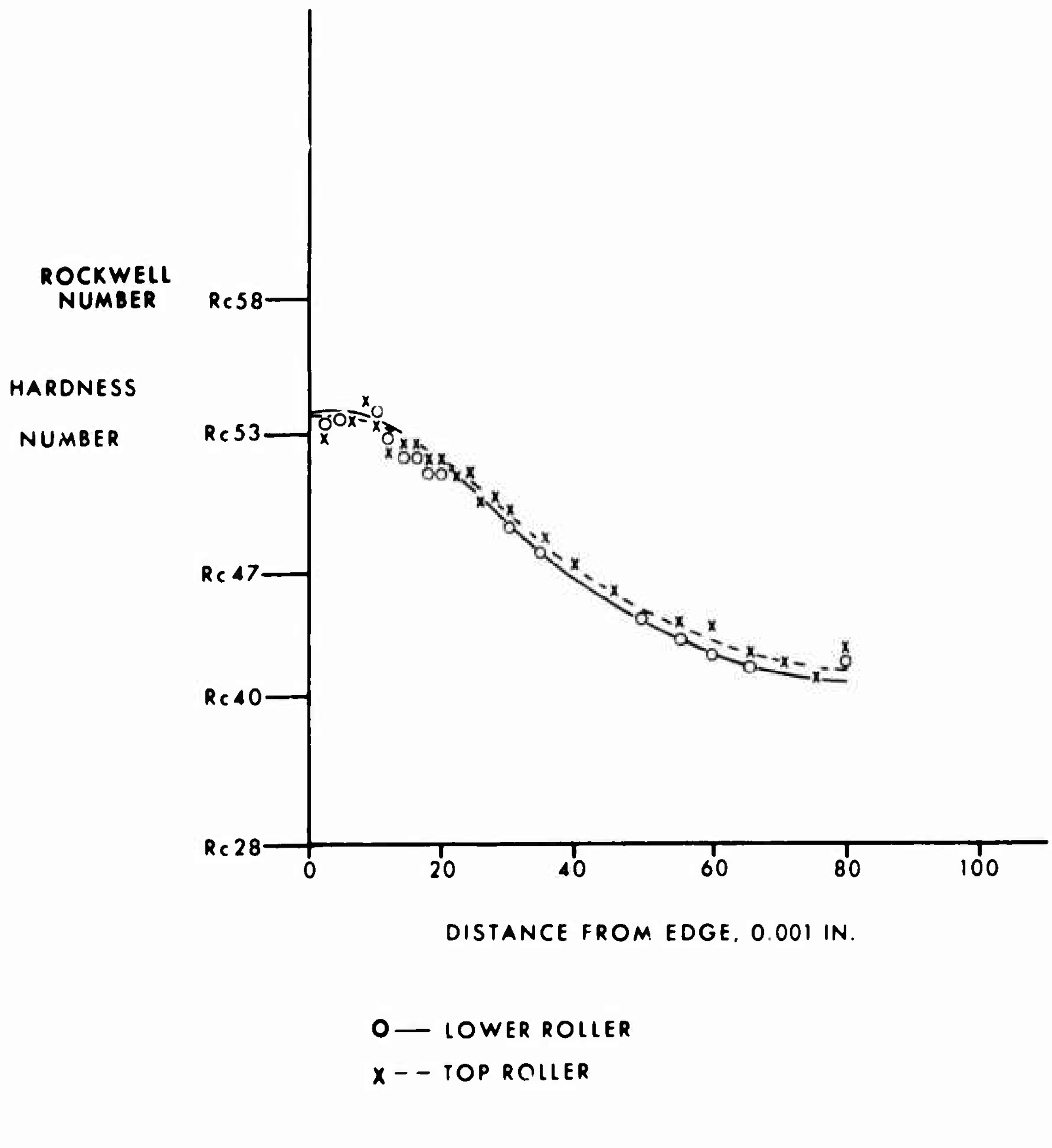


Figure 57. Microhardness Traverse Through Roller Core.

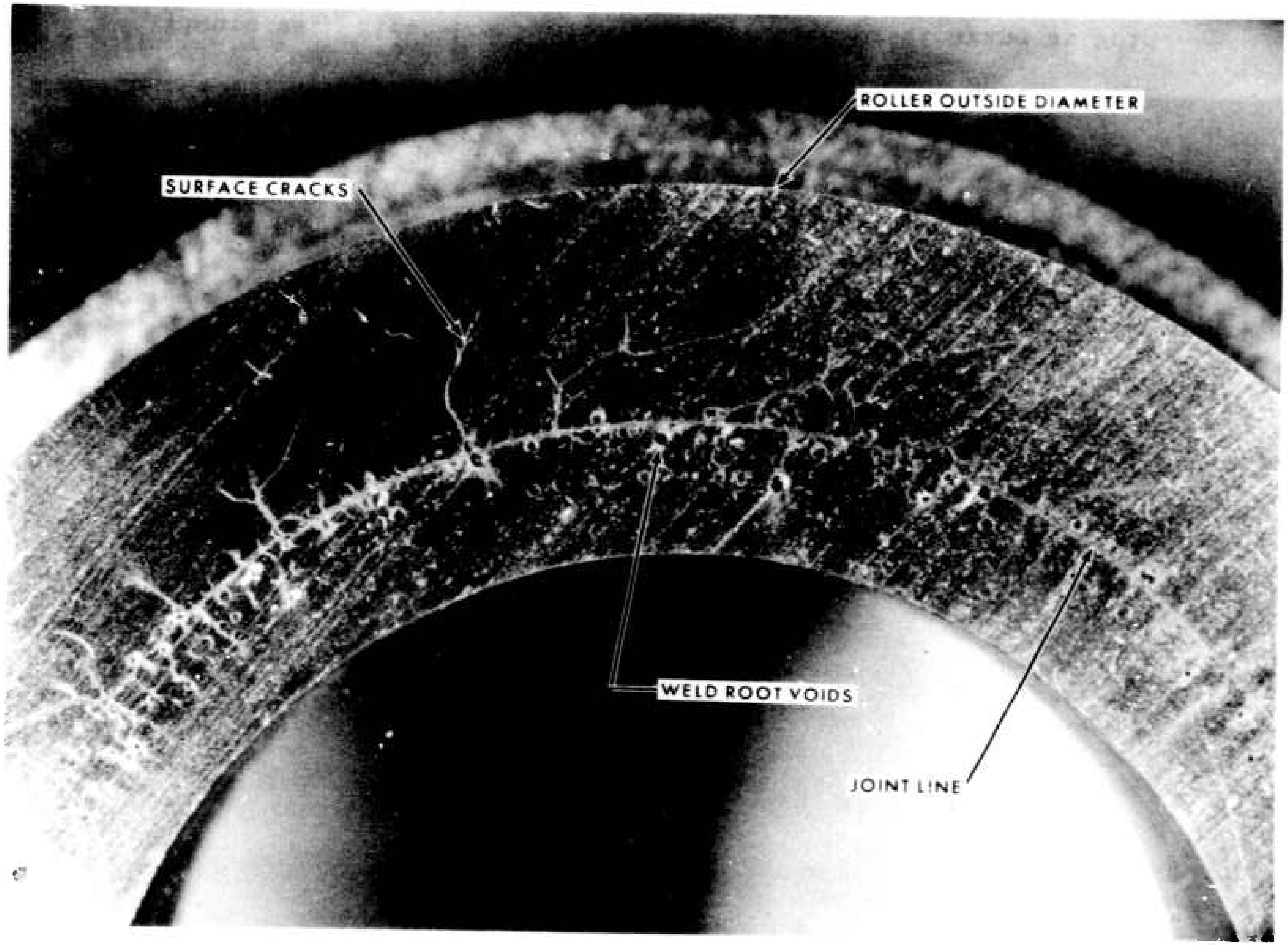


Figure 58. Subsurface Voids and Cracking, First-Row Pinion.

Figure 59. First-Row Pinion Fatigue Crack Originating at Void.

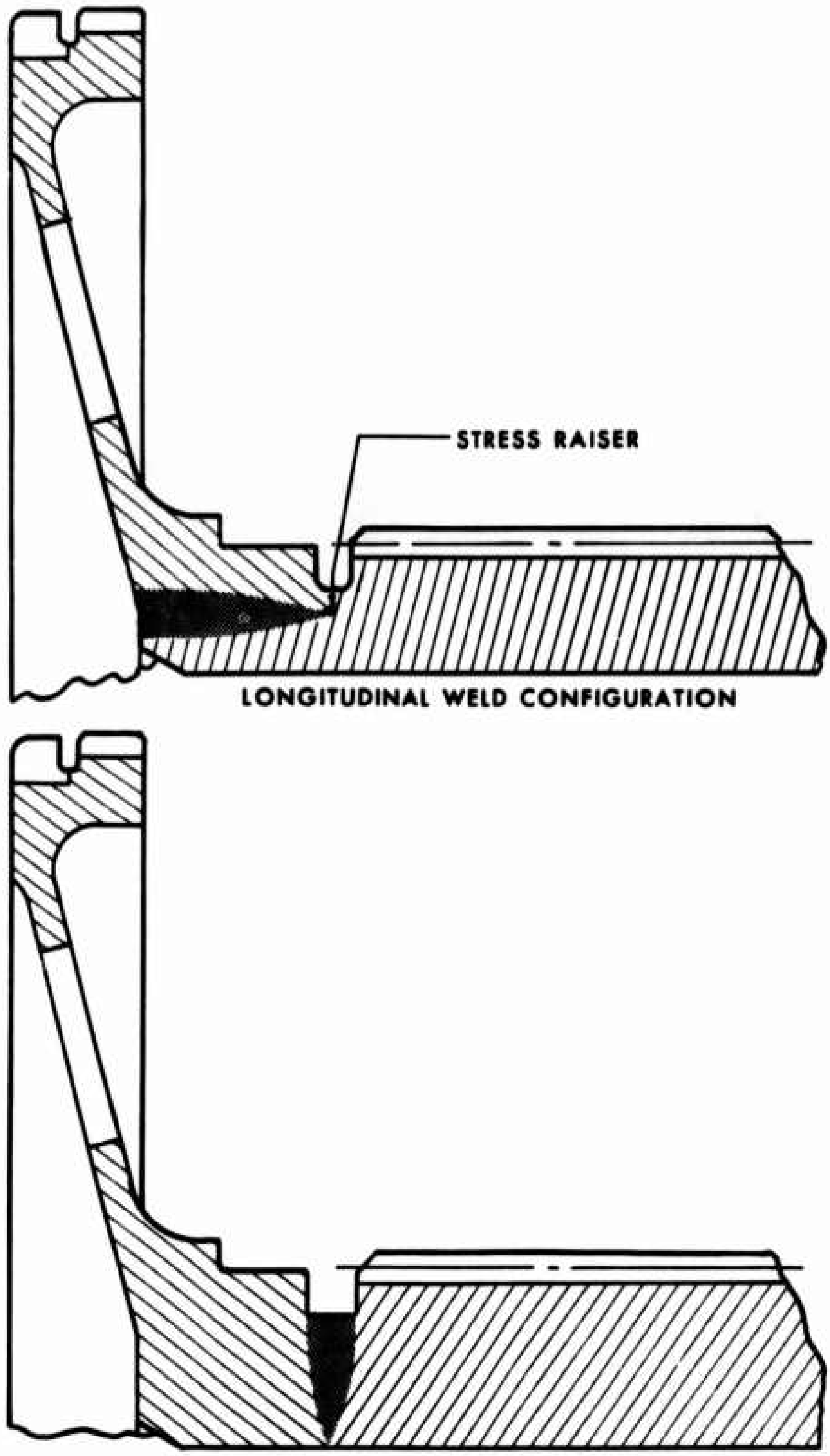


Figure 60. First-Row Pinion Weld Redesign.

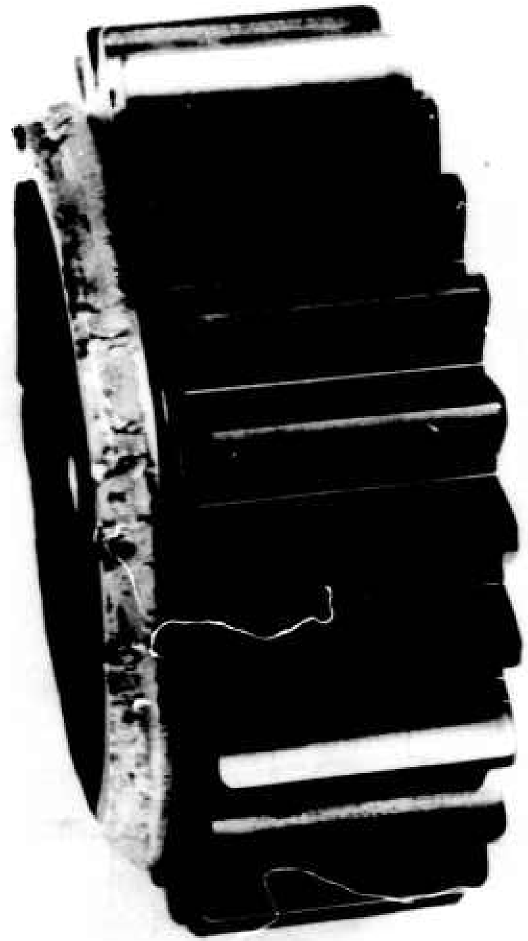


Figure 61. Second-Row Pinion (One of two ring gear mesh gears) Weld Separation.

approximately 0.090 inch wide and extending for approximately 50 percent of the circumference in the fractured area as indicated in Figure 62. This machined diameter is the electron beam weld joint face between the flange and the gear.

Metallurgical examination of the second-row gear assembly revealed a fracture in the weld area between the gear and flange extending for the entire circumference of the gear. Fracture examination revealed fatigue cracking originating at the end of the weld zone. Evident in the fracture is a machined surface. A cross-sectional sample through the weld revealed the weld beam had missed the joint between the mating components, as indicated in Figure 63. Examination revealed that while complete weld beam penetration had been accomplished, fusion had not occurred where the center of the weld beam missed the mating surfaces. Metallographic examination of the microstructure in this area revealed an as-cast weld zone of typical core structure in the mating components. Hardness of the flange, gear and weld zone measured Rc 40, 38 and 40, respectively. Examination of another gear/flange assembly shows a crack propagating from the end of the weld through the weld heat affect zone as seen in Figure 64. It was concluded that fracture occurred because of incomplete fusion on the blow-out side of the weld. To ensure complete fusion of this joint, the welding schedule was revised as shown in Table 9 to produce a wider joint. This required a modification to the gear so that a heavier blast shield could be positioned between the gear and flange to protect the finish gear from weld splatter. Figure 65 shows the modification to the second-row pinion assembly. In addition, an ultrasonic inspection technique used for the first-row pinions was further developed to encompass all electron beam welded joints and acceptance criteria were developed. The resulting ultrasonic inspection technique and weld acceptance criteria are presented in Appendix A.

Prior to installation of these gears in the roller gear transmission, they were subjected to magnetic particle inspection which revealed longitudinal cracking on the inside diameter of the bearing bore, Figure 66, extending approximately 0.44 inch down from the mouth of the bearing bore. Examination of other second-row pinions, which were in the process of rework, revealed similarly located indications of cracking.

Metallurgical examination revealed that the cracks were multiple in nature and typical of cracks associated with grinding stresses. Several assemblies evidenced a series of deeper circumferential cracks extending for approximately 1.5 inches in length as shown in Figure 67. Examination of cross-sectional metallurgical specimens revealed the longitudinal cracks to be between 0.0007-0.001 inch deep. The

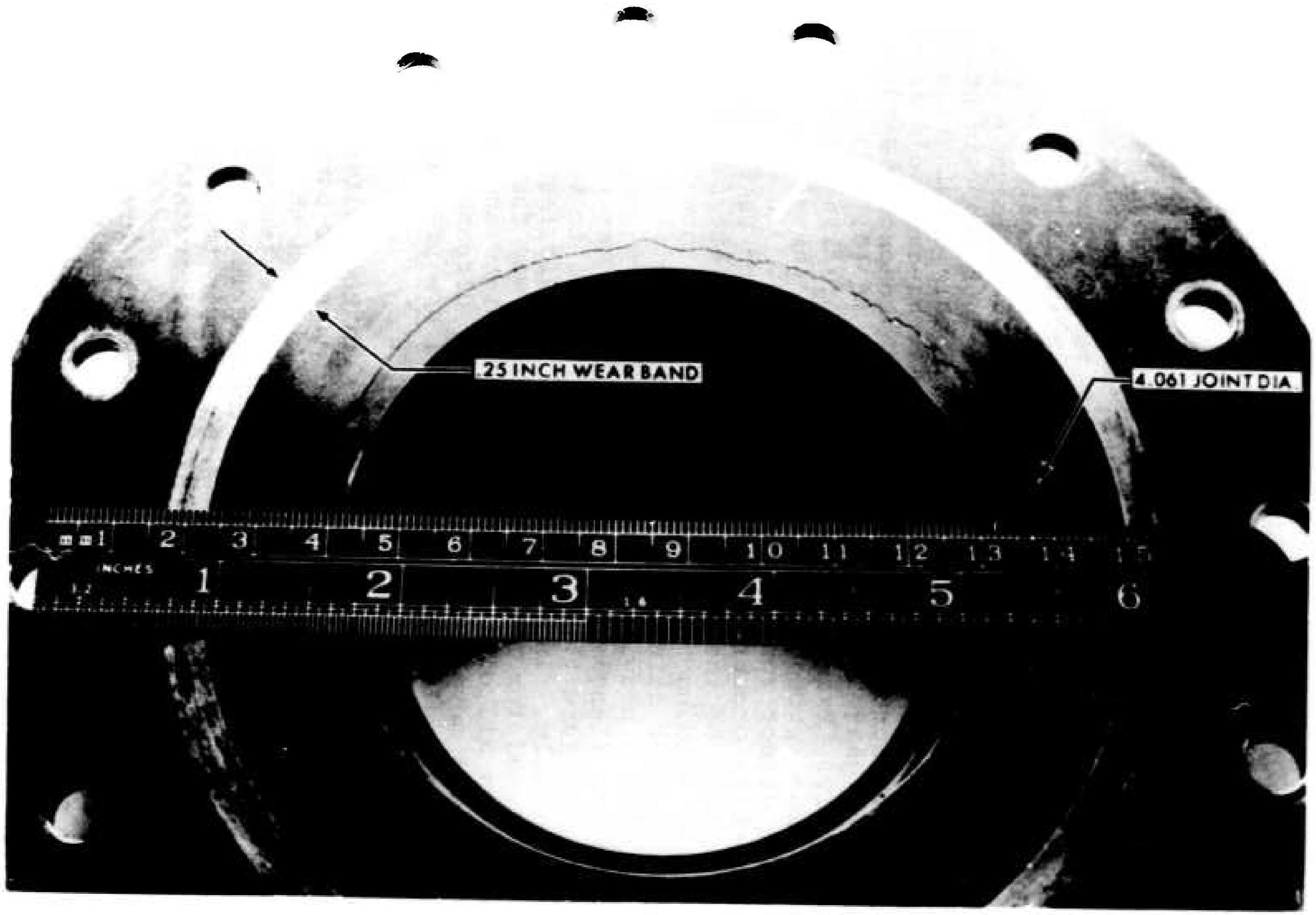


Figure 62. Second-Row Pinion Flange/Gear Weld Fracture.

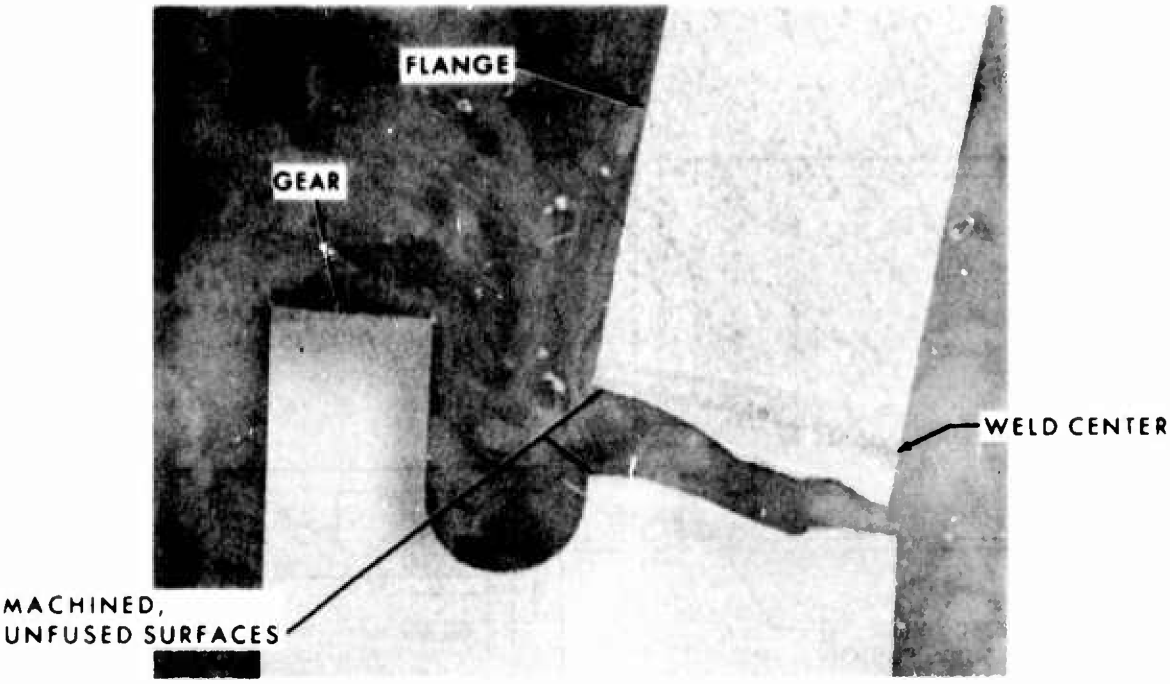


Figure 63. Cross Section of Second-Row Pinion Flange/Gear Weld Fracture.

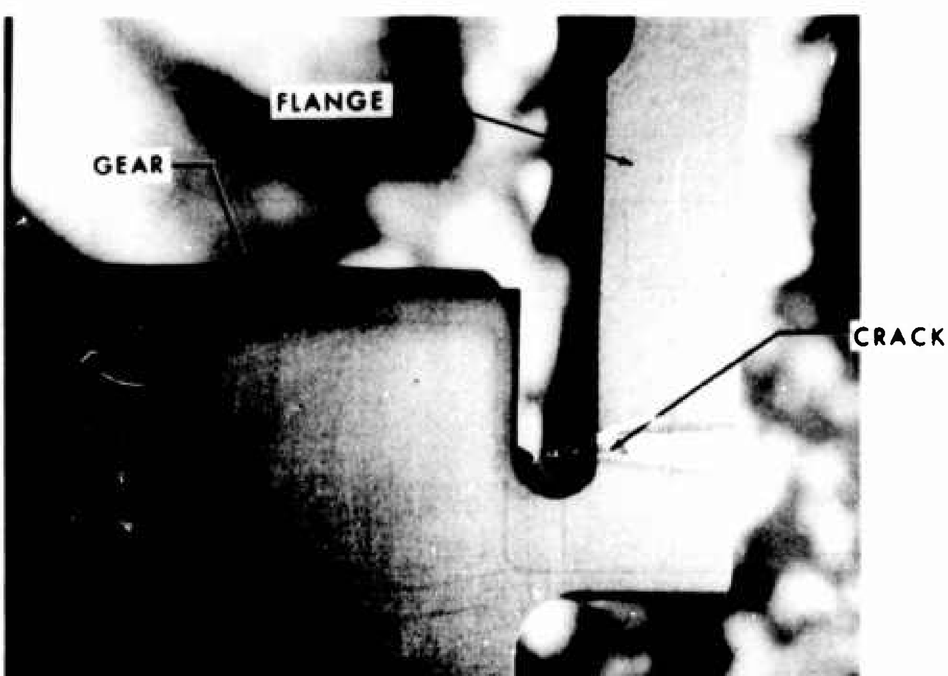


Figure 64. Crack Extending Through Flange/Gear Weld of Second-Row Pinion.

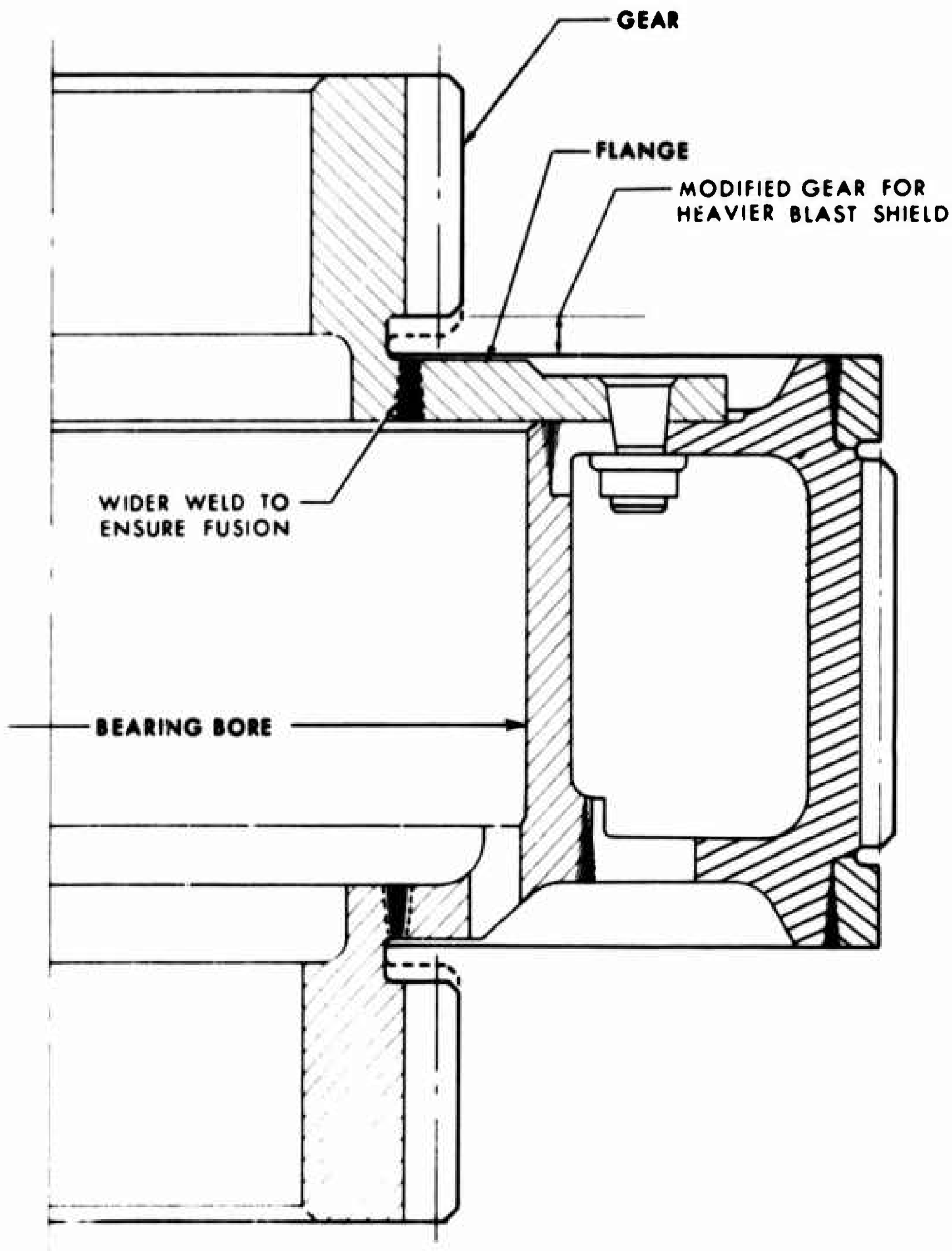


Figure 65. Second-Row Pinion Modification.

Figure 66. Longitudinal Cracking, Second-Row Pinion Bearing Bore

Figure 67. Circumferential Cracking, Second-Row Pinion Bearing Bore.

circumferential cracks measured approximately 0.025-0.030 inch deep. All of the cracking was confined to a band 0.44 inch wide which coincided with the weld zone which is located below this area. There was no cracking evident on the remaining surface area. Hardness of this surface measured uniformly Rc 56 across the width to within 0.25 inch of the edge where a hardness loss to Rc 50 was evident. The time span between the completion of manufacture, when magnetic particle inspection had last been performed, and detection of the cracking was approximately 6 months. It was concluded that cracking of these second-row gear assemblies was caused by residual stresses induced during manufacture, probably during the welding operation.

Since the indications occurred in an area of redundant load support structure, removal of the cracked metal by machining would not be detrimental to the life or function of the part. On this basis the cracks were removed by machining 0.040 inch off the bore diameter for a depth of 0.50 inch. An extended stress relieving cycle, in which the parts were subjected to a 23-hour bake at 325°F, was conducted to alleviate any residual stresses that could have formed during the rework.

After 56 hours 56 minutes of initial development testing, another weld related failure occurred with the fracture of gear teeth on the small diameter gear of the first-row pinion, as shown in Figure 68. Inspection of the fractured first-row pinion teeth revealed that the cracking had originated near the roots of the teeth where the heat affected zone adjacent to the weld had extended into the gear root, Figure 69. The hardness readings, taken in the vicinity of the fracture origin, are shown in Figure 70.

Metallurgical analysis of the heat affected zone showed that transformation changes occurring during the welding process had resulted in an area of residual tensile stress. This created a transition interface where an area of compressive stress (carburized layer) bordered an area of tensile stress. This transition in the material, from a state of tension to a state of compression, led to a stress concentration at the edge of the heat affected zone which, in turn, led to the failure of the gear teeth.

An analysis of tooth bending stress was performed to determine whether or not the allowable stress could have been exceeded at the point of failure in the heat affected zone. This analysis showed that while the allowable stress in this area had been decreased from 55,000 psi to 48,000 psi by heat from the weld, existing tooth bending stresses in the area were still below the allowable stress for a 3-sigma incidence of tooth failure. Torsional stress in this area was calculated

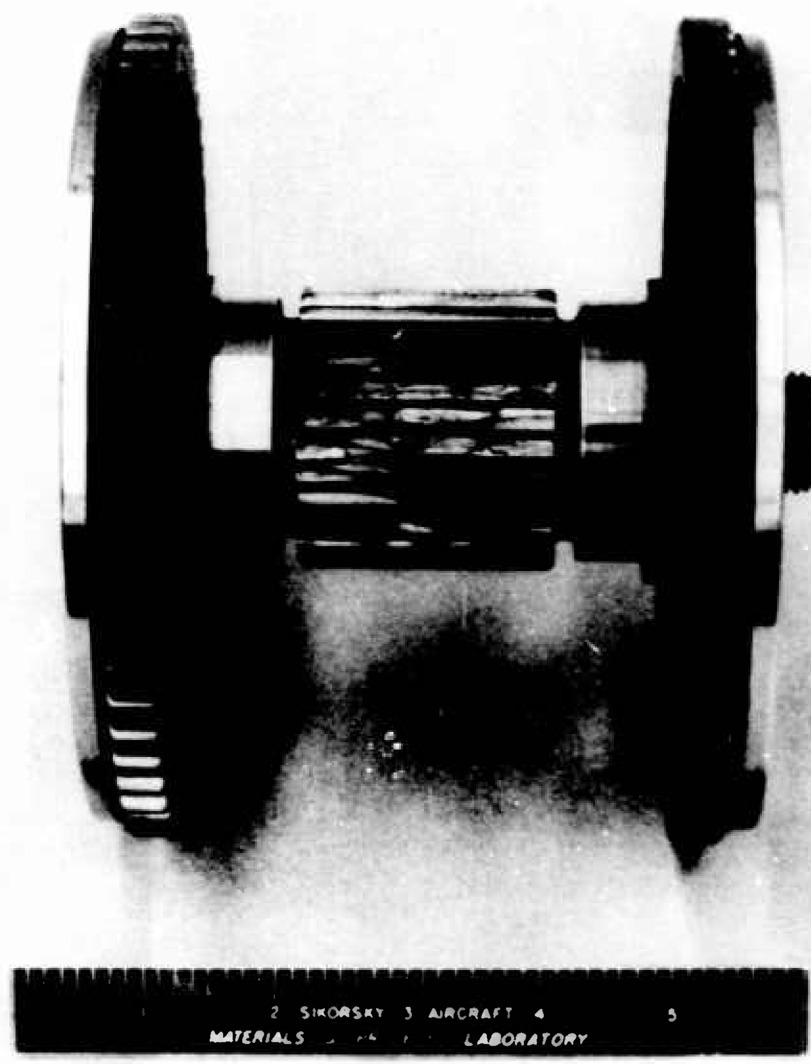


Figure 68. First-Row Pinion Tooth Fracture.

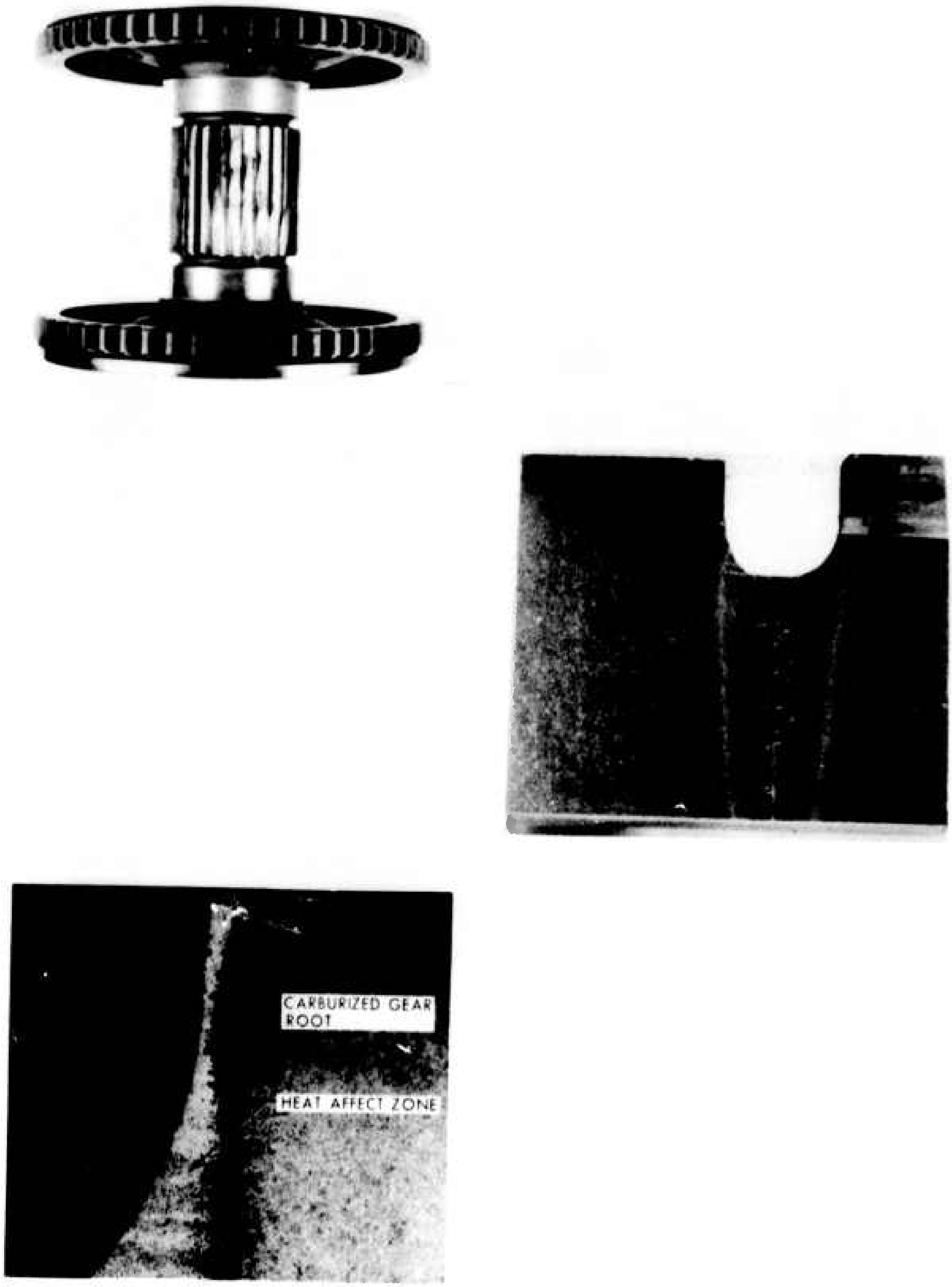


Figure 69. Heat Affected Area of Gear Root.

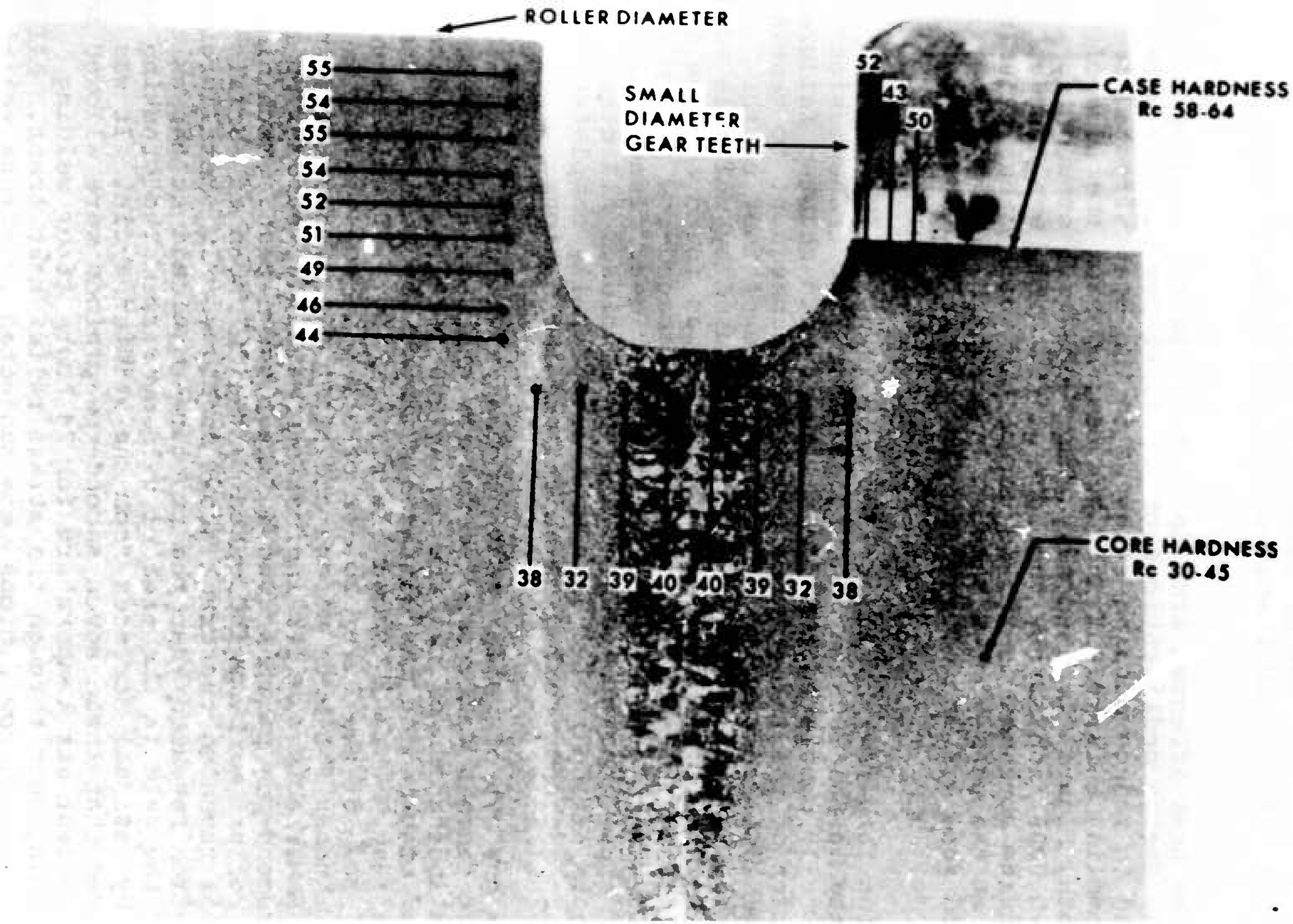


Figure 70. Hardness Readings, Vicinity of First-Row Pinion Tooth Fracture Origin.

to be 4,000 psi, a value judged low enough to have had a negligible effect on the teeth. Bending stress due to overall loading of the gear was calculated to be 3,110 psi, also of negligible effect when resolved into the plane of tooth bending stress.

Since the heat affected area is inherent in the welding process, design modifications of the first-row pinions were selected to reduce bending stresses in the heat affected area. To accomplish this, 0.032 inch was removed from the edge of the teeth, Figure 71. Secondly, the teeth were crowned to 0.0002-0.0005 inch across the face width. This was done to concentrate stresses in the center of the tooth, thus reducing stress at the ends of the teeth. In addition, the heat affected zone was shot-peened to put the surface in compression.

Following this rework, the roller gear transmission was subjected to the 200-hour endurance test. The transmission successfully completed this test with no weld related failures. Inspection of the roller gear components subsequent to testing revealed some cracking of the bearing bore of four of the second-row pinions. These cracks were caused by multiple voids in the weld root. One second-row pinion was found to have a crack in the upper roller, while another second-row pinion was found to have a crack in the lower smaller gear/flange weld. Both of these cracks were caused by weld voids. All other components of the roller gear unit successfully completed the 200-hour endurance test with no failure indications.

Another new set of roller gear components was used in the 50-hour aircraft tiedown test. The second-row pinions, although they gave no indication of failure during the test, showed indications of cracking on the ultrasonic inspection following the tiedown test. This is shown clearly by Figure 72, which shows the "C" scan of the lower roller of a second-row pinion (Serial Number 63) both before and after the 50-hour tiedown test. Remarkably similar indications were also evident on the other second-row pinions used in the tiedown test. Machining of the roller surface indicated by the "C" scan of Serial Number 63 revealed the crack shown in Figure 73. Metallurgical examination revealed that the fracture initiated at the exit side of the weld in the area of weld overlap. The cracking was caused by residual stresses from the welding cycle. It was discovered that these seven second-row pinions were allowed to sit at ambient air temperature for 24 hours after welding before being sent through the stress relief heat treat. All of the other second-row pinions were subjected to stress relief heat treat immediately after welding. It is believed that this was a factor in the cracking of the lower roller welds of these pinions.

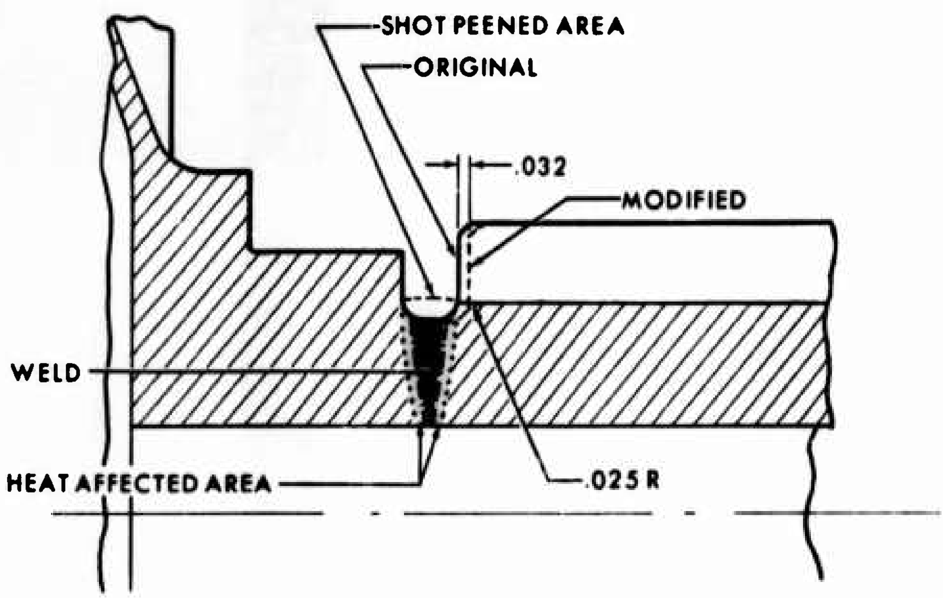
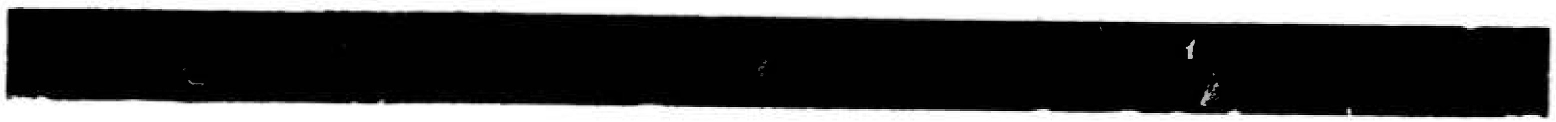
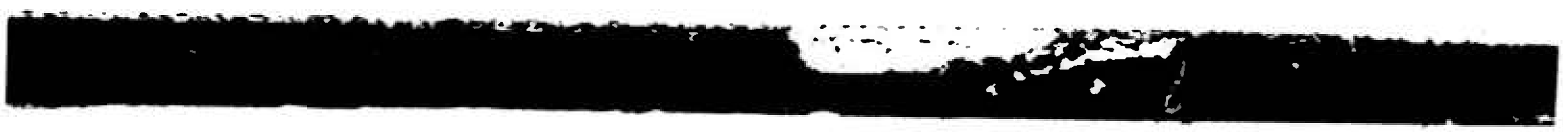


Figure 71. First-Row Pinion Rework.



Before Tiedown Test



After Tiedown Test

Figure 72. Typical Second-Row Pinion Lower Roller Weld "C"-Scans.

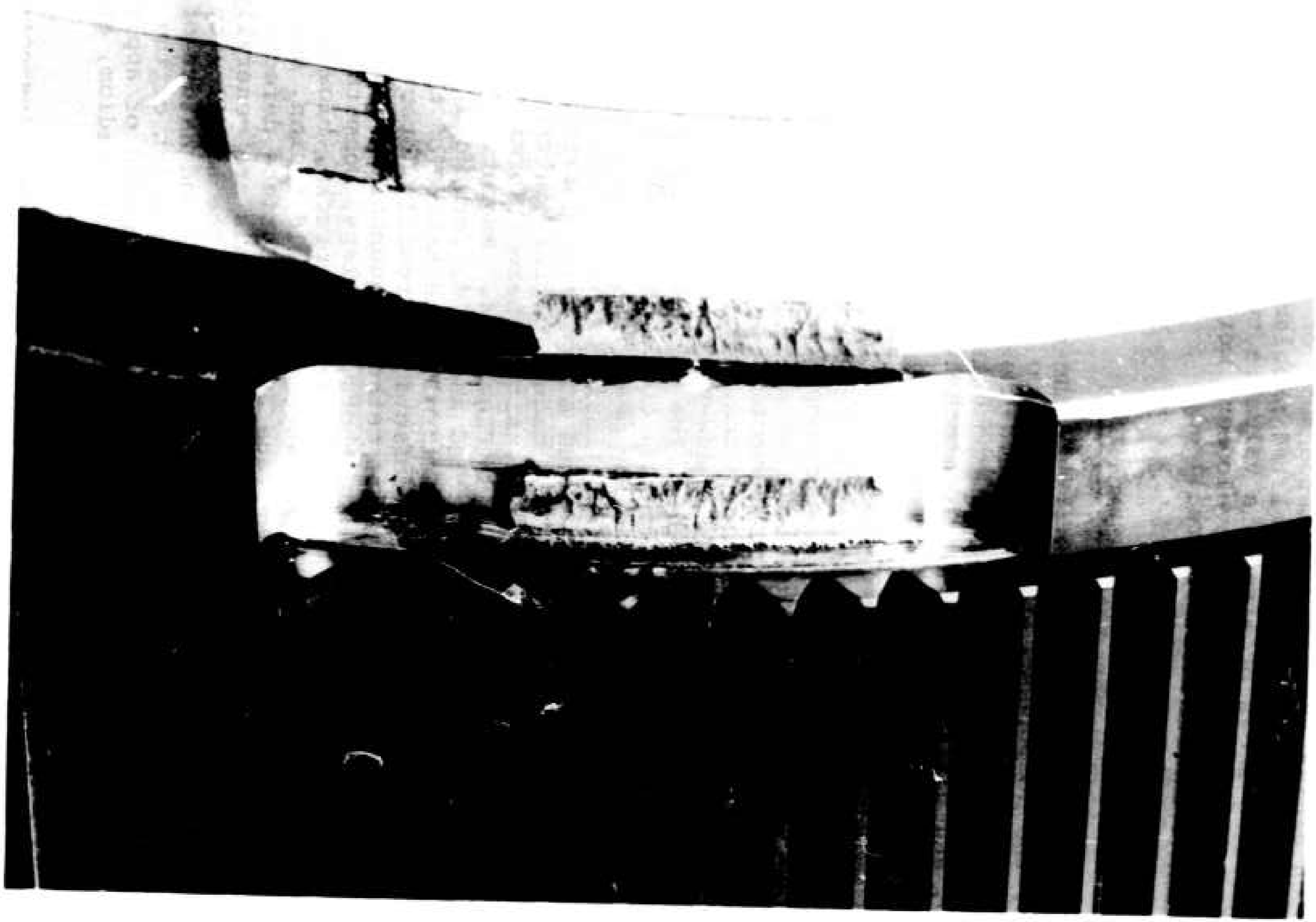


Figure 73. Second-Row Pinion Lower Roller Weld Cracking.

From the above discussion it is clear that electron beam welding was the principal cause of roller gear component failures. Although design changes eliminated some of the problems, many were strictly manufacturing related problems. While electron beam welding shows promise as a valuable tool in the manufacture of aerospace gearing, much development work needs to be done before its potential can be realized.

INSPECTION

In order to insure the integrity of the manufactured roller gear parts, the components were subjected to numerous inspections both during and after manufacture. Among the methods used for inspection of the roller gear components were magnetic particle, X-ray, and ultrasonic inspection techniques.

MAGNETIC-PARTICLE INSPECTION

This inspection method was used to detect surface and near-surface flaws in the roller gear components, particularly on surfaces subjected to high Hertzian stresses such as bearing surfaces. Magnetic-particle inspection is accomplished by first magnetizing the part to be inspected. The magnetization is induced by the application of a low-voltage (4 to 18 volts), high-amperage electric current. The current may be passed through the part itself, through a conductor inserted through a hollow portion of the part, or by means of a coil surrounding or adjacent to the part. Discontinuities at or near the surface of the magnetized part and at an angle (preferably 90 degrees) to the direction of the magnetic field interpose a tremendous barrier to the flux density, thereby forming a leakage field. This is shown in Figure 74. Magnetic particles applied to this area are attracted and held, forming a visible indication from which one can determine the nature of the discontinuity. The following defects are readily detected by the magnetic-particle inspection method: quenching cracks, thermal cracks, hot tears, cold shots, overlaps, nonmetallic inclusions, seams, grinding checks, fatigue cracks, blow holes, weld bead and underbead cracks, incomplete weld fusion, and embrittlement cracks. All surface and near-surface defects commonly encountered in ferromagnetic materials are generally detectable by magnetic-particle inspection. The sensitivity of the method is a function of the depth, size and nature of the defect, density of the magnetic field, direction of the magnetic field, type of magnetizing current, method of applying the inspection medium, mobility of the inspection medium, and skill of the inspector.

All of the components of the roller gear drive were inspected by the wet continuous method. In the application of this

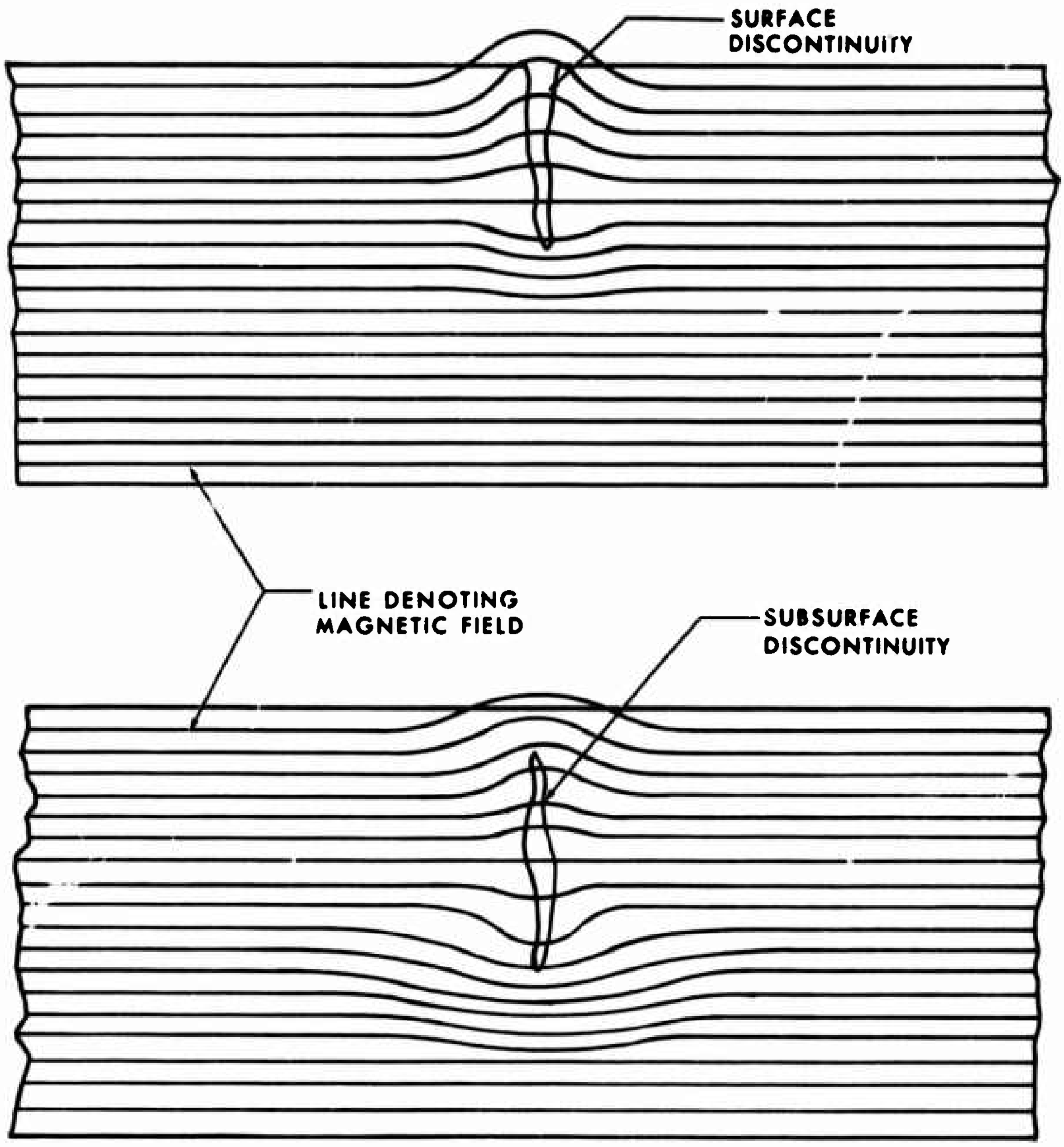


Figure 74. Effect of Discontinuities on Magnetic Field.

method, the part is covered completely with fluorescent magnetic particles suspended in a liquid while the magnetizing current is flowing. The fluid flow is then cut off just before the current flow to prevent any flushing off of the magnetic particles which may have gathered because of flux leakage. This type of magnetic-particle inspection is the most sensitive to detection of flaws in the metal.

For the magnetic-particle inspection of the roller gear components a d.c. current of from 1,500 to 4,200 amps was used for magnetization depending on the part inspected. Figures 75 and 76 show magnetization current values and orientations for the magnetic-particle inspection of the second-row pinion. This type of inspection proved effective in detecting residual stress cracks in the bearing bore of the second-row pinions as well as revealing a cracked roller on a second-row pinion. Detection of subsurface flaws, such as the weld voids encountered in this program, was not successful with magnetic-particle inspection.

RADIOGRAPHIC INSPECTION (X-RAYS)

X-rays were used extensively in the post-manufacture inspection of the electron beam welded roller gear components. The X-rays were also used to inspect castings and in the early stages of the program to detect the presence of any voids in the electron beam welds which would have rendered them unacceptable.

X-rays are produced when electrons, boiled off a tungsten filament heated to incandescence, bombard a suitable target under a high accelerating voltage. About 98 percent of the kinetic energy of these electrons is converted into heat. The remaining 2 percent is given off as high frequency electromagnetic waves known as X-rays. The X-ray radiation is heterogeneous in that it is composed of a mixture of wavelenghts of varied intensity. Most of the X-ray radiation, when directed at a target such as steel, will be absorbed. Only a small portion of the shorter wavelength radiation will be transmitted through the steel.

The range of X-ray accelerating, or tube voltage, ordinarily used for the examination of metals is about 30 to 2,000 kilovolts peak. The higher the tube voltage the greater the intensity and the shorter the wavelengths of the X-rays produced.

Primary transmitted radiation is that X-ray energy which has continued in a straight line from a primary source through the material to be inspected without absorption or deflection. This radiation, when recorded on photosensitive film, produces the radiograph of the inspection part. If the material to be

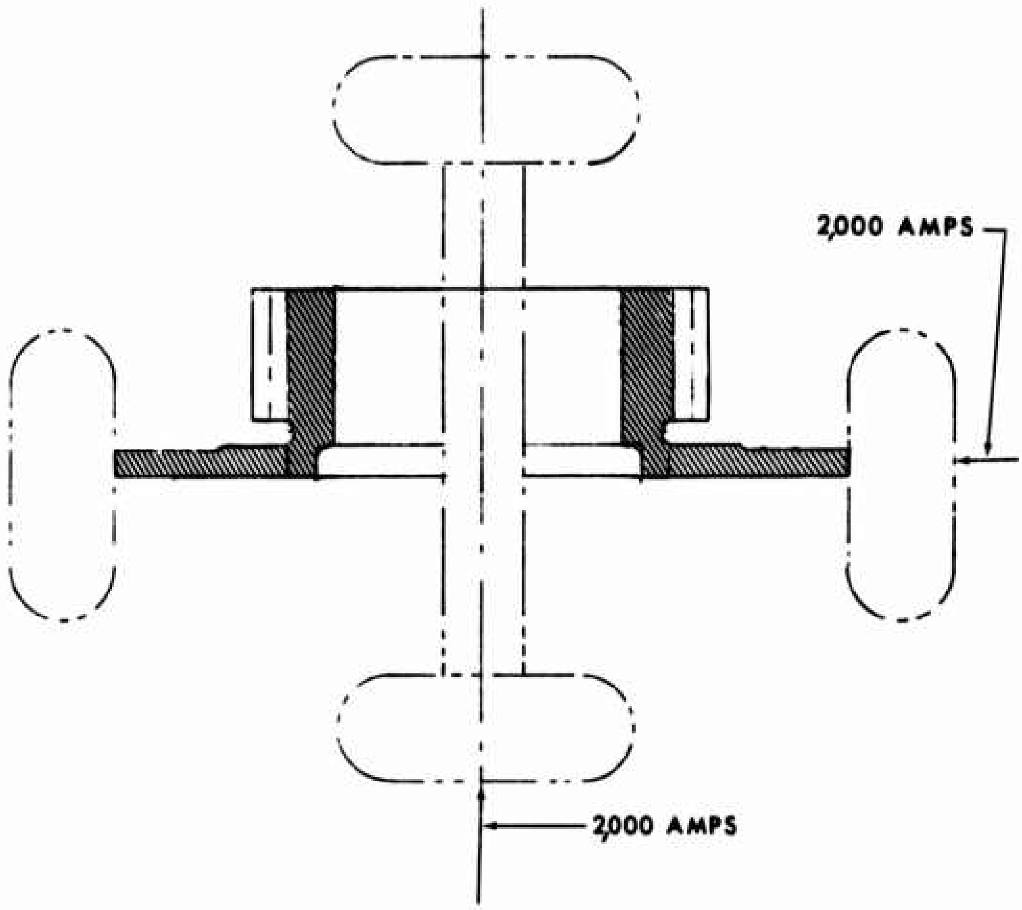


Figure 75 . Magnetization Currents and Orientation for Inspection of Second-Row Pinion, Upper Gear and Flange.

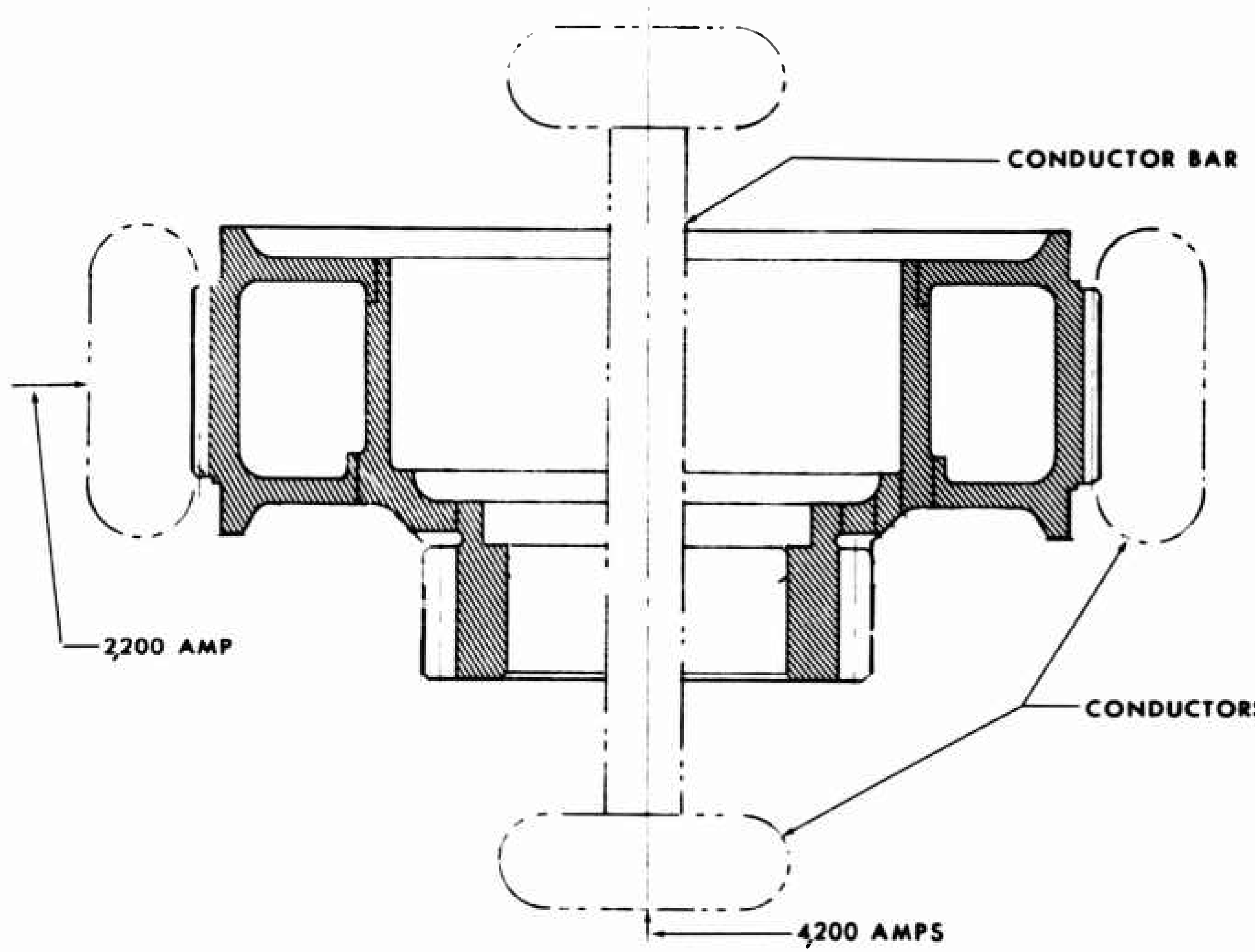


Figure 76. Magnetization Currents and Orientation for Inspection of Second-Row Pinion, Lower Gear and Shaft.

inspected contains a void, the X-rays passing through the void will be stronger and produce a darker image at that point on the film than in the surrounding area. If the material to be inspected contains an inclusion, it will be recorded on the film as either lighter or darker than the surrounding area, depending on the relative absorption coefficients of the inclusion and parent material.

Standard practice requires that radiographs show a minimum sensitivity of 2 percent. Thus, if a 1.00-inch section is being examined, the X-ray must differentiate between a section change of .02 inch. In order to assure the meeting of this requirement, a device called a penetrameter is used. A penetrameter is simply a rectangular wafer of the material being X-rayed with a thickness equal to 2 percent of the X-rayed cross section. There are three small holes drilled through the wafer. When an X-ray is taken through a section with the proper penetrameter resting on top, the three holes should be visible on the resulting radiograph.

Figure 77 shows the setup used to X-ray inspect the butt welds of the first-row pinion. Figure 78 shows schematically the radiograph resulting from the X-ray inspection of the first-row pinion. In order to completely inspect this weld, 11 views per weld were taken. For X-rays of the first-row pinion butt welds, a source to specimen distance of 40 inches was used, with an exposure time of 45 seconds. Accelerating voltage was 240 kilovolts with a tube current of 14 milliamps.

In general, X-ray inspection of electron beam welded roller gear components proved ineffective in the detection of voids except for the butt welds at the first-row pinions. This was the result of part and weld geometry preventing proper location of the film. Because of this limitation on X-ray inspection, an ultrasonic inspection technique was developed and used quite successfully in the detection of electron beam weld voids.

ULTRASONIC INSPECTION

By far the most effective method used to inspect electron beam welds for voids was the ultrasonic method. Ultrasonic inspection of metals is usually performed using frequencies between 0.5 and 25 megacycles. These are high frequency mechanical vibrations compressive in nature and very similar to sound waves. Although these waves are rapidly attenuated in air or gases, they travel long distances through most liquids and solids. These waves will be reflected at discontinuities or boundaries of different elastic and physical properties.

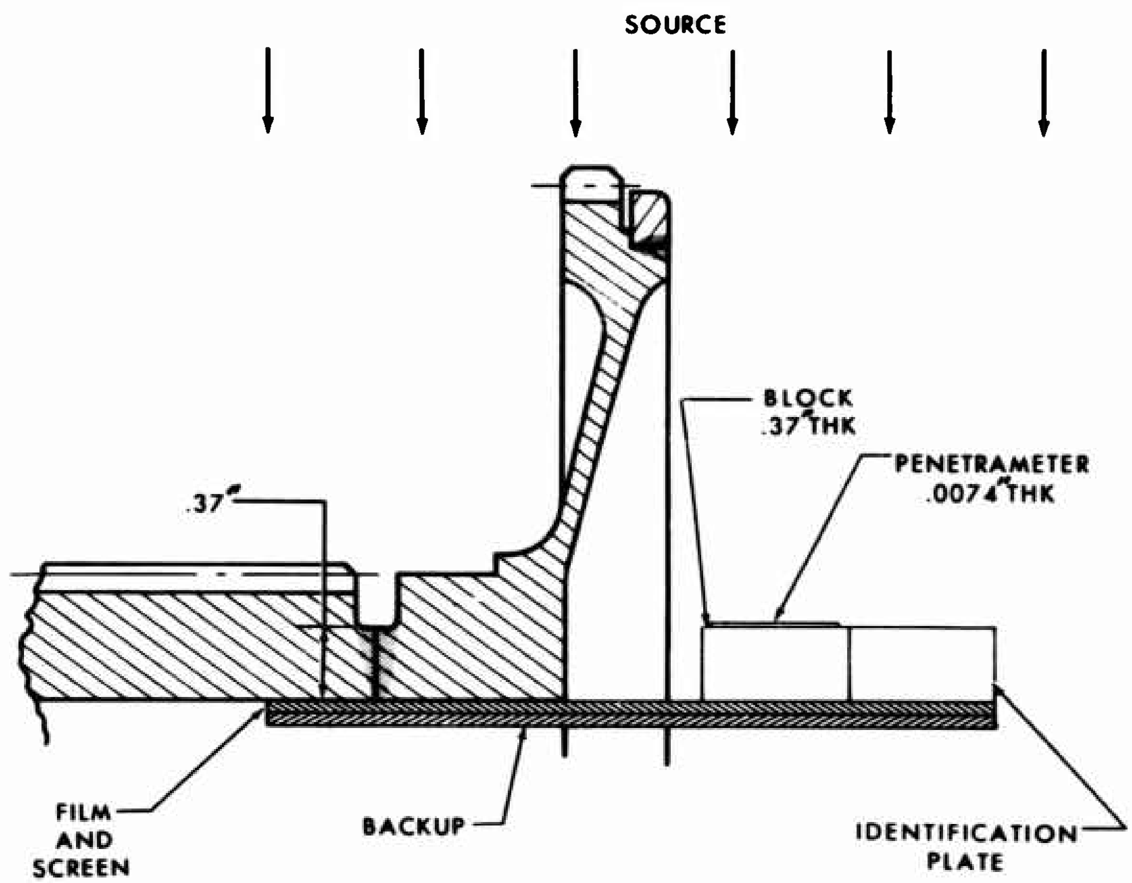


Figure 77. Setup for X-Ray Inspection of First-Row Pinion Butt Welds.

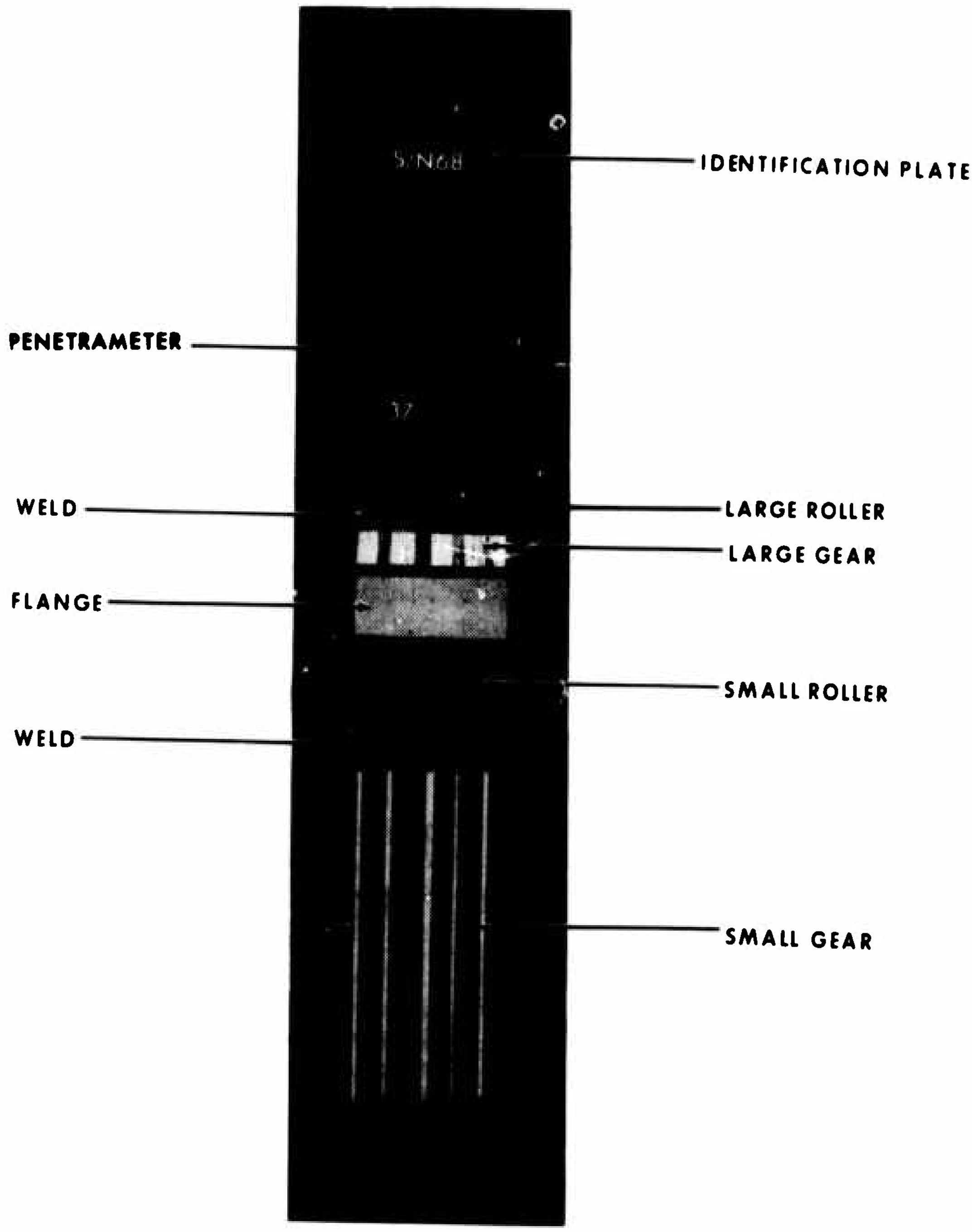


Figure 78. Representation of Radiograph Produced in Inspection of First-Row Pinion Butt Weld.

Piezoelectric transducers are usually used for generating the ultrasonic vibrations in materials and for detecting the reflected portion of the beam. They have the ability to convert electrical oscillations into mechanical vibrations and mechanical vibrations into electrical oscillations. Lithium sulfate was used for the transducers in this program.

The principle of ultrasonic inspection is best illustrated by the "A"-scan (one of the many ways of presenting ultrasonic test information) shown in Figure 79. A short burst of ultrasonic energy is emitted from the piezoelectric crystal. When the pulse reaches the front surface of the test specimen, a portion of the energy is reflected, due to an acoustic impedance mismatch, back to a pick-up and displayed on the oscilloscope as the interface signal. The portion of the pulse not reflected from the front surface continues through the material until it reaches the discontinuity where the pulse is again reflected and displayed on the oscilloscope. The remainder of the wave passes through the material and is reflected off the back surface and recorded as the back reflection signal.

The particular method used for inspection of the electron beam welds of the roller gear components is known as the full immersion technique, shown in Figure 80. In this method, the test specimen is fully immersed in water containing a wetting agent. The water acts as a conductor of the ultrasonic waves, thus eliminating the need for the probe to be in physical contact with the test specimen. This method allows automation to be employed in the inspection and produces more consistent results than the contact method.

Instead of the "A"-scan display technique, "C"-scans were used for the inspection of the roller gear components. "C"-scans are top view layouts of the relative position of discontinuities or reflecting areas of the test piece. Figure 81 shows schematically the C-scan display method. All of the electron beam welds of the roller gear drive were ultrasonically inspected using the C-scan technique. Figure 82 shows a typical C-scan of a first-row pinion butt weld, the calibration standard showing .020 inch and .040 inch holes and the orientation from which the C-scan was taken. The C-scan shows a void of about .030 inch as can be seen by comparison with the calibration standard.

Because of the amount of ultrasonic inspection that had to be done, a standard roller gear ultrasonic inspection procedure was developed. This procedure is presented in Appendix A.

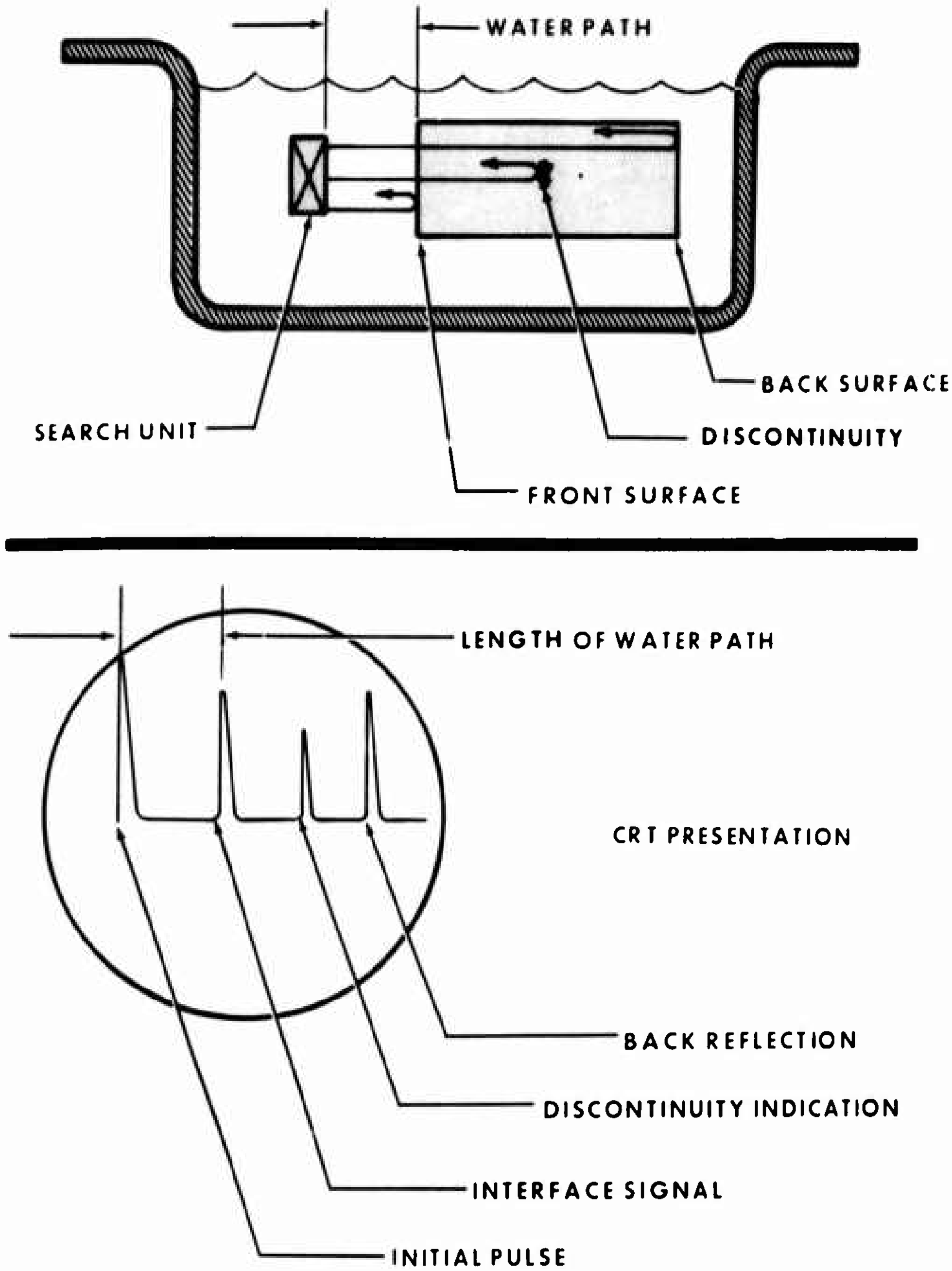


Figure 79. Ultrasonic Inspection, "A"-Scan.

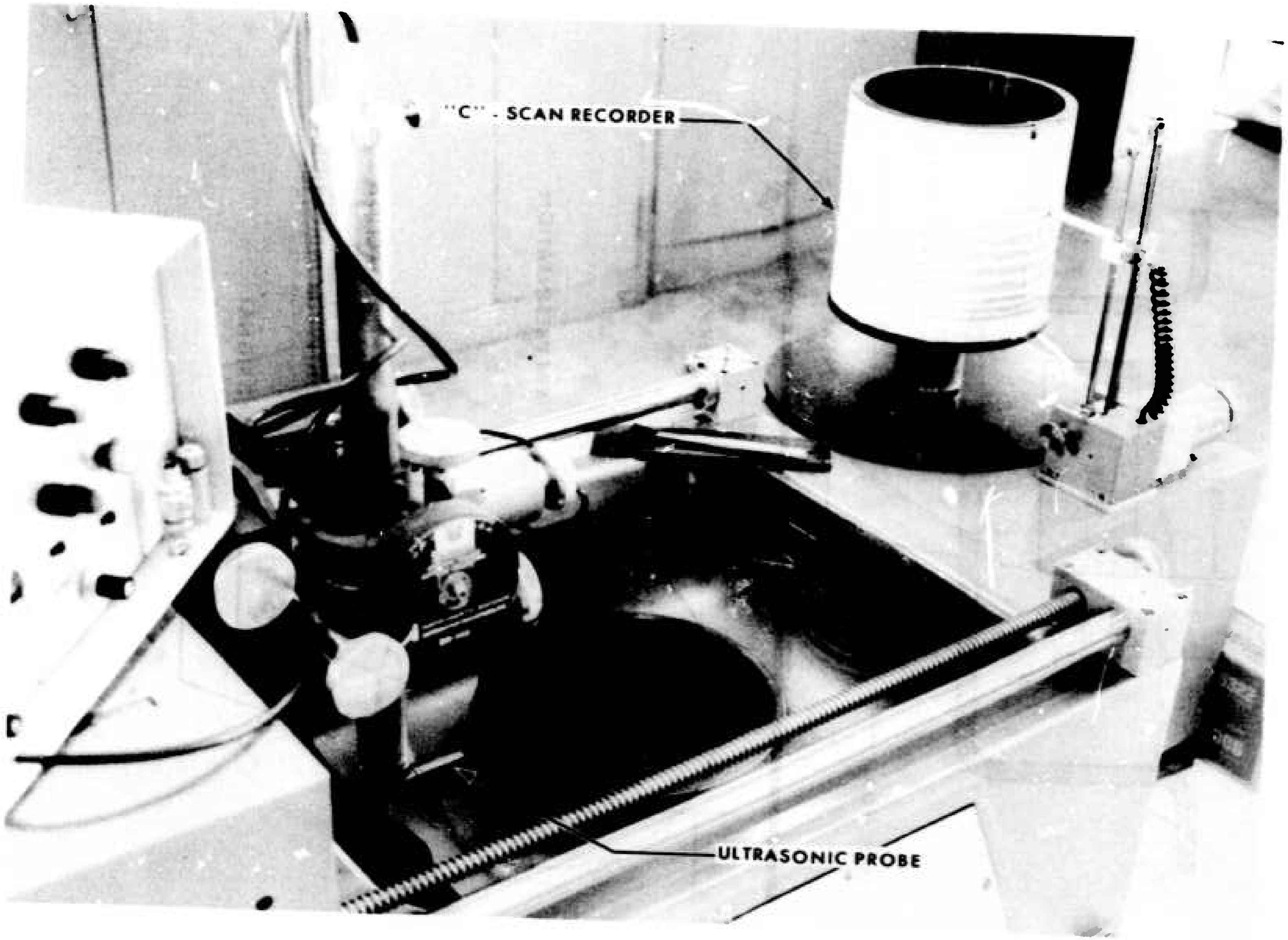


Figure 80. Ultrasonic Inspection, Full Immersion Technique.

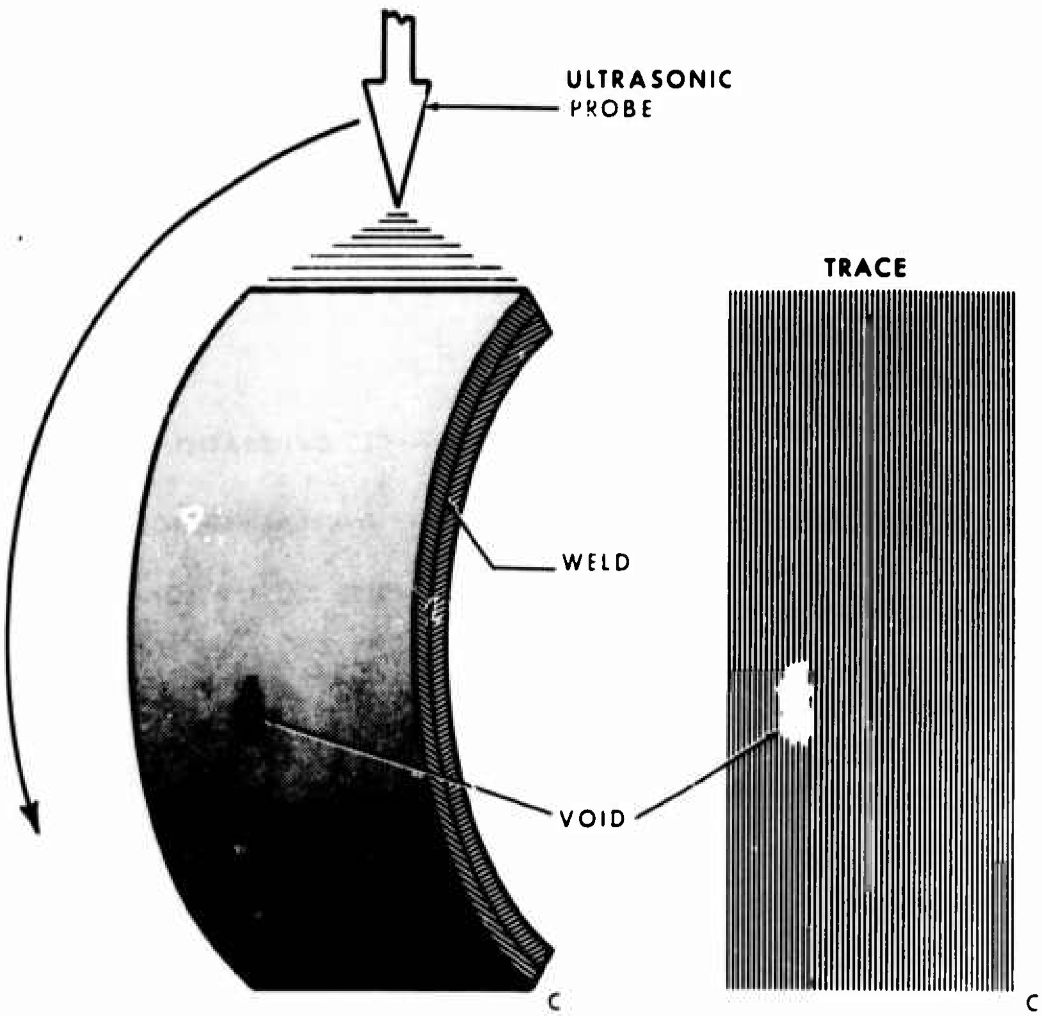


Figure 81. C-Scan Display of Inspection Trace.

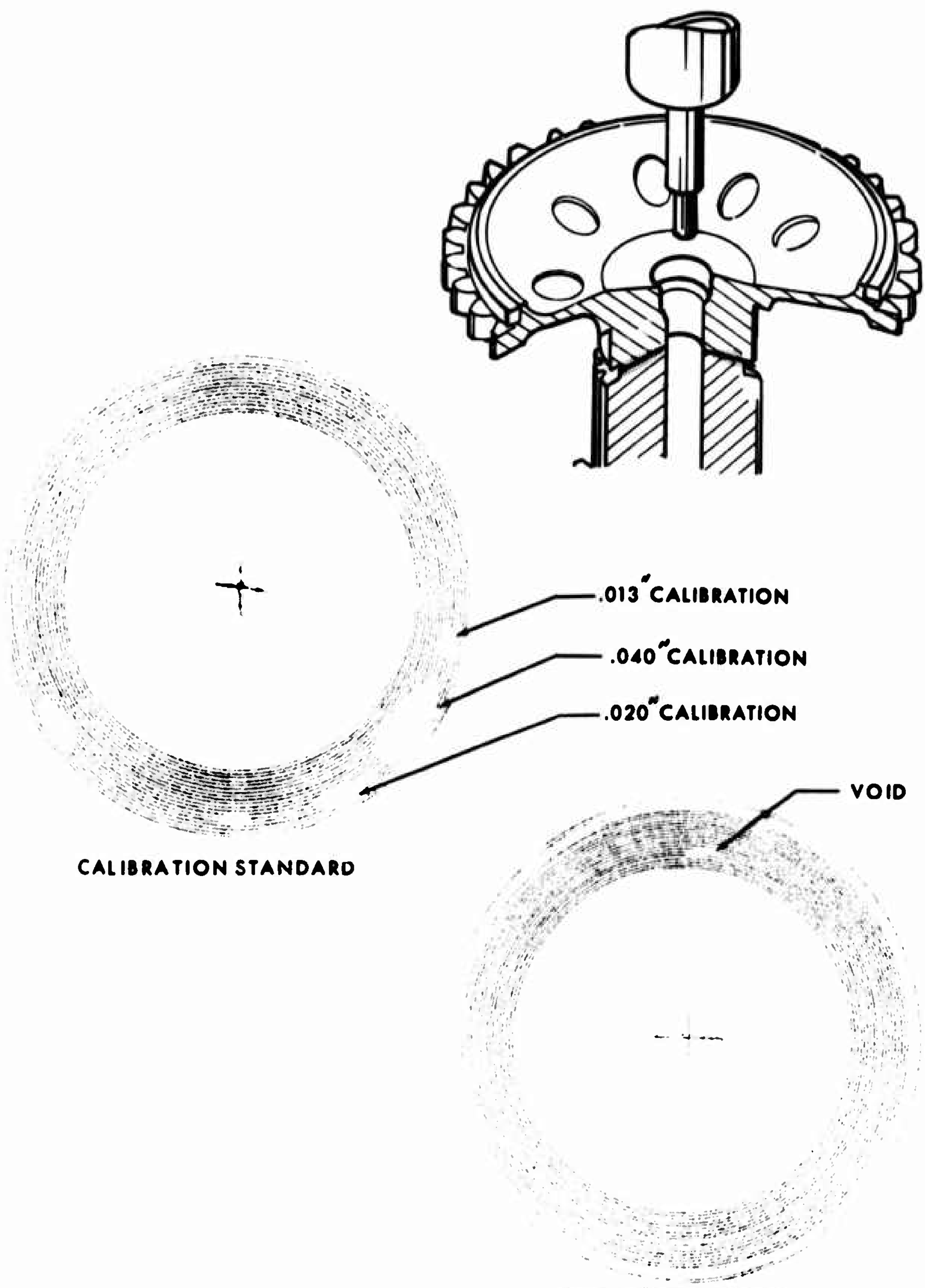


Figure 82. C-Scan of First-Row Pinion Butt Weld.

ASSEMBLY OF ROLLER GEAR UNIT

Because of the unique geometry of the roller gear components, special attention had to be given to the assembly procedures of the roller gear unit. If assembly of the roller gear unit is attempted by first assembling all first-row pinions, then assembling all second-row pinions, it is found that the last second-row pinion cannot be placed in mesh with the first-row pinions. Assembly is prevented by the size of the angle between the meshes with the two first-row pinions, known as the toggle angle.

In order to overcome this difficulty, a special order of assembly was developed. The first step is to mate one of the first-row pinions with the sun gear as shown in Figure 83. Next a mating pair consisting of one first- and one second-row pinion is placed into mesh as shown in Figure 84. This step is repeated until all but one first-row pinion and two second-row pinions are in place. The remaining three gears are then positioned as a set as shown in Figure 85.

The second-row pinion bearing posts are then installed, followed by placement of the output flange and hub assemblies. The two halves of the ring gear are then positioned to complete assembly of the roller gear unit. The completely assembled roller gear unit is shown in Figure 86.

Also illustrated in this figure is the timing which is critical to the assembly of the roller gear unit. Each first-row pinion is timed to the sun gear and the two second-row pinions with which it mates.

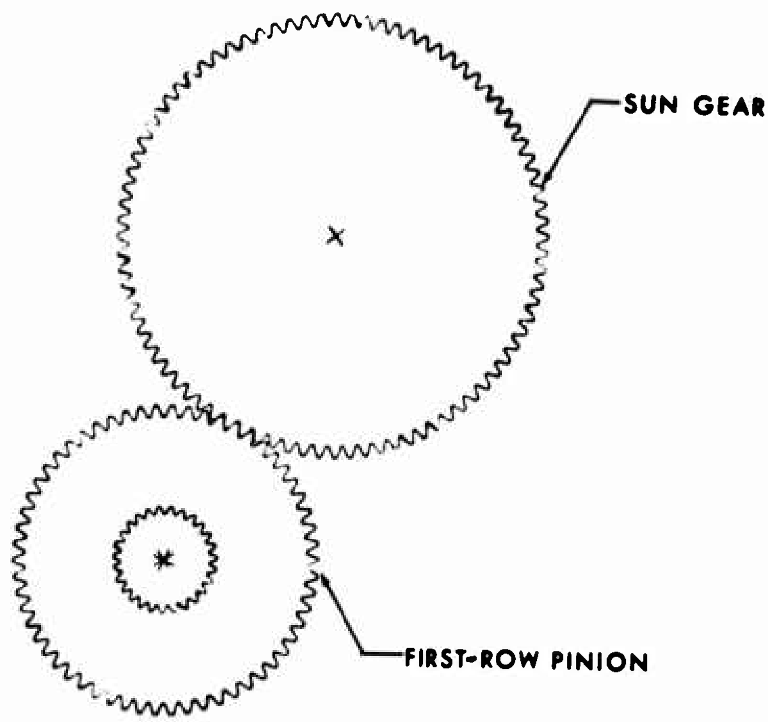


Figure 83. Roller Gear Unit Assembly, Step One.

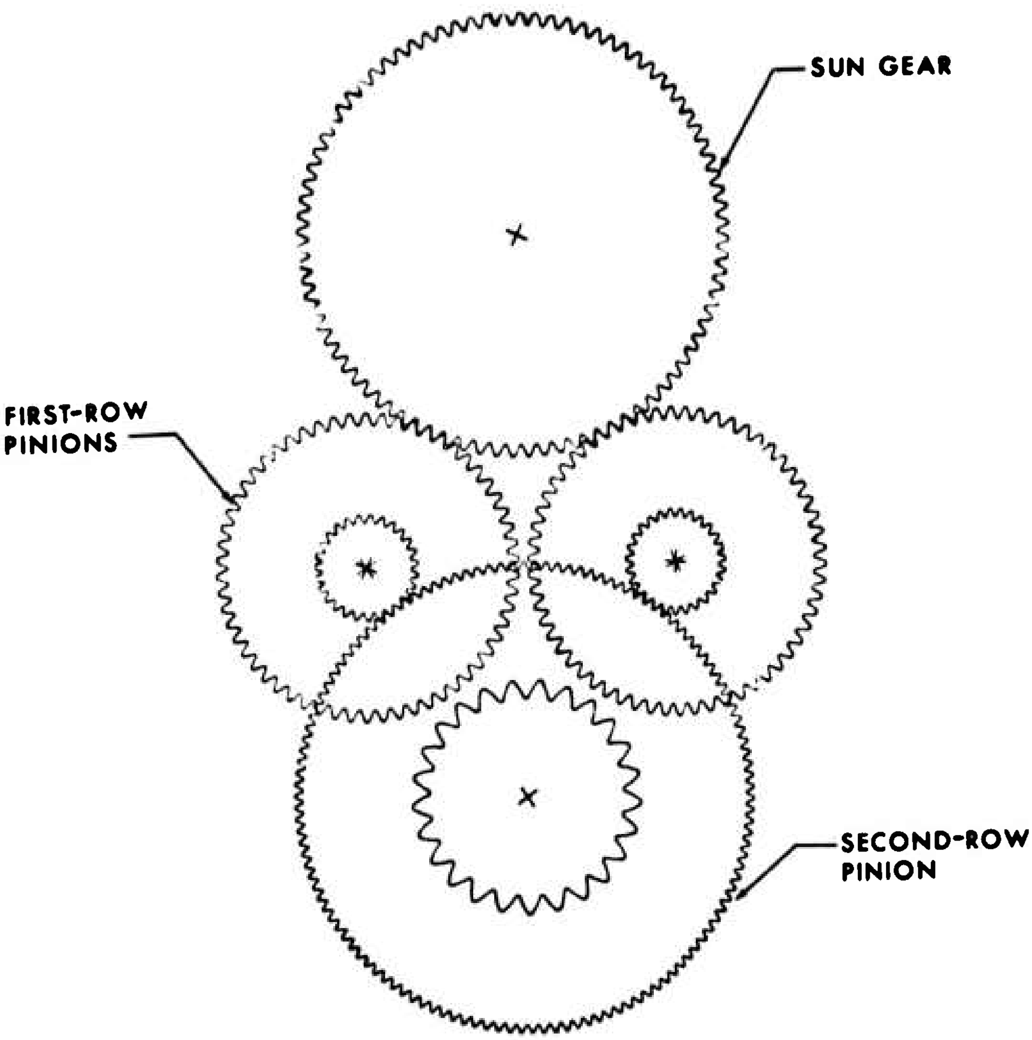


Figure 84. Roller Gear Unit Assembly, Step Two.

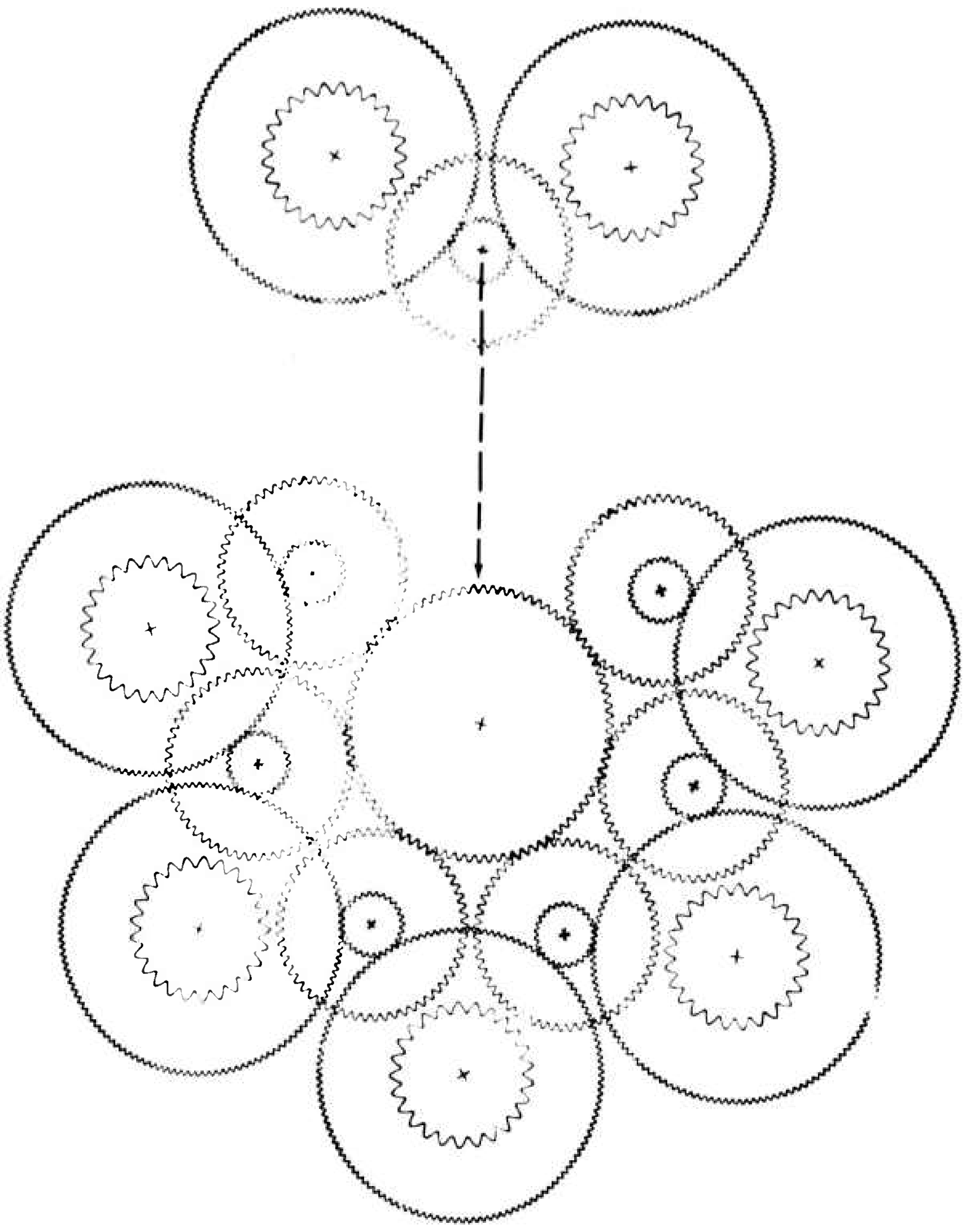


Figure 85. Roller Gear Unit Assembly, Final Step.

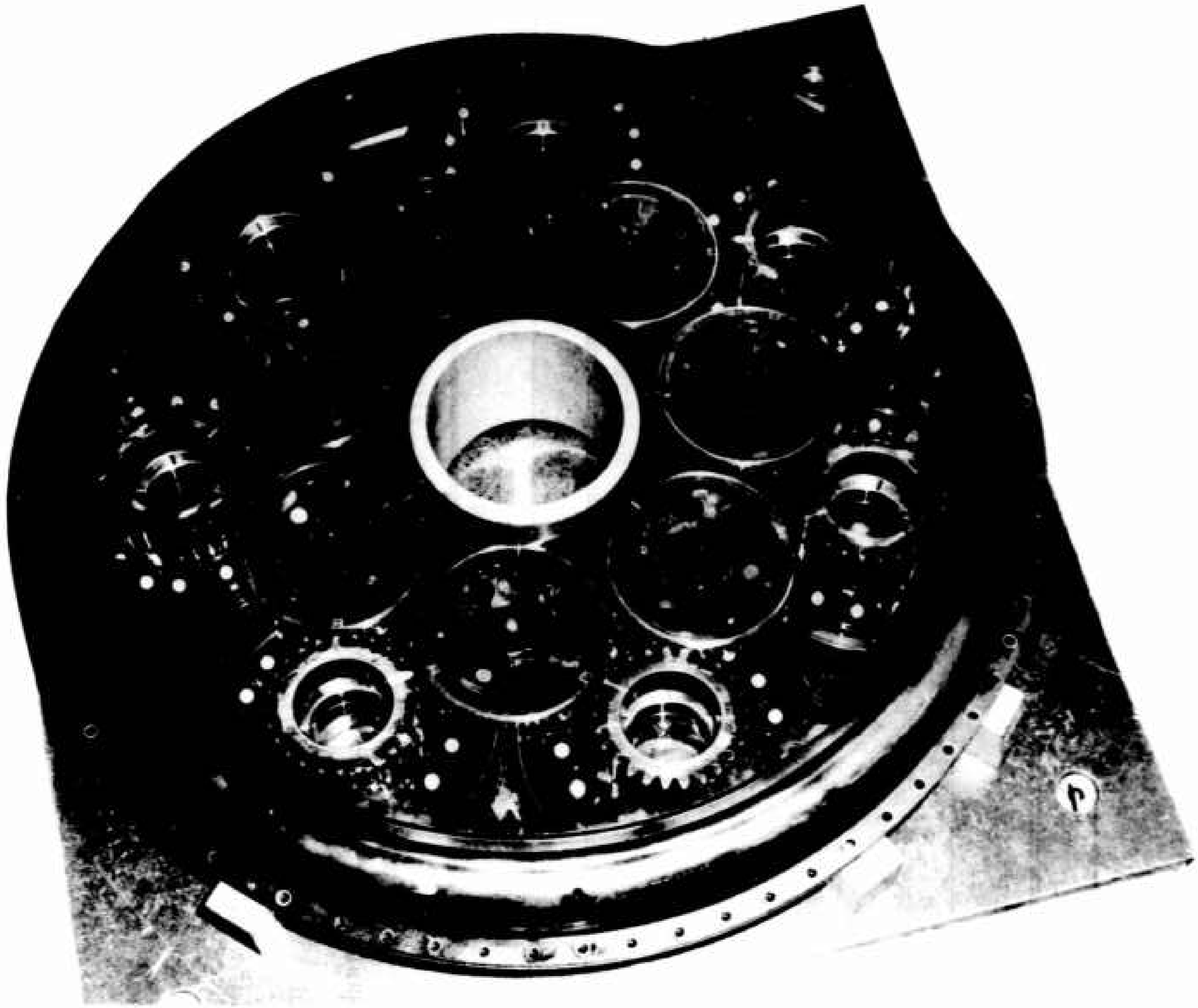


Figure 86. Assembled Roller Gear Unit.

HOUSING MANUFACTURE

The roller gear transmission represented the first time for Sikorsky Aircraft that a main housing was made from the magnesium alloy ZE41A instead of the usual AZ91C. Table 10 compares the composition of these two materials, while Table 11 compares their mechanical properties.

TABLE 10. COMPOSITIONS OF ZE41A AND AZ91C MAGNESIUM ALLOYS

Element	Percentage AZ91C	ZE41A
Aluminum	8.1 - 9.3	-
Zinc	0.4 - 1.0	3.5 - 5.0
Manganese	0.13 max	0.15 max
Silicon	0.30 max	0.01 max
Copper	0.10 max	0.10 max
Nickel	0.01 max	0.01 max
Rare Earth Metals (CE)	-	0.75 - 1.75
Zirconium	-	0.40 - 1.0
Iron	-	.01 max
Other	0.30 max	0.30 max
Magnesium	Balance	Balance

TABLE 11. MECHANICAL PROPERTIES OF ZE41A AND AZ91C MAGNESIUM ALLOYS

	AZ91C	ZE41A
Ultimate Tensile Strength (psi)	17,000	26,000
Yield Strength (psi)	12,000	17,500
Elongation	3.0%	2.0%
Tensile Modulus of Elasticity (10^6 psi)	6.5	6.5
Shear Modulus of Elasticity (10^6 psi)	2.4	2.4
Thermal Expansion Coefficient (10^6 in./in./°F)	14	15.1

ZE41A, while slightly more costly than AZ91C, offers several advantages. Not only is it stronger than AZ91C, as can be seen from Table 11, but it also displays more uniform properties throughout the casting. ZE41A has much better foundry characteristics than the AZ alloys, in that it produces a casting that is virtually free of microporosity. Fatigue properties of ZE41A are approximately 20% higher than for the AZ alloys. ZE41A is also less prone to cracking during welding due to the rare earth additions, and it has much better machining properties. The heat treatment required to obtain the best properties for ZE41A is precipitation heat treatment (T5) as compared to the more complicated and costlier solution heat treatment (T6) required for the AZ alloys.

Because this was an experimental program and it was Sikorsky's first attempt to use a ZE41A casting, the housing design effort was aimed at cost saving instead of weight saving. For example, cored lines were kept to a minimum and bolt circle flanges were kept solid instead of scalloped. In addition, a cardboard model of the casting, shown in Figure 87, was built and used as a geometric and structural check. From this model the casting vendor made additional suggestions to save casting cost.

The casting of the main housing was very successful. The second casting poured was a usable casting, although it usually takes five or six castings before such a usable one is produced.

Figure 88 shows the assembly of the mold, the pouring of the molten magnesium and the trimming of the new casting. Visual inspection of the casting was performed prior to the dimensional and radiographic inspections to ensure a casting force of blowholes, hand spots and cracks. Critical zones of the casting which were X-ray inspected for porosity are shown in Figures 89 through 91.

In order to obtain the best properties for the cast housing, Figure 92, it was heat treated at the relatively low precipitation temperature of 625°F for 2 hours, air cooled, then heated at 340°F for 16 hours and air cooled.

The major portion of machining of the main housing consisted of boring for bearings and housings. This was performed on a single spindle S.I.P. (Societe Geneovise d'Instruments de Physique) jig borer. Figures 93 and 94 show the tolerances to which the bevel pinion bores were machined in addition to the critical dimensions of the main housing. The S.I.P. machine was also used to drill, tap, and counterbore the holes for the numerous inserts that are assembled with the main housing. A typical example of one of these inserts, a Rosan, is shown in Figure 95.

A Sundstrand Omnimil R was used for facing and contour milling of the noncircular contours of the casting. This is a tape controlled machine with 5 operational axes: table stroke (x-axis), vertical stroke (y-axis), cross stroke (z-axis), rotary turntable, and rotary contouring head. This machine is equipped with an automatic tool changer enabling facing, contour milling, drilling, and topping operations to be sequenced automatically. Steel liners, with a case-hardened inner bore, are press fitted into the housing prior to finish grinding on a jig grinder.

At the completion of machining of the housing and prior to installation of liners and studs, the housing was given a protective treatment. The protective treatment consisted of cleaning the coating and immersing it in a hydrofluidic acid bath. This was followed by a cold water rinse and dipping in a boiling solution of sodium dichromate. The casting was then rinsed again with water. A resin coating was then applied to the surfaces of the casting which was then baked at 325°F. The outside surfaces of the casting were given the added protection of a zinc-chromate primer and two coats of aluminum epoxy paint. The completed housing is shown in Figure 96.

All other housings in the roller gear transmission were made from the AZ91C magnesium alloy. Critical zones of these housings are illustrated in Figures 97 through 102. These zones, depicted by the shaded areas, are inspected in accordance with MIL-C-6021. The darker shaded areas, Figures 99 and 100, are inspected to classification Class 1A, the lighter shaded areas to Class 2A. The main housing, top cover, lower housing and adaptor box housing and cover shaded areas are inspected to the less stringent requirement of Class 2A.

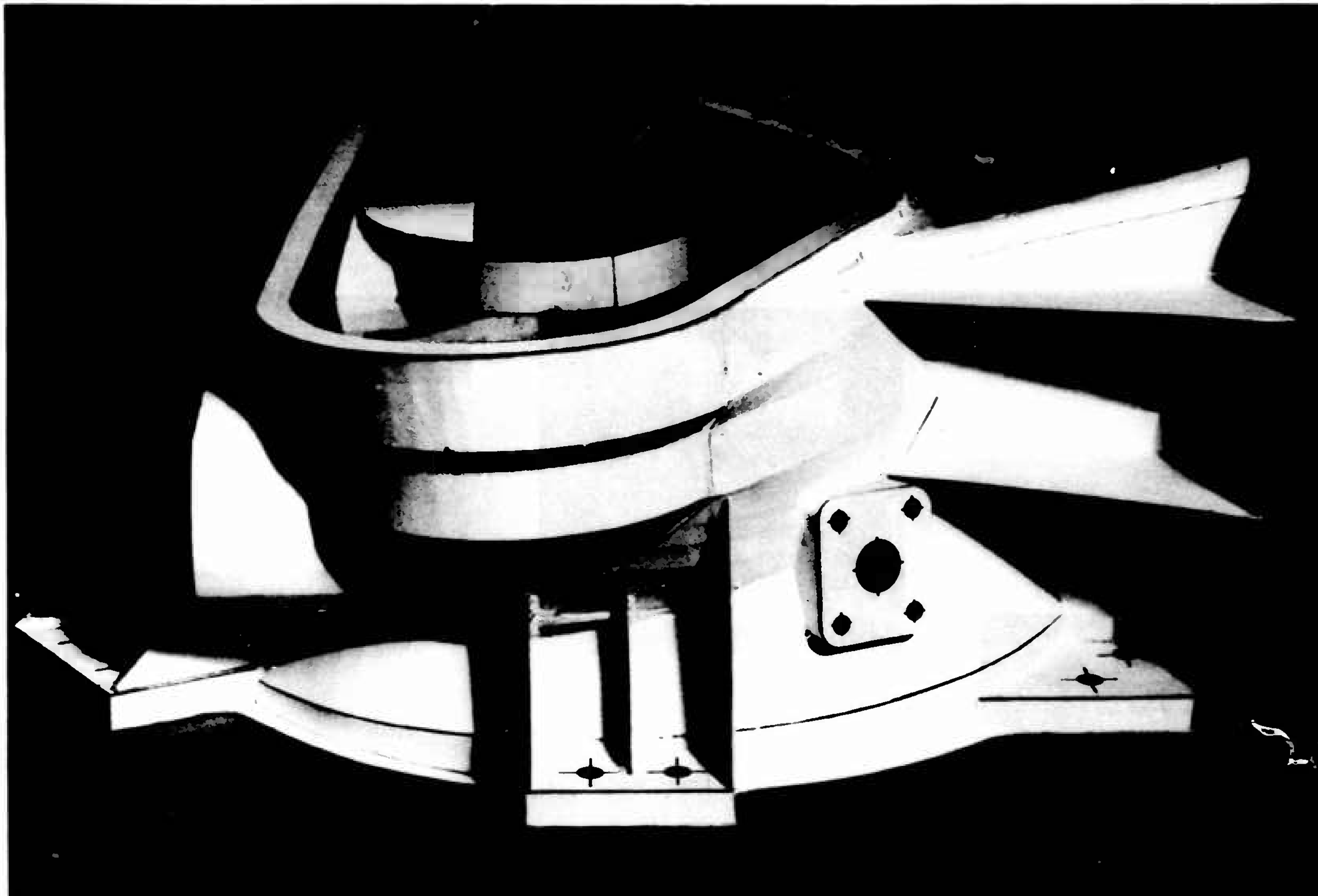


Figure 87. Model of Main Casting.

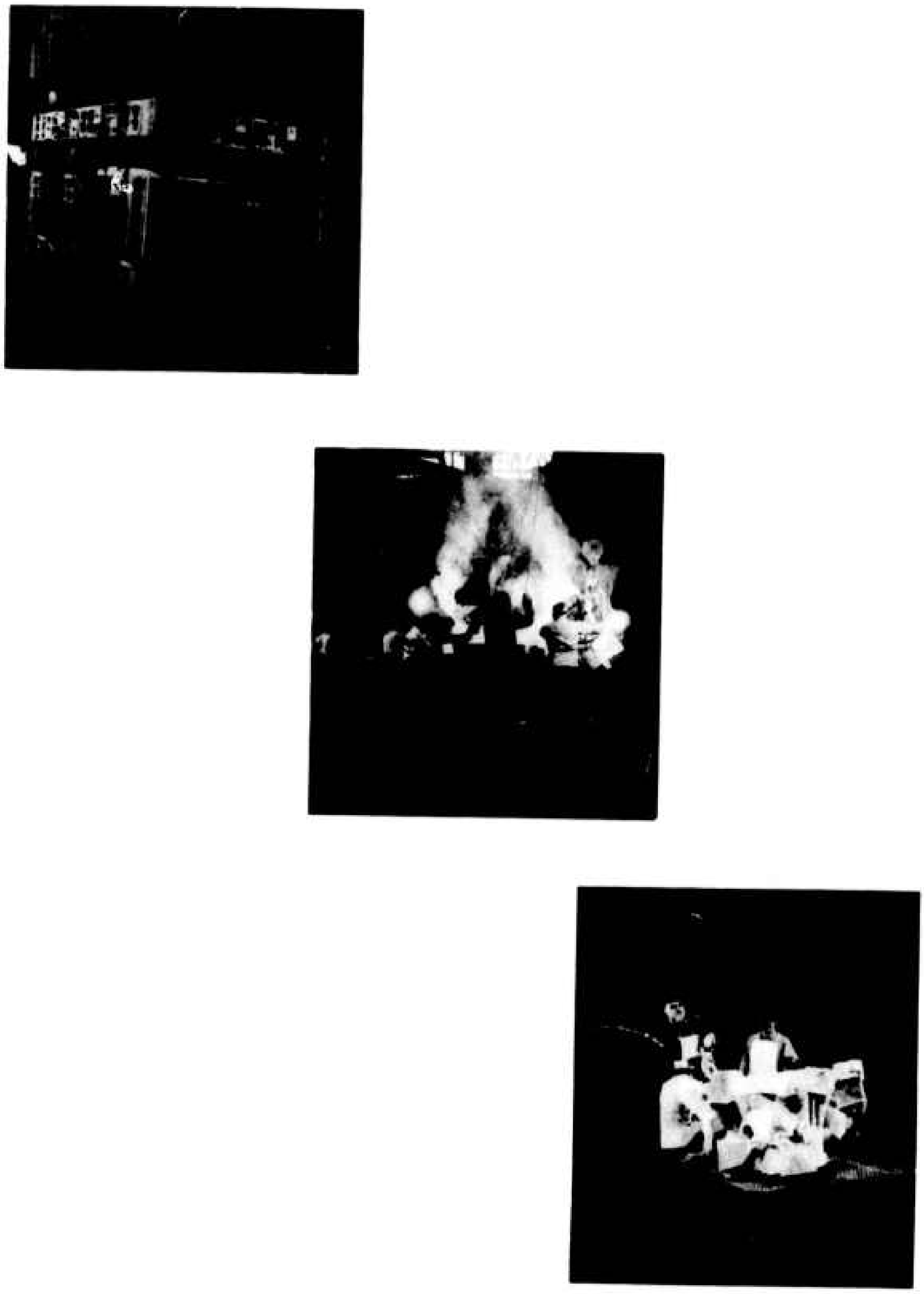


Figure 88. Main Housing Manufacture.

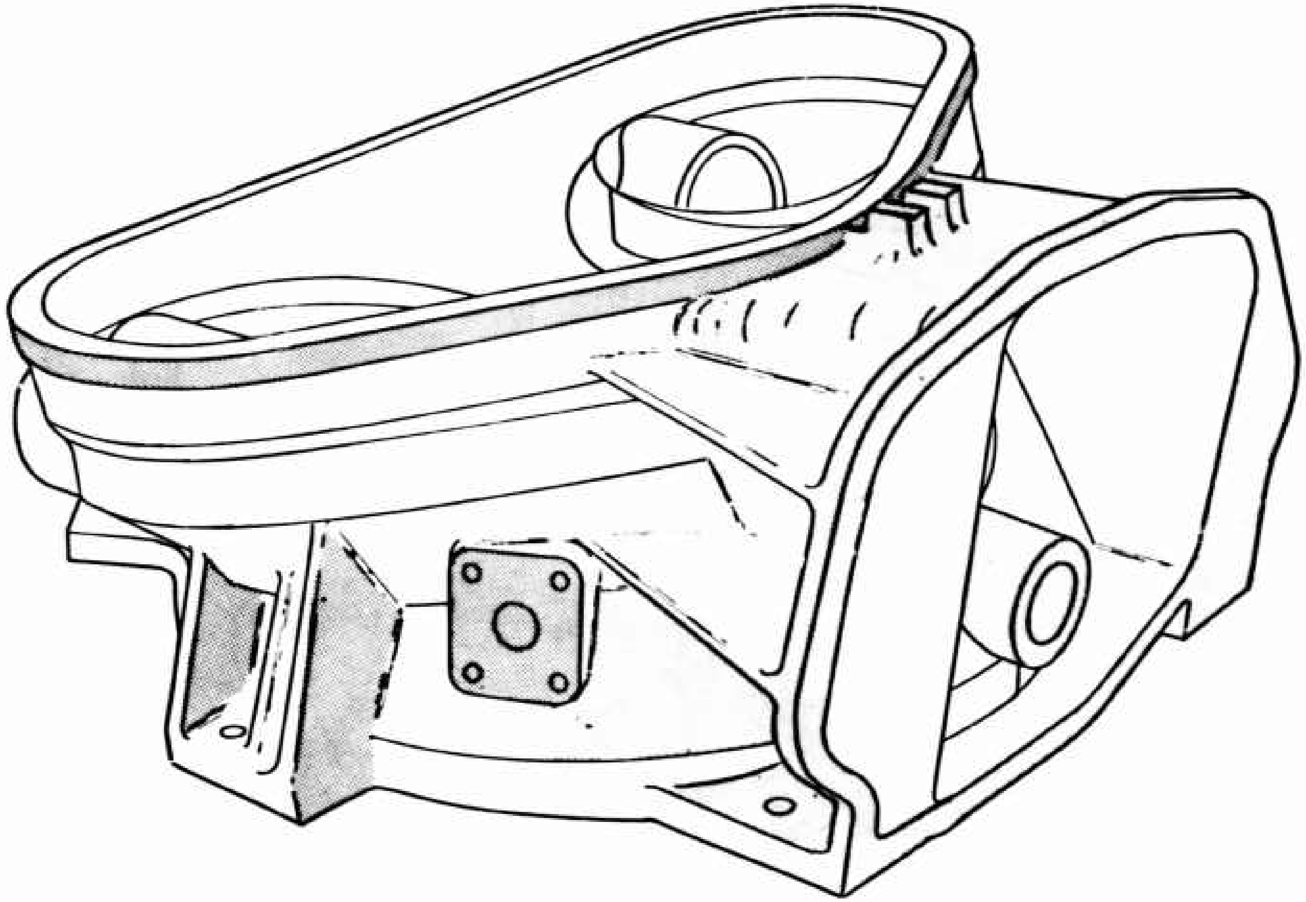


Figure 89. Critical Zones, Main Housing.

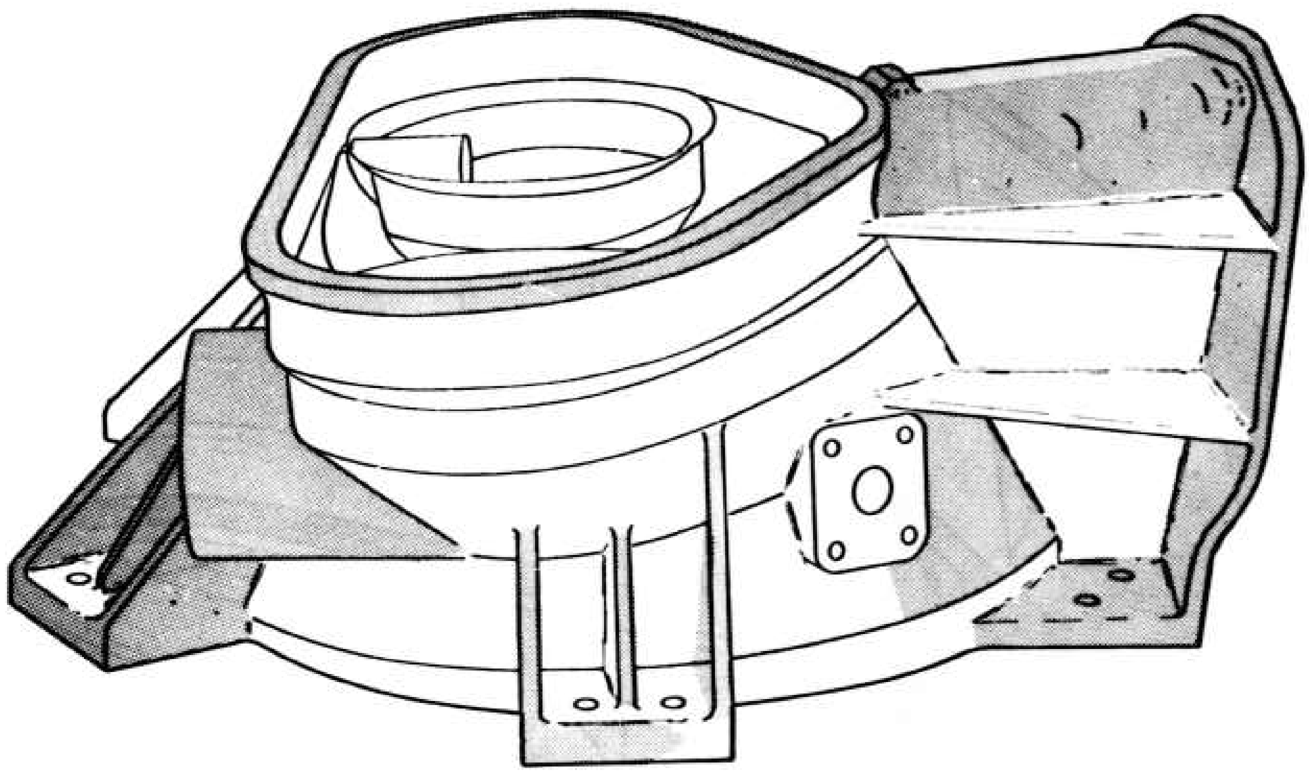


Figure 90. Critical Zones, Main Housing.

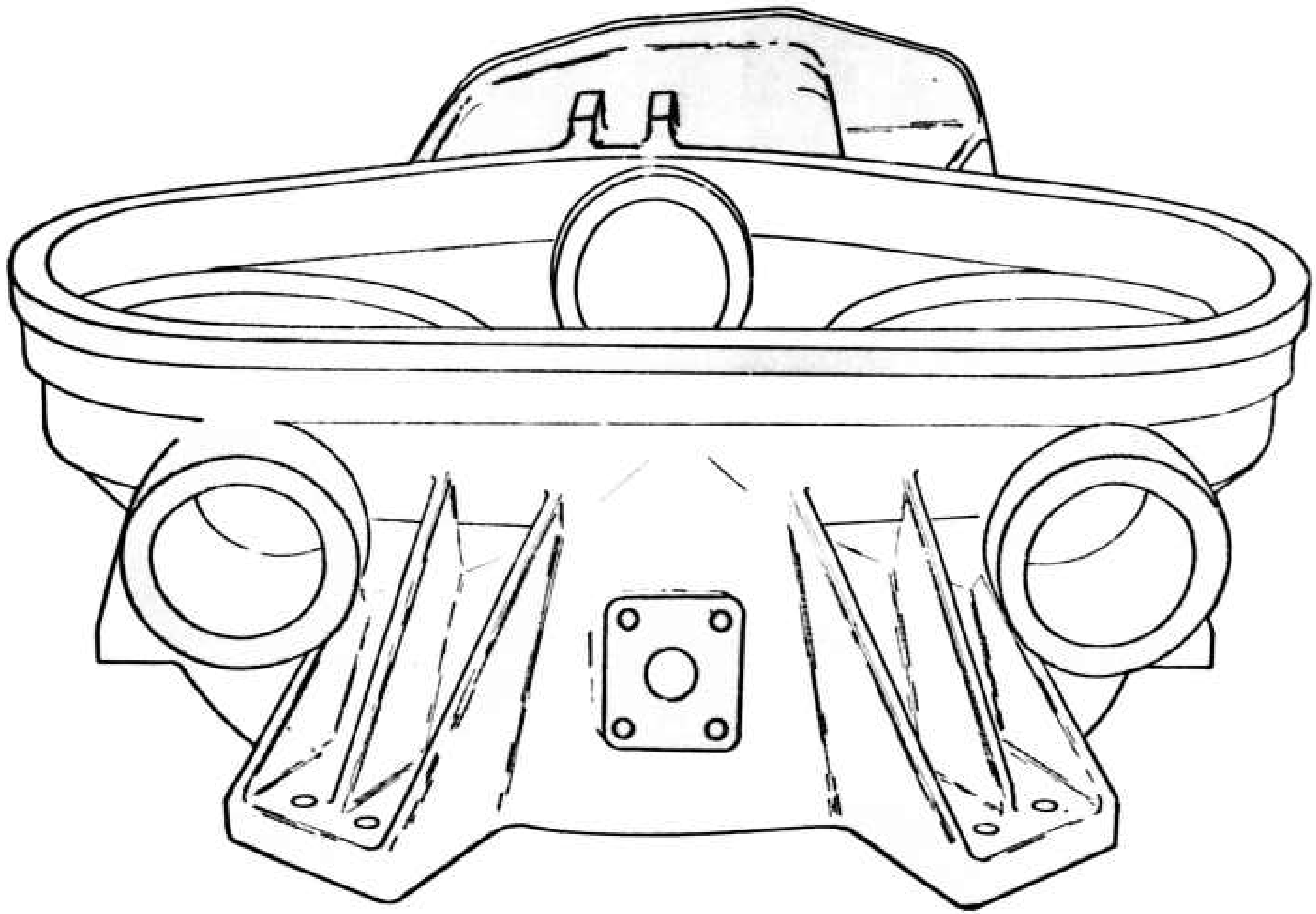
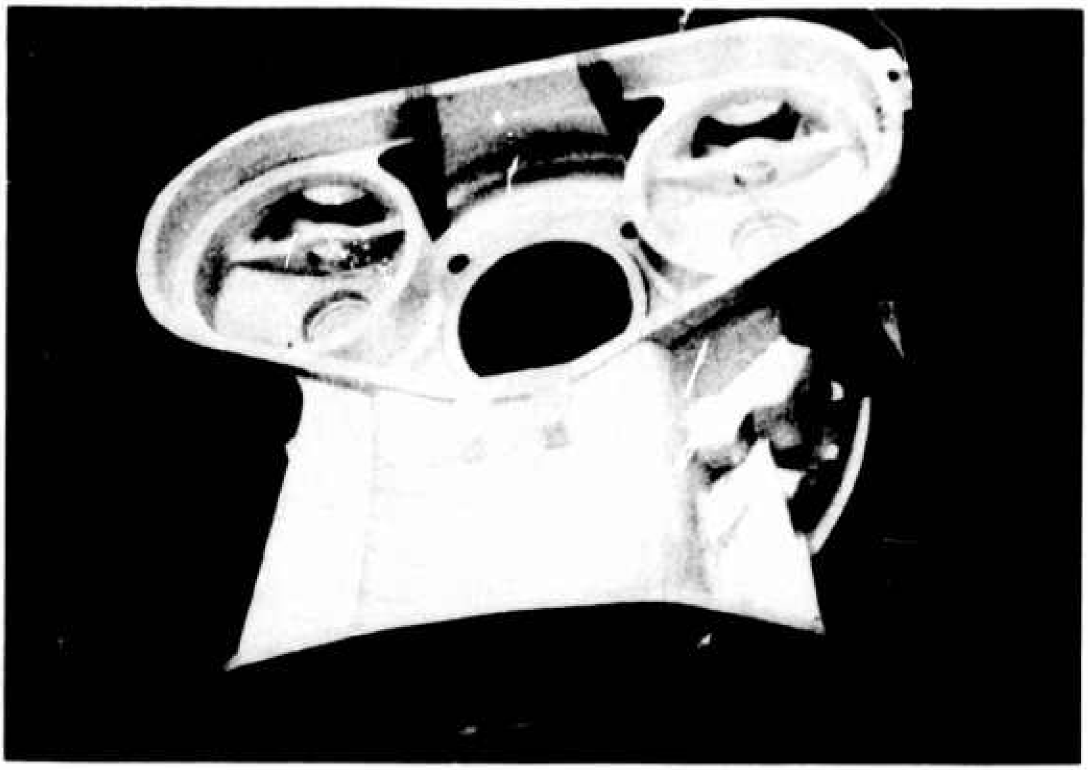


Figure 91. Critical Zones, Main Housing.



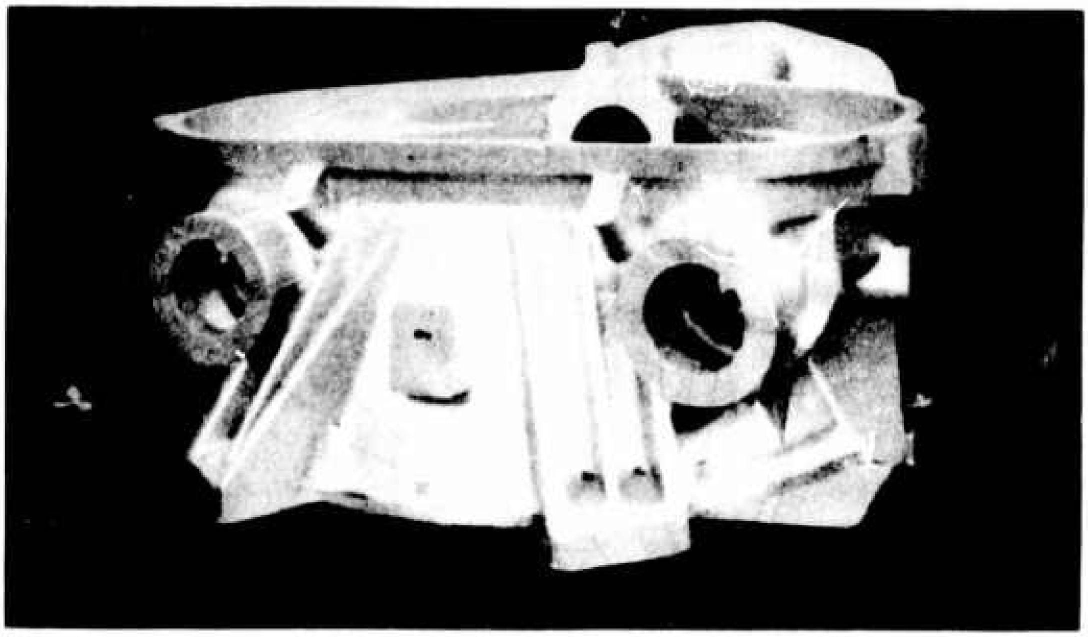
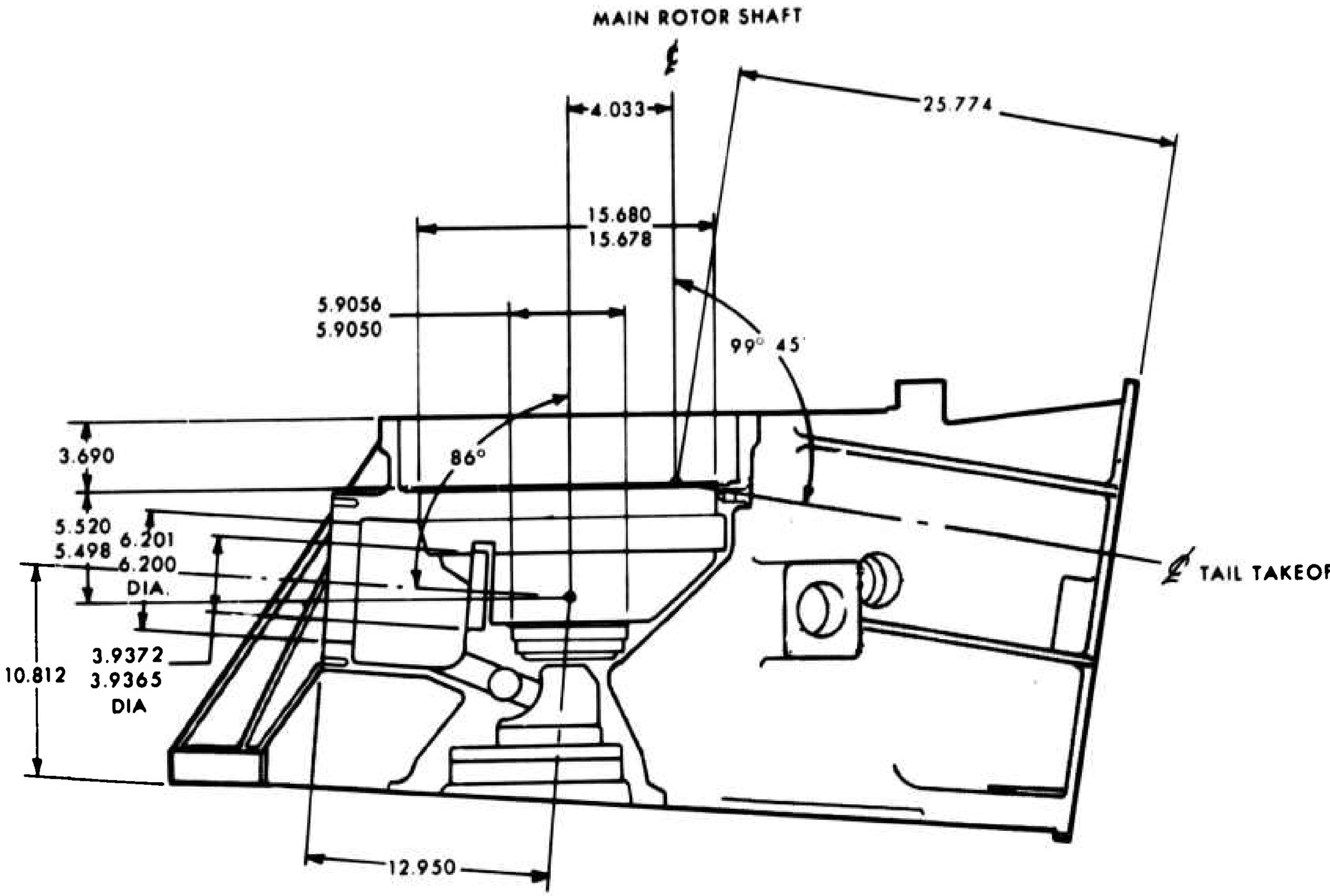
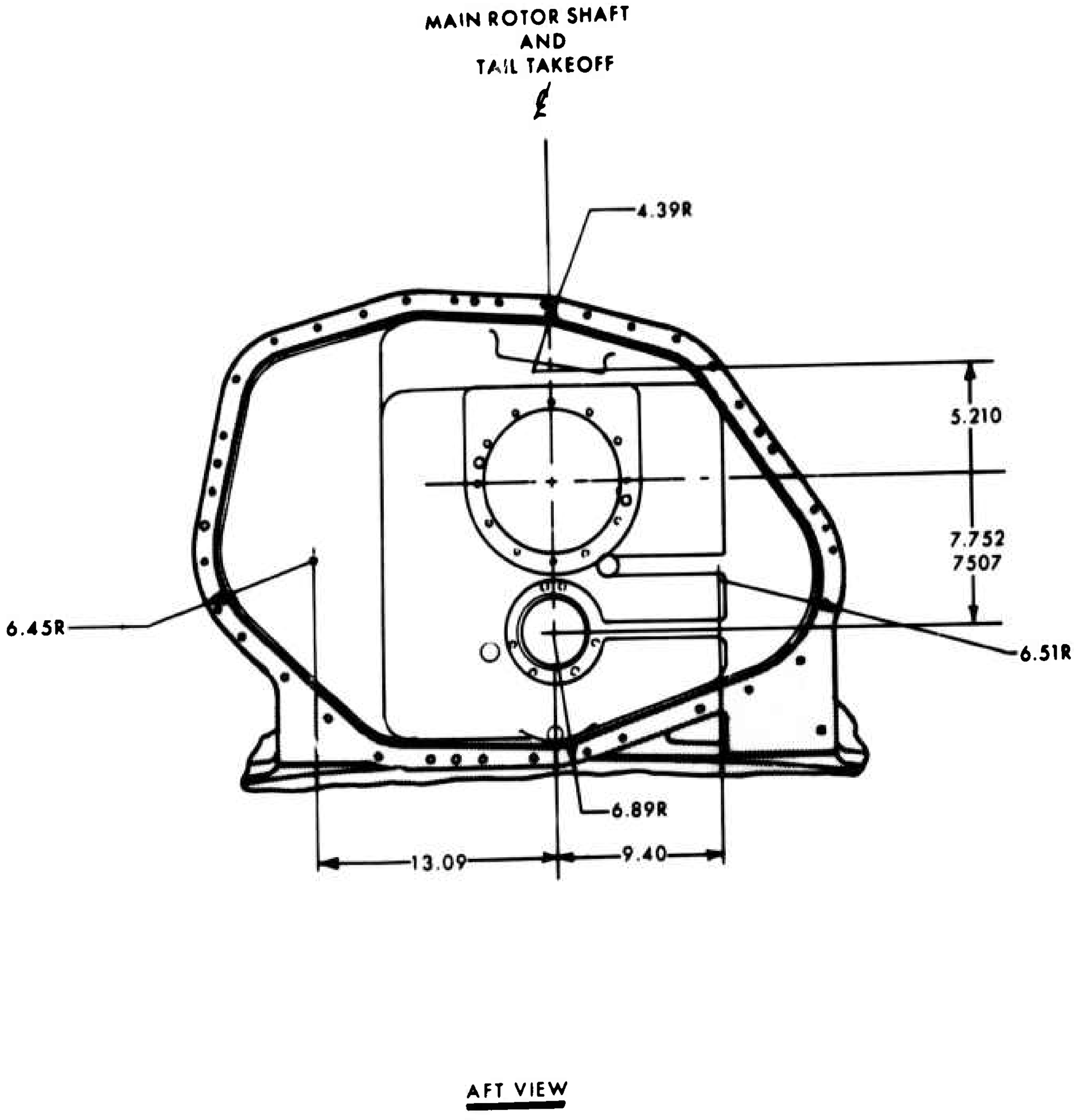


Figure 92. Completed Main Housing Casting.



LEFT SIDE

Figure 93. Main Housing, Critical Dimensions.



MAIN ROTOR SHAFT
AND
TAIL TAKEOFF
℄
4.39R
5.210
7.752
7507
6.45R
6.51R
6.89R
13.09
9.40

AFT VIEW

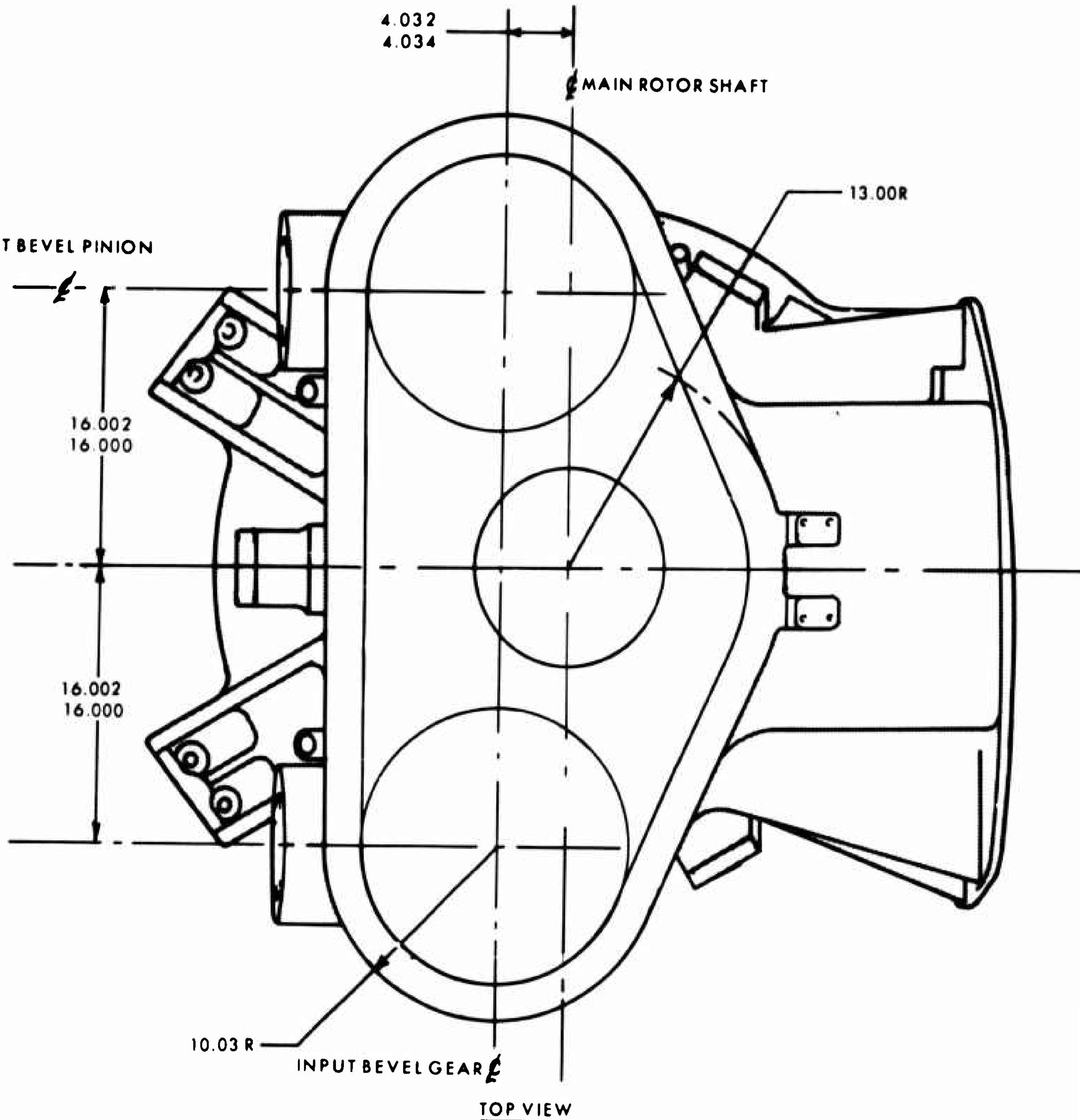


Figure 94. Main Housing, Critical Dimensions.

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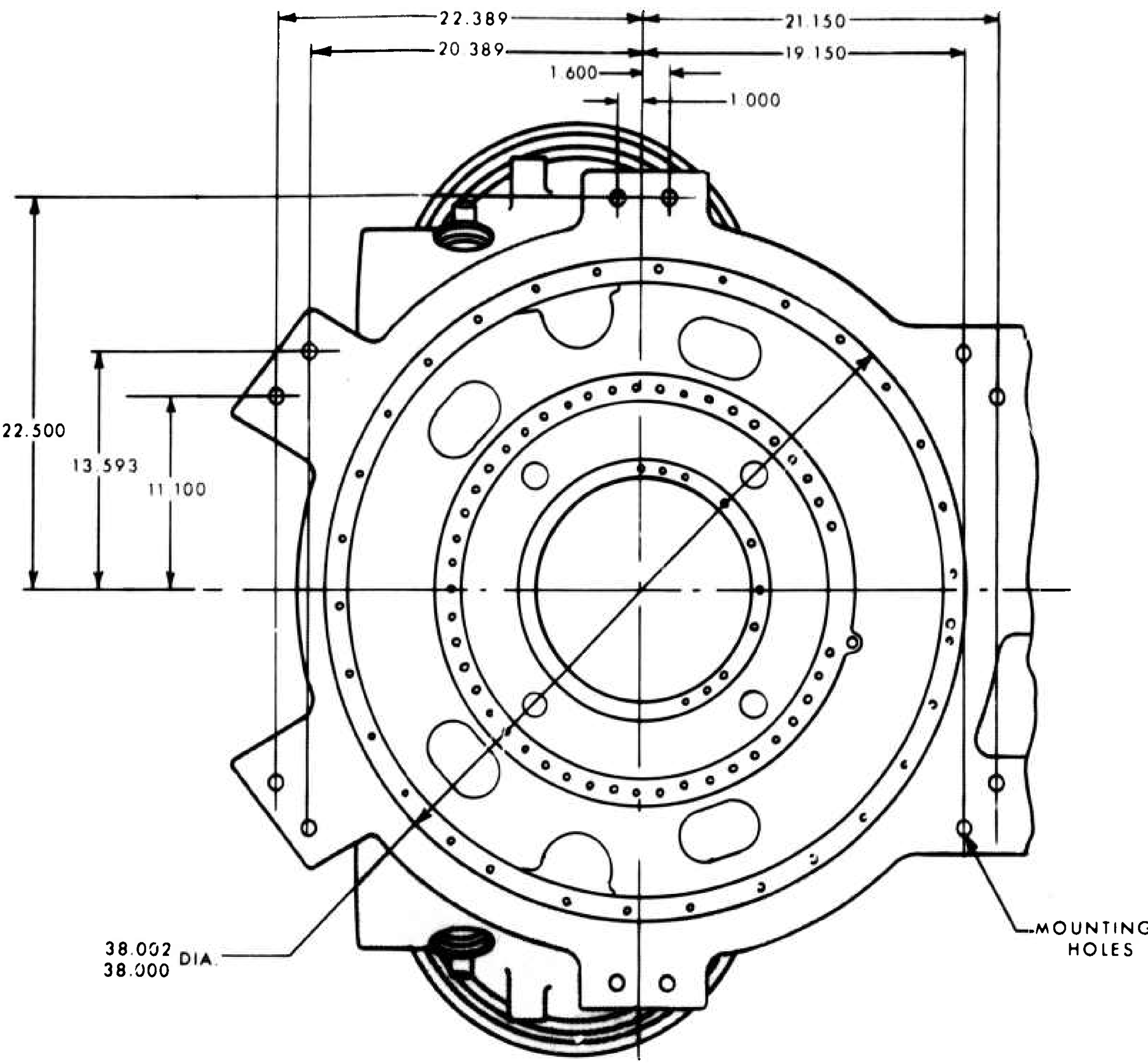

22.389
21.150
20.389
19.150
1.600
1.000
22.500
13.593
11.100
38.002
38.000
DIA.
MOUNTING
HOLES

BOTTOM VIEW

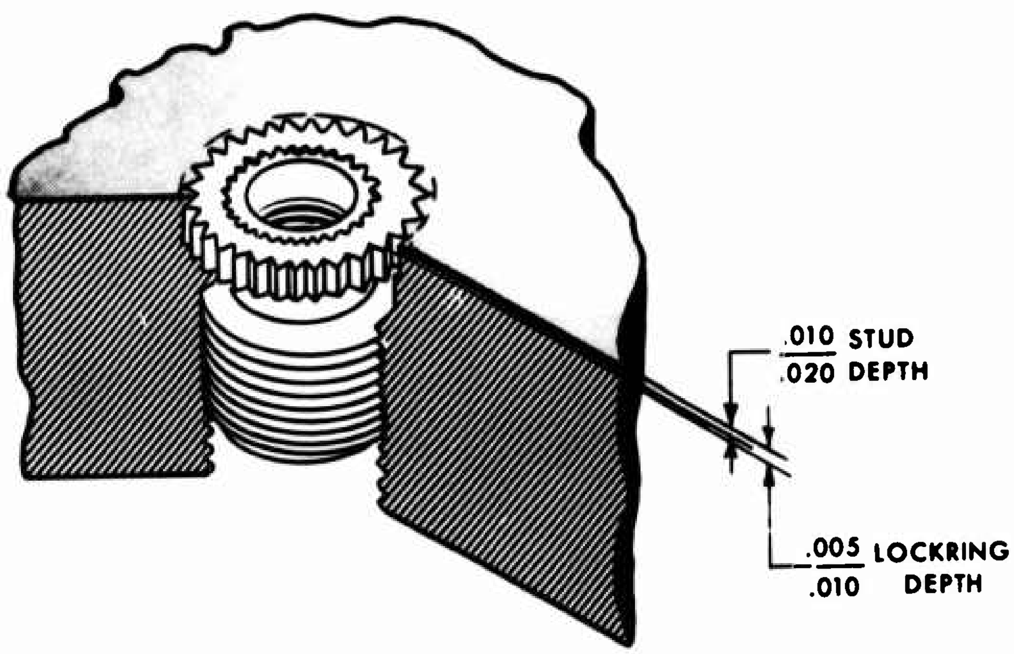


Figure 95. Rosan Insert for Main Housing.

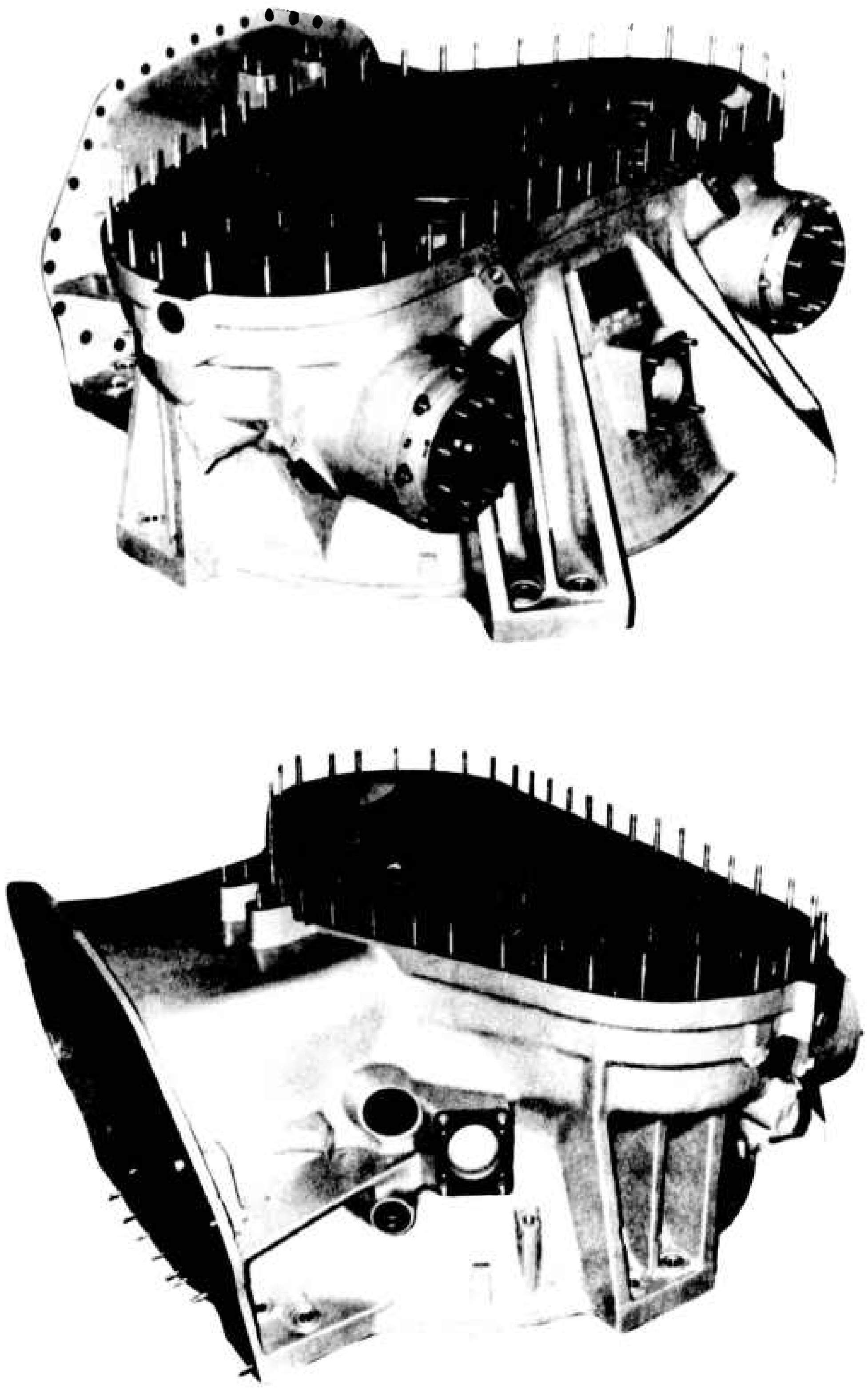


Figure 96. Main Housing With Liner and Studs.

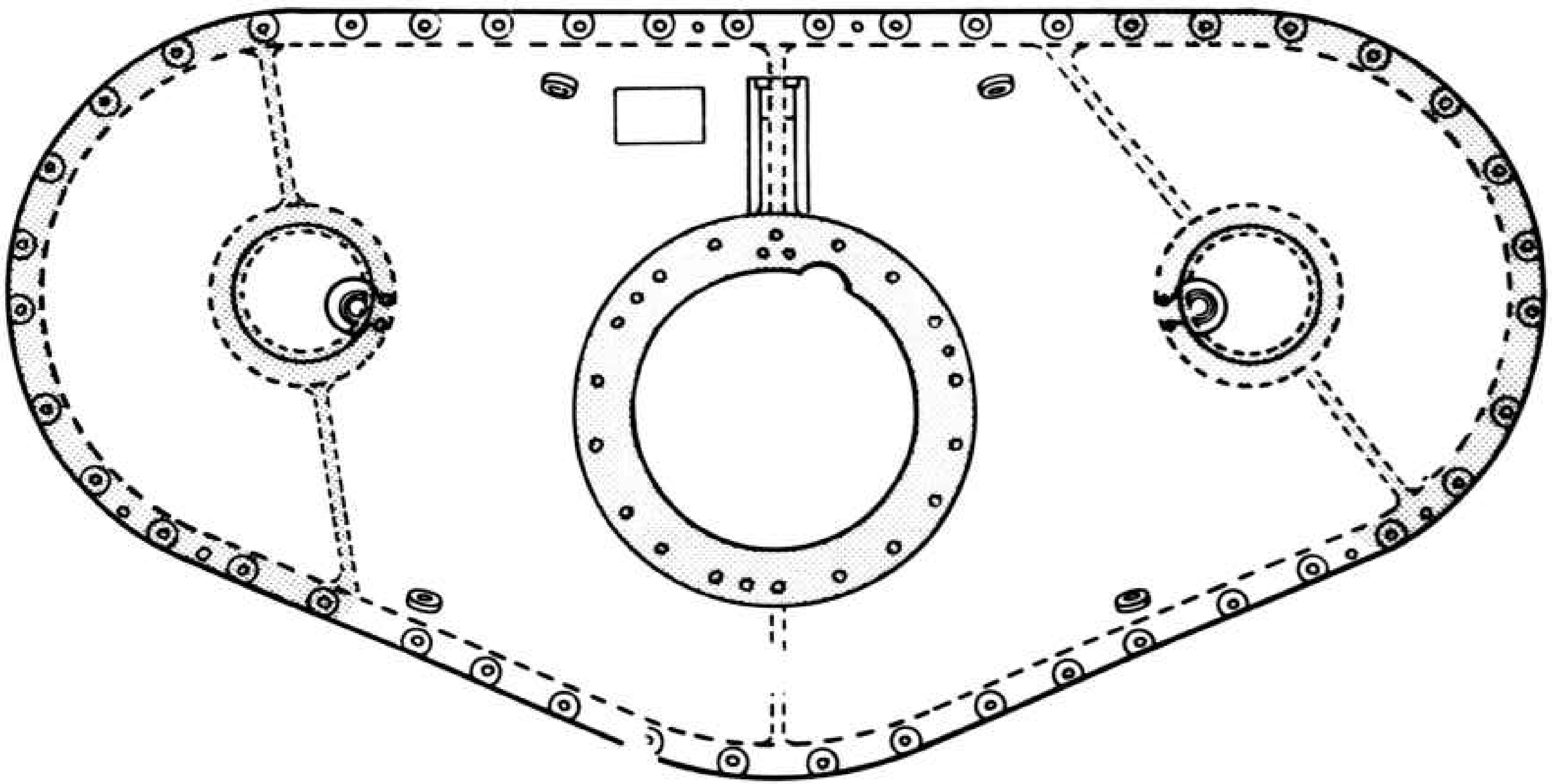


Figure 97. Critical Zones, Top Cover.

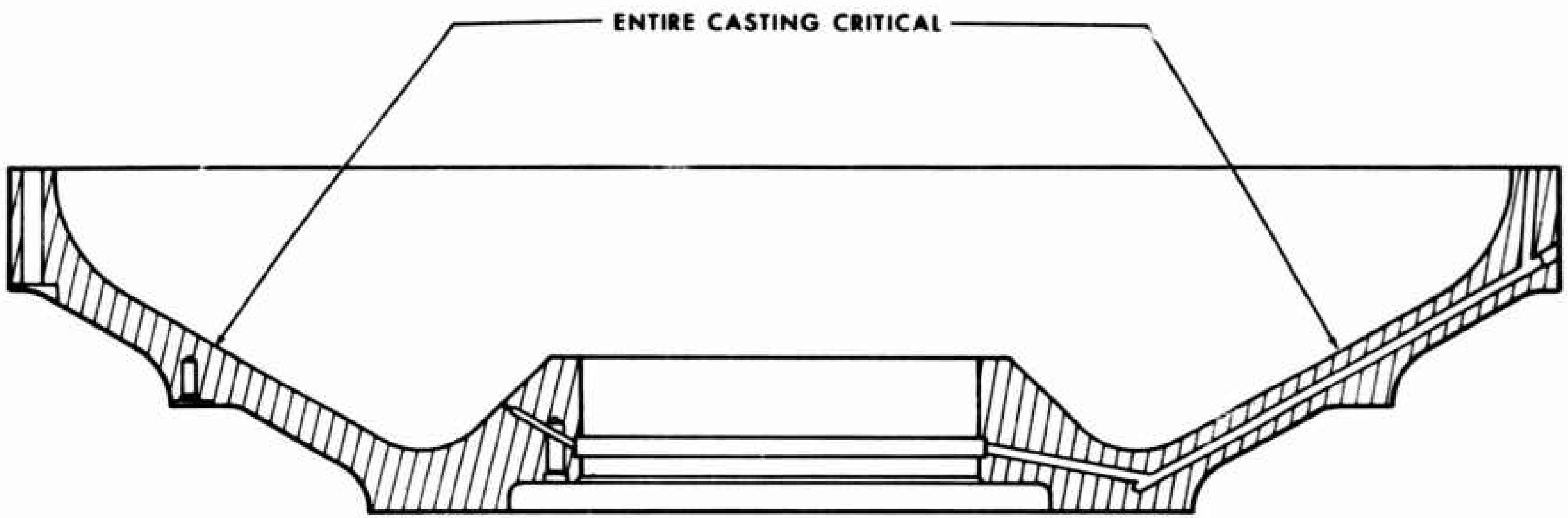


Figure 98. Critical Zones, Lower Housing.

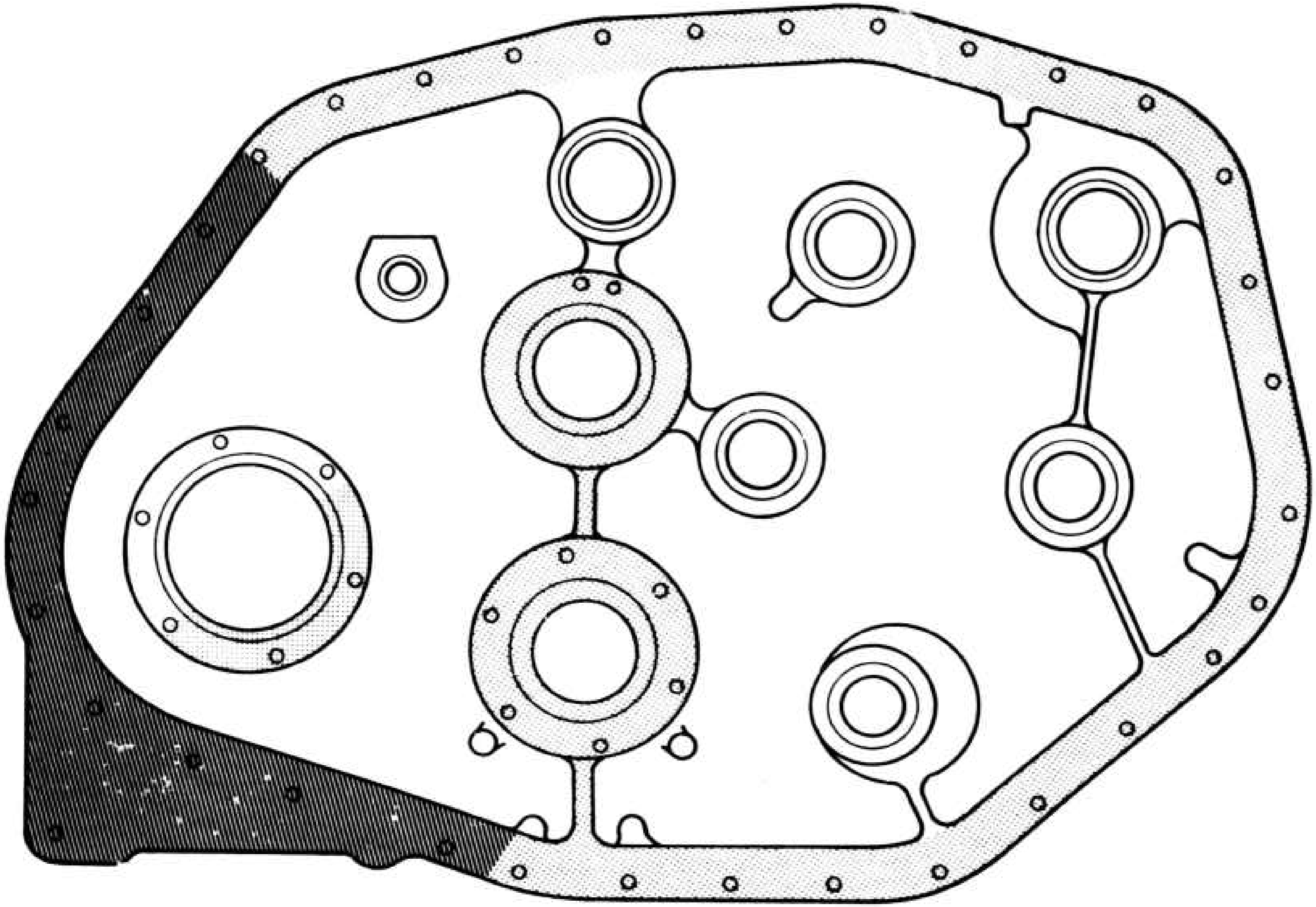


Figure 99. Critical Zones, Rear Cover Inboard.

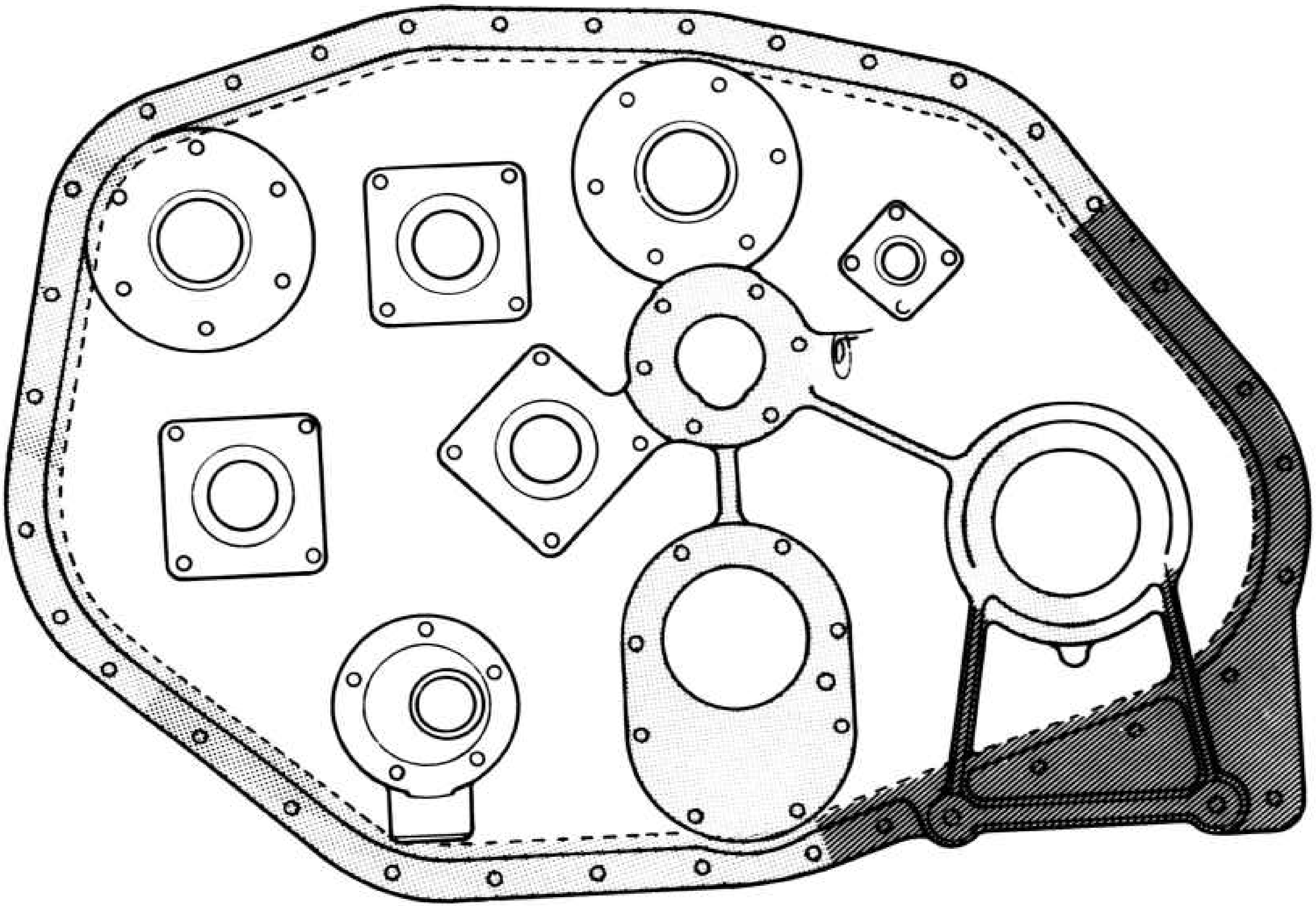


Figure 100. Critical Zones, Rear Cover Outboard.

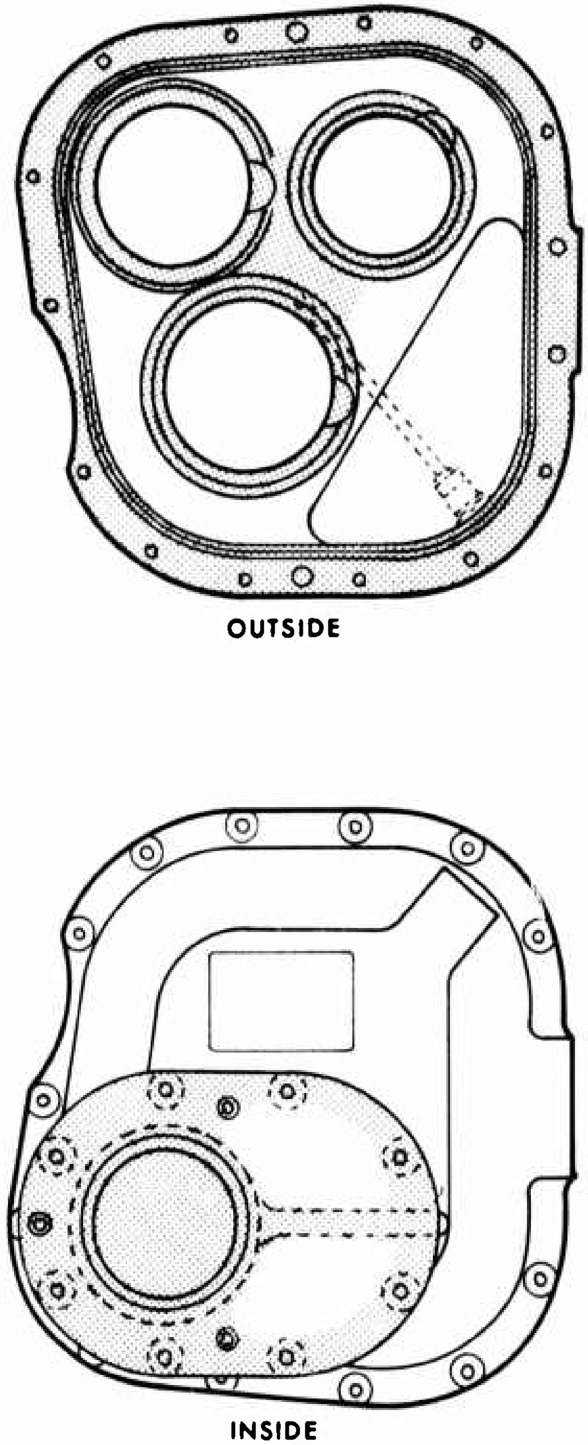
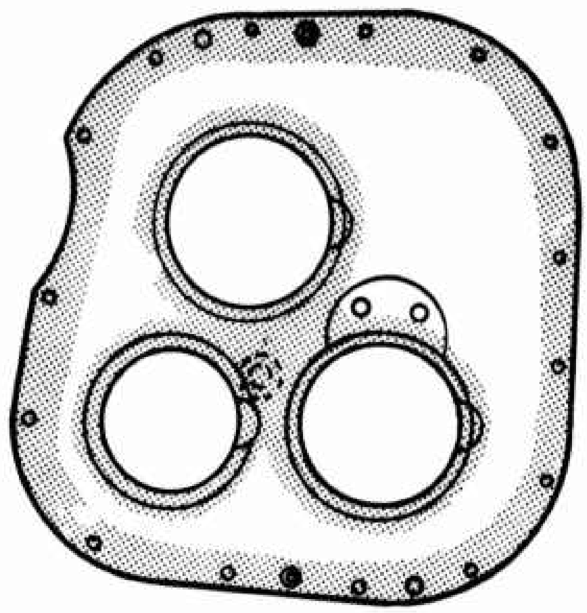
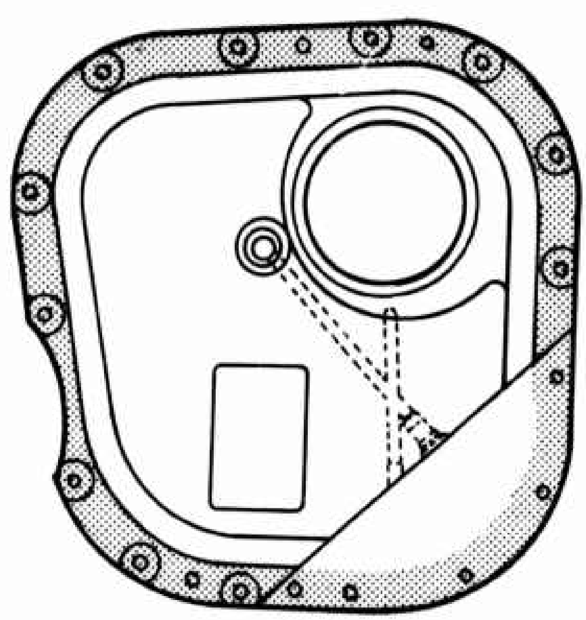


Figure 101. Critical Zones, Adaptor Box Housing.



INSIDE



OUTSIDE

Figure 102. Critical Zones, Adaptor Box Cover.

FREEWHEEL UNIT

The principal components of the ramp roller clutch type freewheel unit are the cam, rollers, outer housing, and case. The cam and cage are pictured in Figure 103. A spring and plunger mechanism acts on the roller retainer which, in turn, forces the rollers up the inner cam against the outer housing. In this position the clutch is located in the driving mode by the wedging action of the rollers between the driving member, the outer housing, and the driven member, the cam. Overruning occurs whenever the cam attempts to turn faster than the outer housing. The rollers in this case tend to slide on the cam and roll on the outer housing.

The cam, housing, rollers, and cage are made from AMS 6265 consumable electrode vacuum melt steel (see Table II for composition). The cam and housing have carburized areas where the rollers contact them in order to inhibit wear. The basic manufacturing procedure follows the standard sequence for carburized parts: rough machine, normalize, anneal, semi-finish machine, carburize, harden and freeze, temper, finish grind, and temper. Magnetic-particle inspection for cracks is continually performed throughout the manufacturing process.

The flats of the cam, shown in Figure 104, are finish ground on an external grinder fitted with a dividing head. This head accurately indexes the cam so that the fourteen flats are finish ground with equal spacing to within 0.0001 inch. The flats are ground parallel to the pilot diameter to within 0.0002 inch and the distance across the flats is held to within 0.0003 inch for any two adjacent flats. The surface finish of these flats is 20 microinches A.A.

The slots of the cage are rough machined on a vertical milling machine with a dividing head for indexing. This permits accurate positioning of the fourteen slots. The case is then carburized and heat treated to produce a case hardness of Rockwell C 58-64 with a core hardness of Rockwell C 30 to 45. The cage is then finish machined to blueprint tolerances.

The manufacture of the housing follows the same basic procedure as for the cam and cage. The bore, however, where the rollers wedge and skid is finished to 16 microinches A.A. (Arithmetic Average). This finish is obtained by honing, a low velocity abrading process. Honing also serves to correct the minor distortion caused by heat treatment. The fourteen rollers of the freewheel unit are crowned to elminate high contact stresses on the ends of the rollers. These rollers, supplied by a bearing manufacturer, are machined from SAE 52100 through-hardened to Rockwell C 60-64. Surface finish is held to 20 microinches or better with a roller diameter held to $0.6249 \pm .0001$ inch.

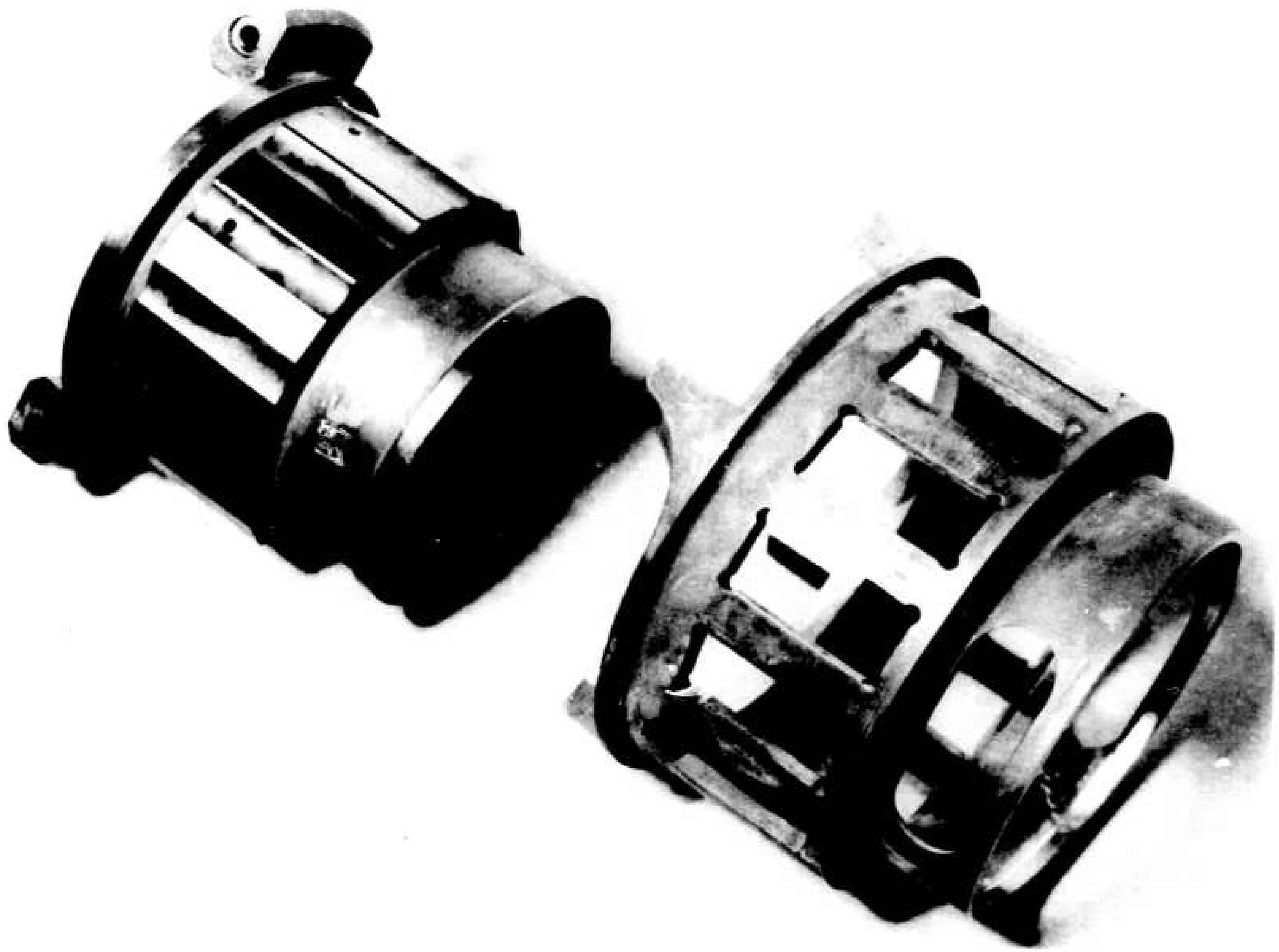


Figure 103. Cam and Cage of Freewheel Unit.

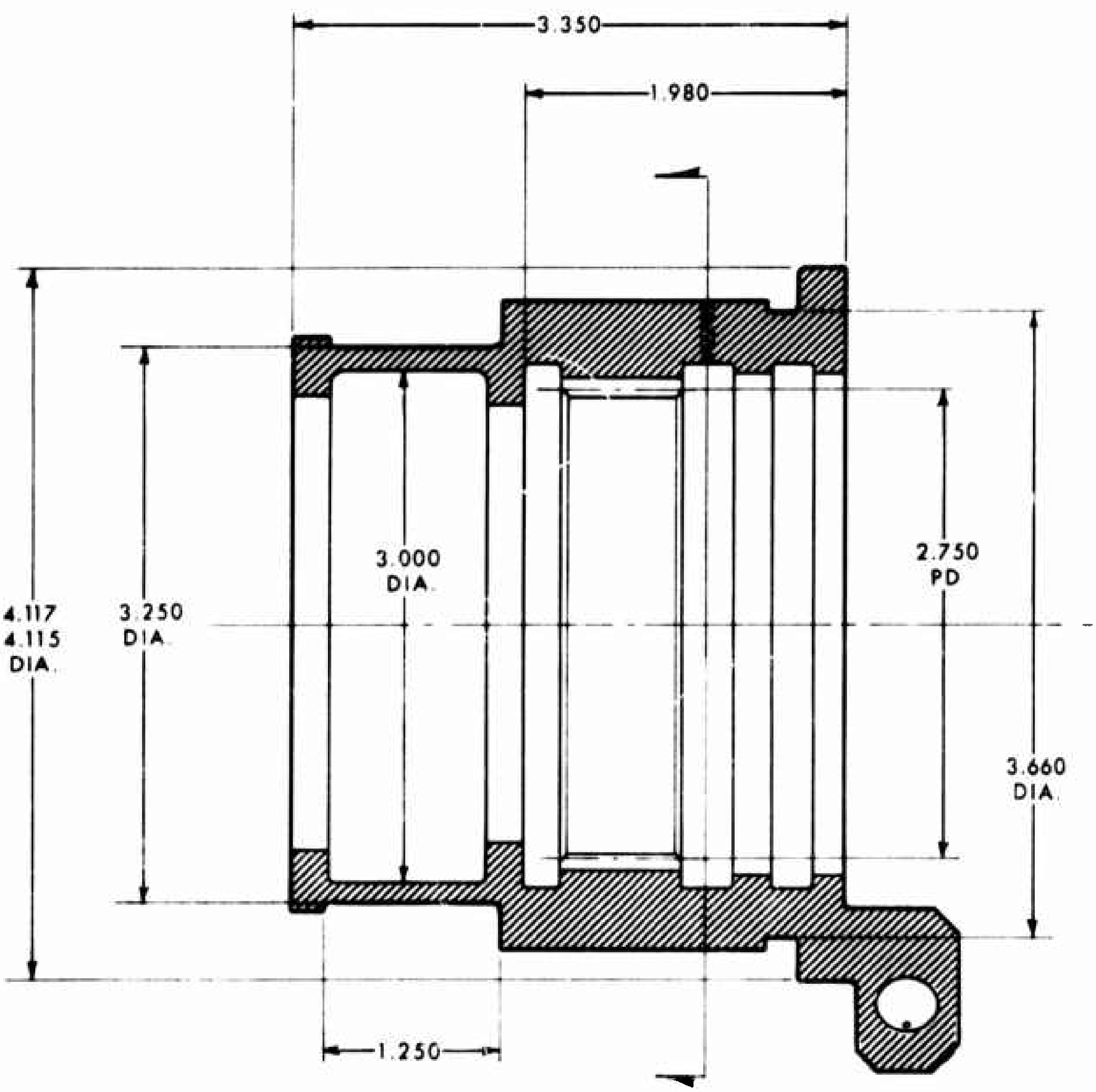
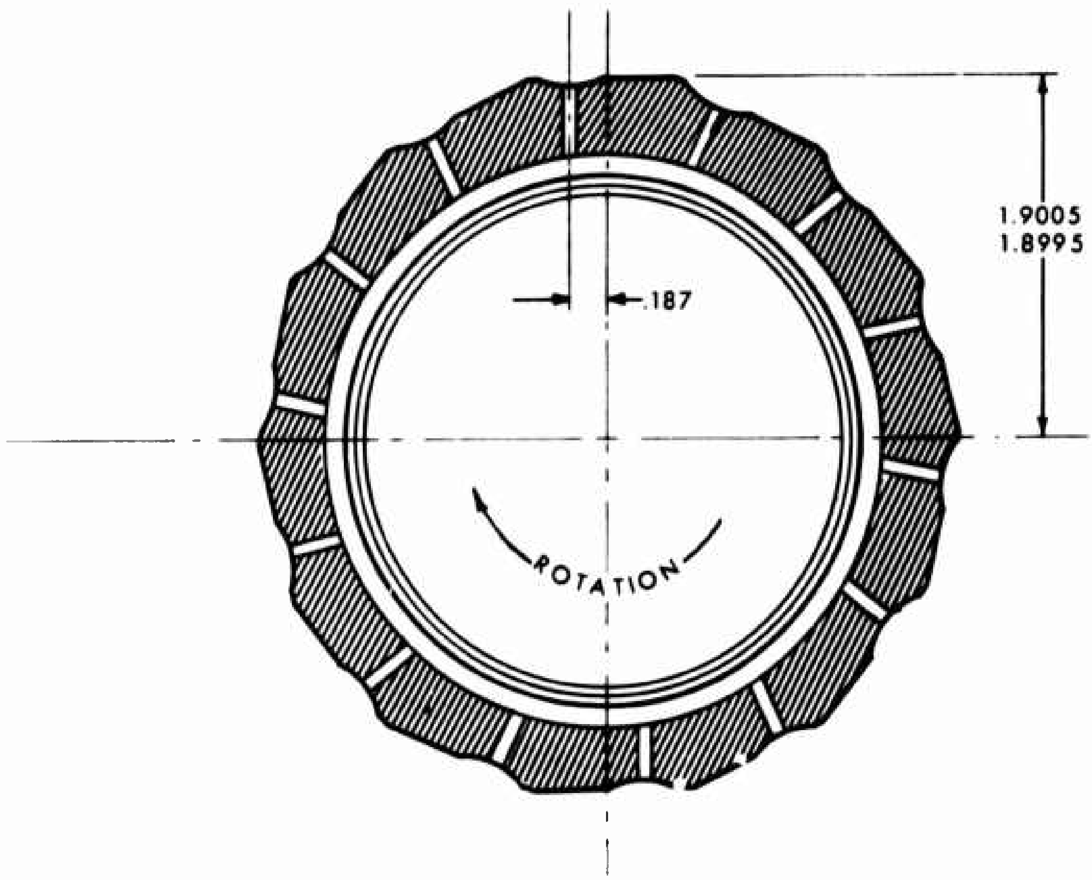


Figure 104. Freewheel Unit Cam, Dimensions.



1.9005
1.8995
.187
ROTATION

MAIN ROTOR SHAFT

The main rotor shaft is machined from a forging of AISI 4340, a medium carbon content, nickel, chromium, molybdenum steel. The forging process produces a definite grain flow in the steel, thereby maximizing strength and toughness.

The manufacturing process for the main rotor shaft is depicted in Figure 105. Due to the length of the shaft, trepanning is conducted from both ends, thereby reducing tool overhang and permitting greater accuracy. After rough machining of the outside diameter and trepanning, the shaft is heated to its austenitizing temperature of 1475°-1550°F and quenched in an agitated oil bath. The main rotor shaft was then tempered to produce an ultimate strength of 200,000 psi with a hardness of Rockwell C 43-46.

After heat treatment, the shaft is finish machined on both the inside and outside diameters. The splines are then hobbed with a vertical hobber. The final step is the coating of the inside of the shaft with a baked resin. Finished shaft dimensions are shown in Figure 106.

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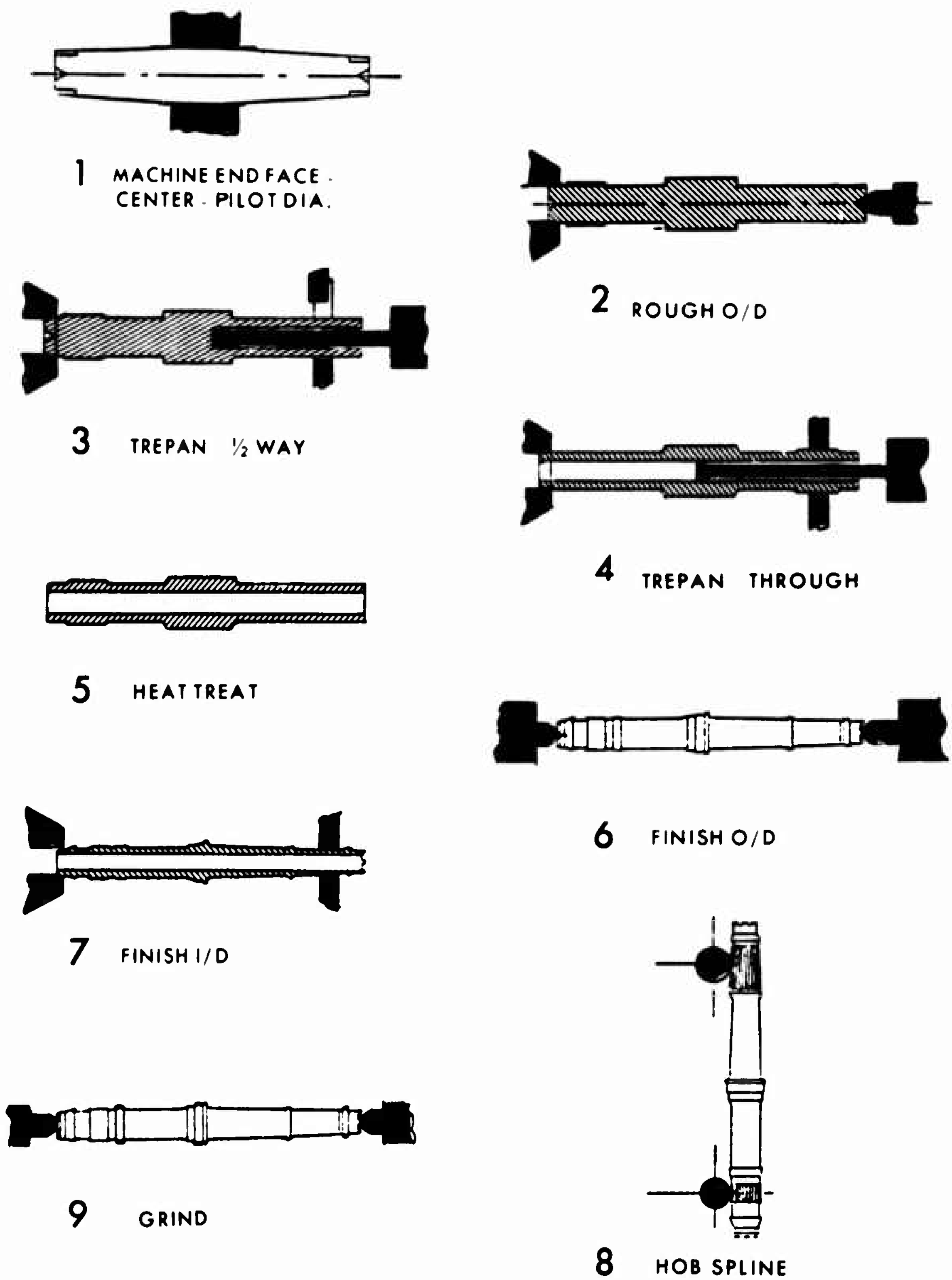


Figure 105. Main Rotor Shaft Manufacturing Process.

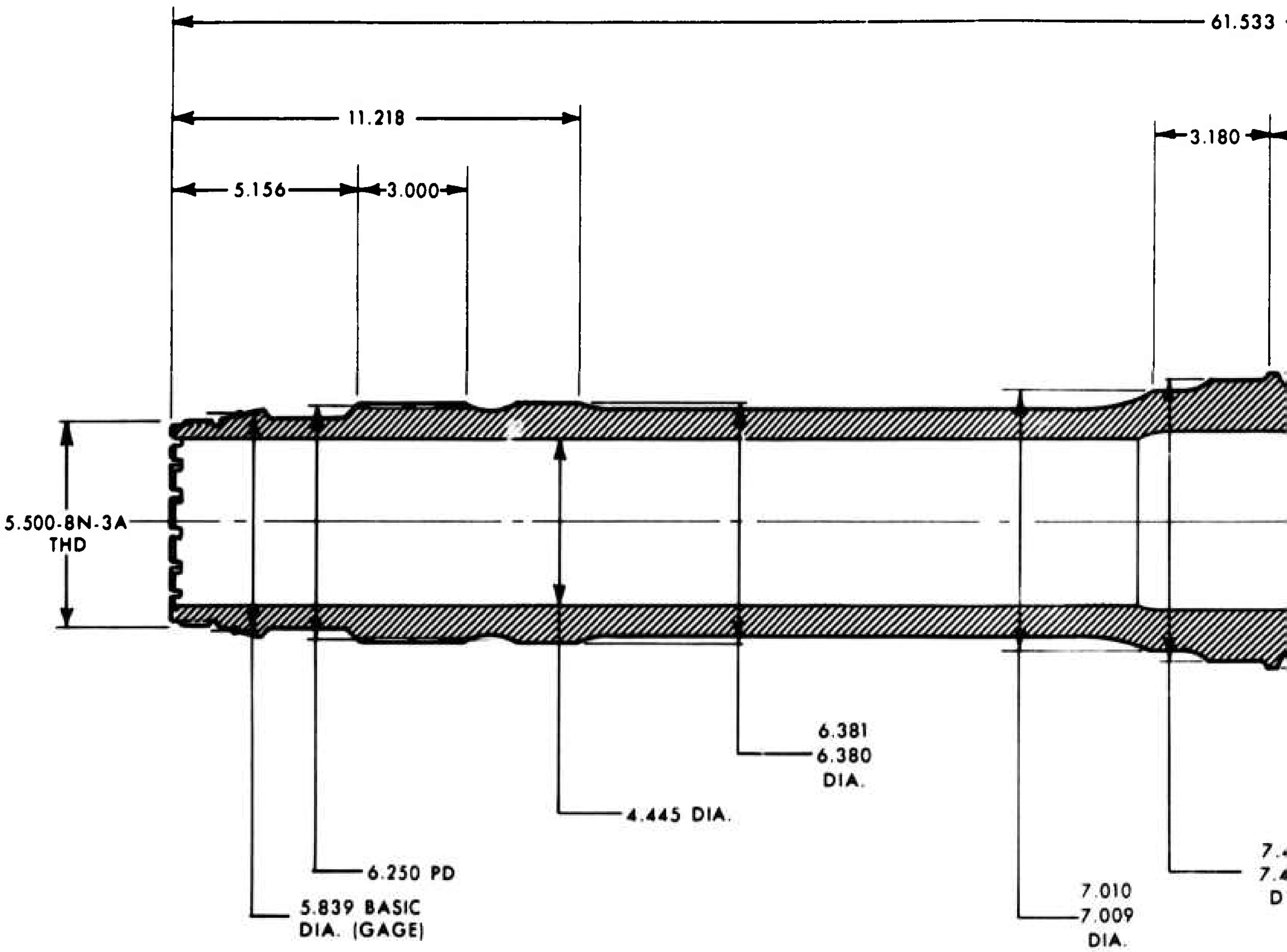
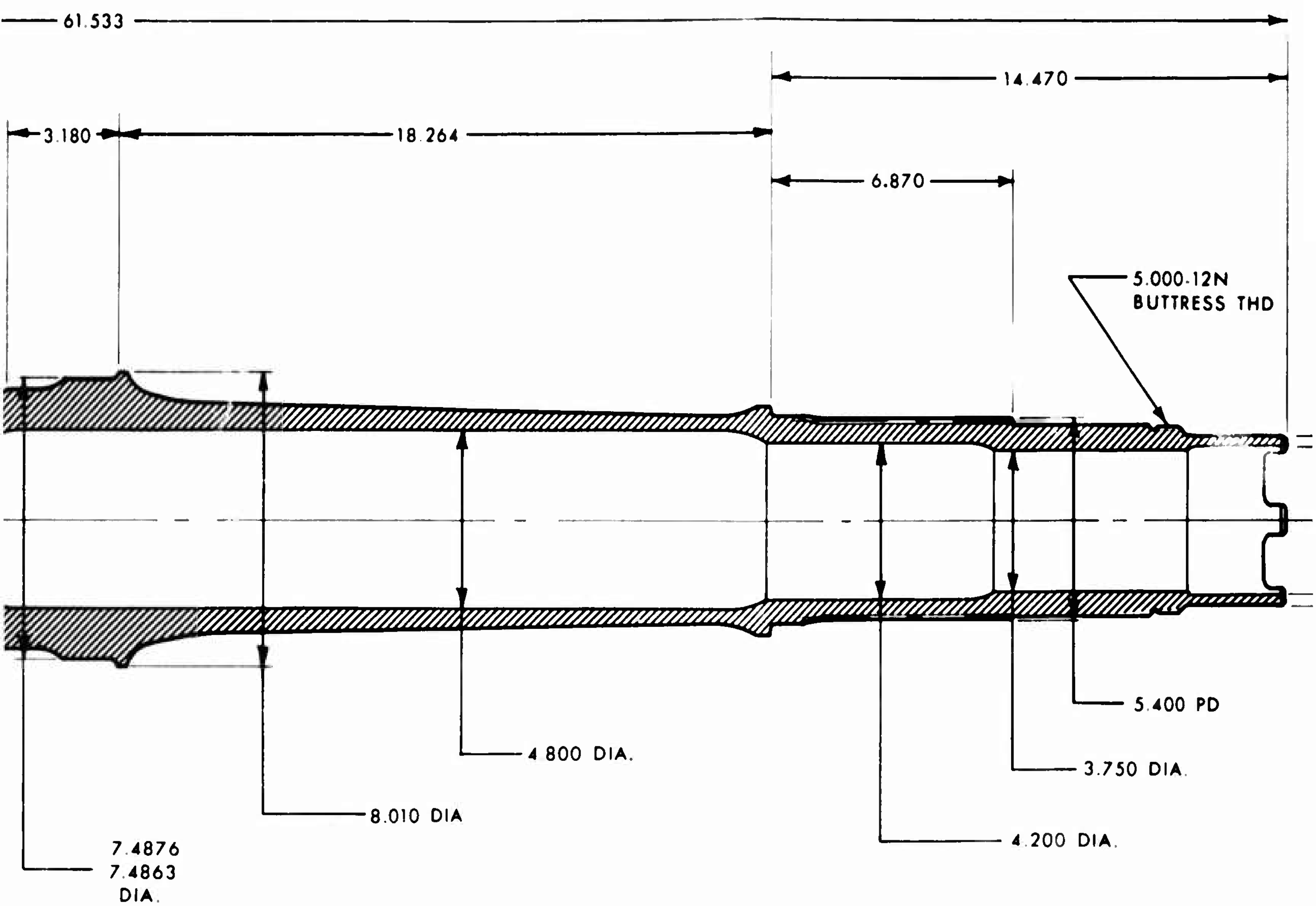
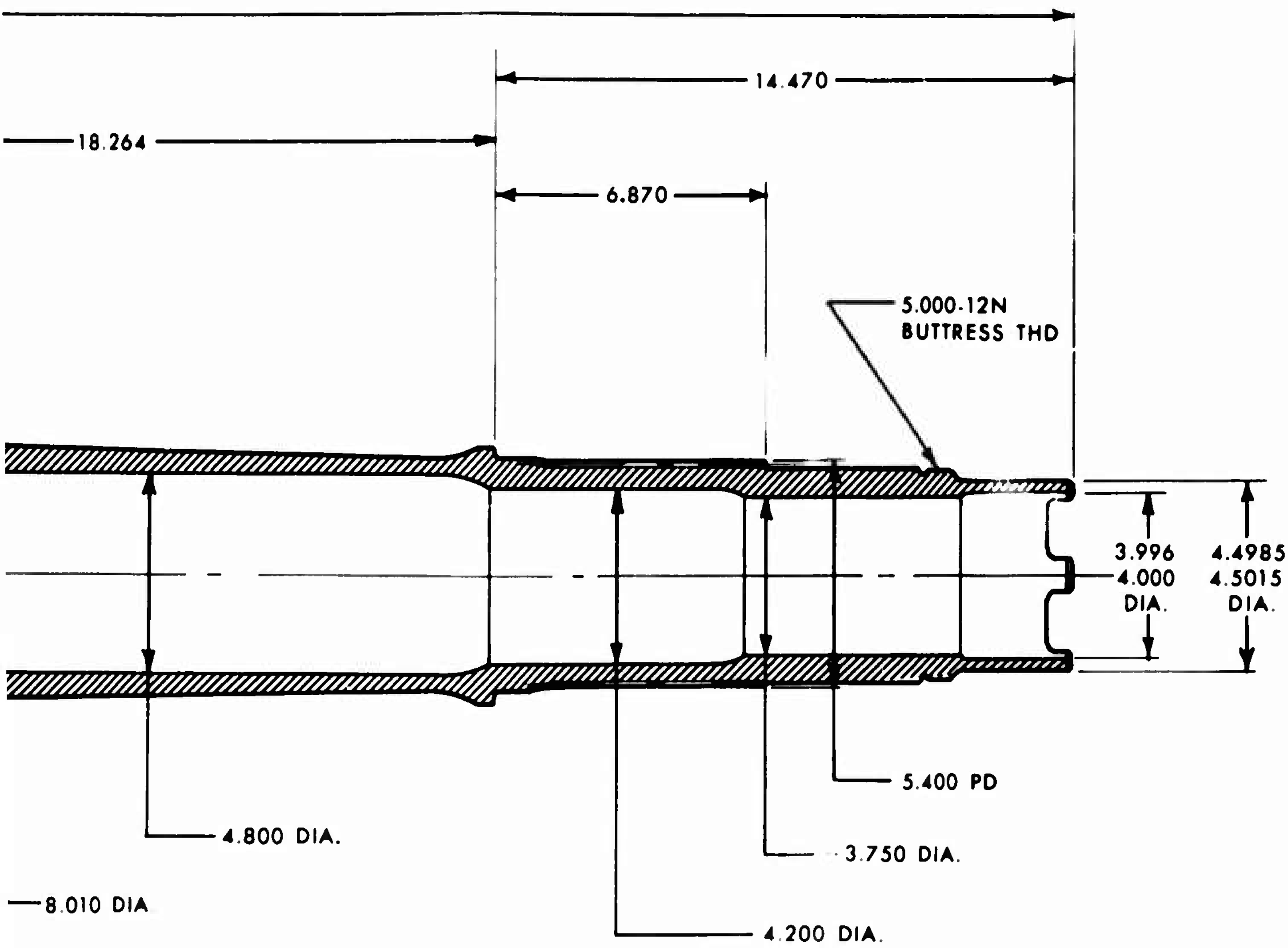


Figure 106. Main Rotor Shaft.


61.533
14.470
3.180
18.264
6.870
5.000-12N
BUTTRESS THD
5.400 PD
4.800 DIA.
3.750 DIA.
8.010 DIA
4.200 DIA.
7.4876
7.4863
DIA.



14.470
18.264
6.870
5.000-12N
BUTTRESS THD
3.996
4.000
DIA.
4.4985
4.5015
DIA.
5.400 PD
4.800 DIA.
3.750 DIA.
8.010 DIA
4.200 DIA.

CONCLUSIONS

1. Integrity of the electron beam welds, particularly in certain highly stressed ducting, was by far the most serious problem in the manufacture of the roller gear transmission.

2. While magnetic particle and X-ray inspection techniques proved ineffective in the detection of electron beam weld flaws, ultrasonic inspection proved to be exceedingly effective in this application.

3. Indexing and concentricity tolerances were held very well during electron beam weld assembly

4. Using ZE-41 magnesium alloy as the material for the main housing worked out very well. There were no significant casting problems despite the size of the housing.

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RECOMMENDATIONS

1. A study should be conducted to determine optimum electron beam weld configurations. Improved weld joint design could facilitate manufacture and inspection while increasing component reliability.

2. Further development of both the electron beam welding process and post weld heat treatment should be carried out to improve weld integrity, i.e., eliminate voids.

3. Ultrasonic inspection should be used whenever possible in the inspection of welded joints. This method proved far superior to any other method employed in this program.

4. Additional testing of ZE41A as a material for cast housings should be performed. Experience in this program showed it to be an extremely castable material, but no tests were performed to evaluate its strength in high stress situations.

APPENDIX A

ULTRASONIC INSPECTION OF ELECTRON BEAM WELDED GEARS

SCOPE

This procedure covers the requirements for conducting ultrasonic inspection tests by the immersion method and in accordance with Reference 6 to determine the presence of internal discontinuities in the electron beam weld currently used in the manufacture of roller gear drive components.

The procedure is applicable for the following components.

(a)	RG351-11181	Second-Row Pinion Gear 4.061 dia. weld 5.755 dia. weld 6.121 dia. weld 9.031 dia. weld
(b)	RG351-11182	First-Row Pinion Gear 5.515 dia. weld 1.710/1.000 dia. butt weld
(c)	RG351-11183	Sun Gear 8.392 dia. weld

The standards for acceptance of defects detected by ultrasonic inspection shall be as specified on the drawings.

REQUIREMENTS

The equipment used shall be an automated system with C-scan capability such as Sperry SR-154 or US-454.

The electronic equipment used shall be a Sperry Reflectoscope UM721 or UM771 with a 10-N Pulser/Receiver and a Fast Transi-gate.

The search unit shall be suitable for immersion inspection.

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6. Department of Defense, MIL-I-9850B - MILITARY SPECIFICATION INSPECTION, ULTRASONIC, WROUGHT METALS, PROCESS FOR, U. S. Government Printing Office, 1970.

The search unit for the diametral welds shall be Lithium Sulfate, 0.25 inch diameter, medium focus 10 MHz, #57A-2766.

The search unit for the butt welds (RG351-11182) shall be a J type, 0.25 inch flat focus, #J385-SIJ-10 MHz.

The calibration standard shall be representative of the test sample, particularly at the entry surface with regard to curvature and surface condition.

For the diametral welds listed, the calibration standard shall be as shown in Figure 107.

The butt weld (RG351-11182) calibration standard shall be as shown in Figure 108.

CALIBRATION

The calibration standard with the curvature and entry surface condition similar to the production part being tested shall be as follows:

Calibration for the diametral welds - the amplitude of the 0.020-inch-diameter test hole shall be set at 2 inches and the gate set to alarm at 90 percent of the test hole amplitude.

Calibration for the butt weld requires two "setups":

1. To determine voids equal to or greater than the response from a 0.020-inch-diameter test hole. The amplitude of the 0.020-inch-diameter test hole shall be set at 1.8 inches and the gate set to alarm at 90 percent of the test hole amplitude.

2. To determine voids equal to or greater than the response from 0.013-inch-diameter test hole. With the amplitude of the 0.020-inch-diameter test hole set at 1.8 inches (the 0.013-inch test hole amplitude is 0.75 inch), the gate shall then be set to alarm at 90 percent of the 0.013-inch test hole amplitude.

PROCEDURE

For each different type of gear and direction of scanning the corresponding calibration standard C-scan is required.

The surface from which the test is to be performed shall be clean and free from dirt, grease and scale.

Upon the component being immersed in the tank, all air bubbles shall be removed from the surface being tested.

The search unit shall be maintained normal to the test surface, with the search unit positioned as shown in Figures 109, 110, and 111.

The weldments shall be inspected at 10 MHz.

Complete coverage of the weld area shall be accomplished by indexing after each complete scan. The transducer shall be moved in such manner that each scan overlaps the previous pass by at least 25 percent of the effective beam diameter.

The start position of scanning shall be indicated on the C-scan and marked on the gear with the direction of rotation.

A C-scan recording shall be made each time the calibration standard is run.

The production parts shall be run under the same conditions as the calibration standard, and a C-scan shall be made for each weld.

The C-scan shall be positively identified with the serial number of the production part for the appropriate weld.

All C-scans of the butt weld RG351011182 shall be of a scale equal to twice the actual weld diameter (i.e., the C-scan weld outside diameter shall be 3.4 inches).

All C-scans of the diametral welds shall be recorded on an 8-inch-diameter drum.

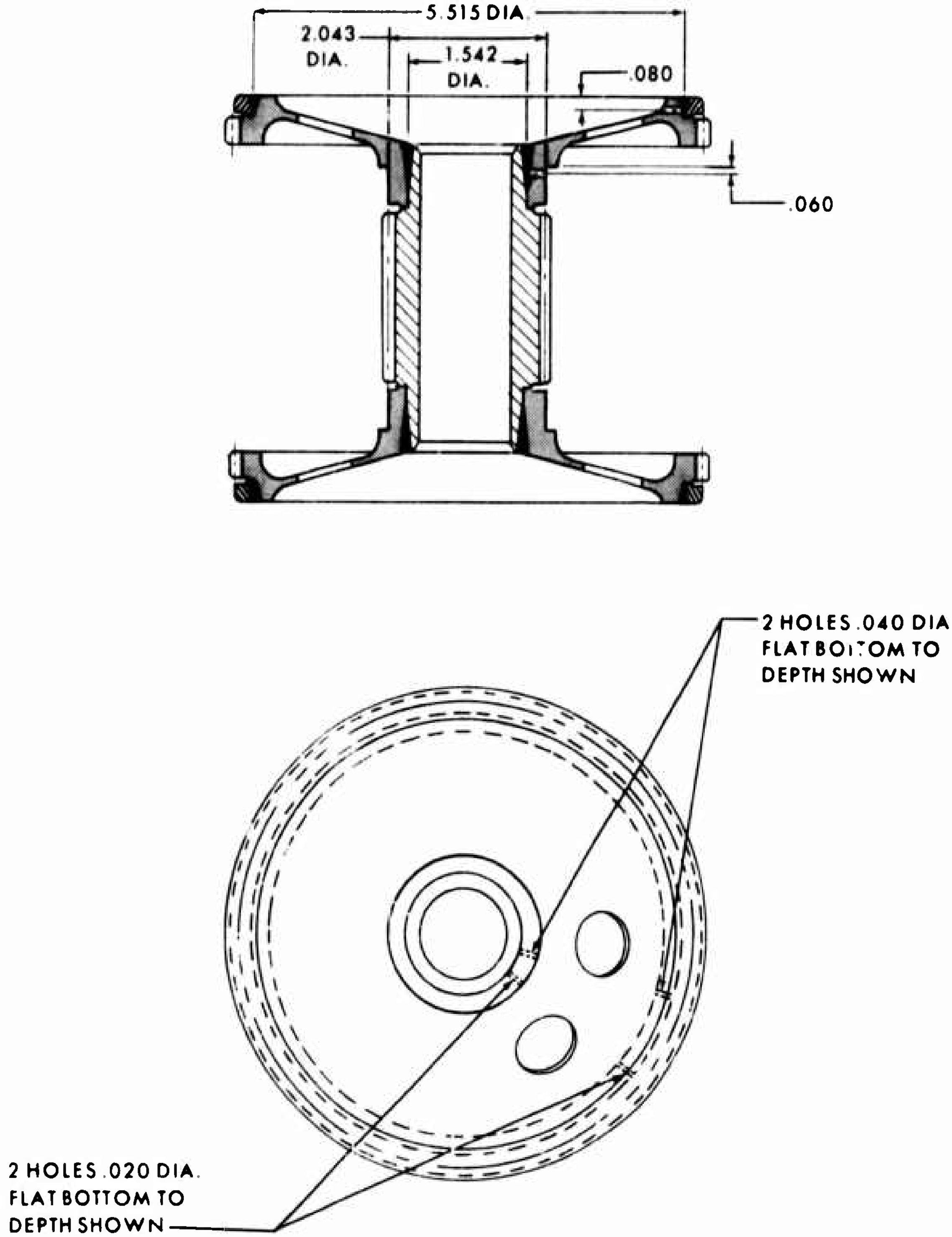


Figure A-1. Calibration Standard, Diametral Weld.

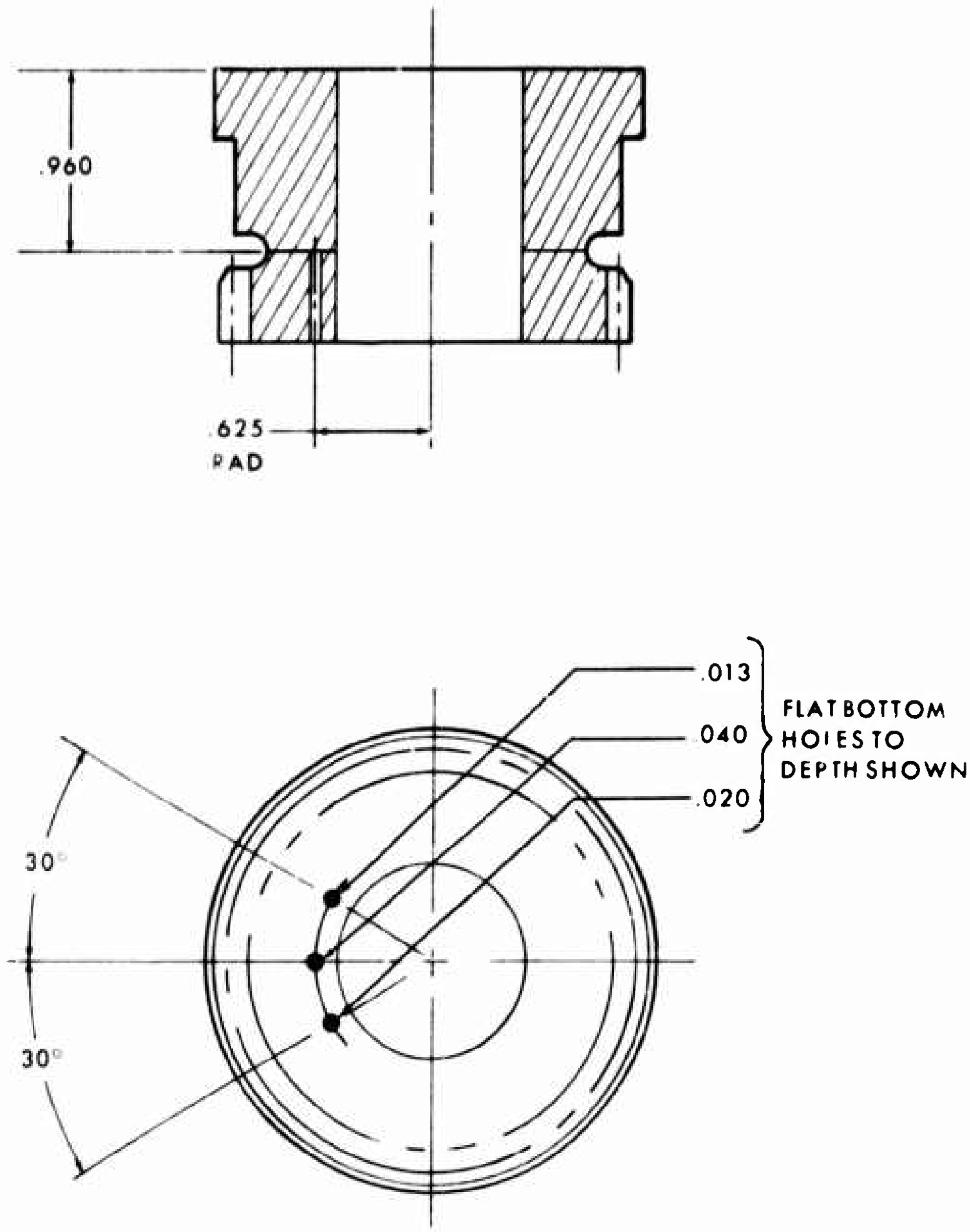


Figure A-2. Calibration Standard, Butt Weld.

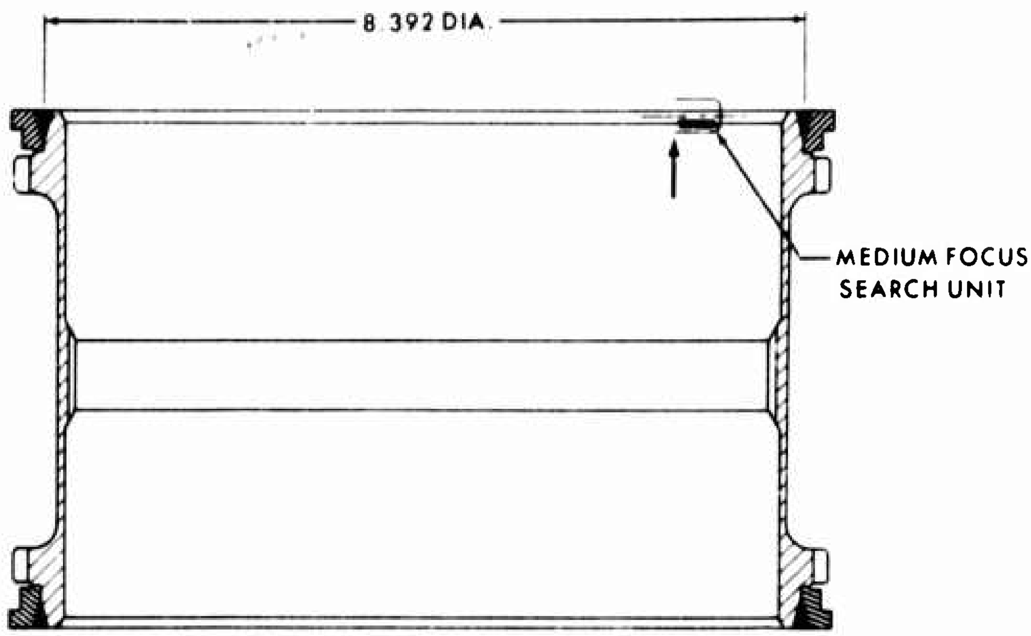


Figure A-3. Ultrasonic Inspection, Sun Gear.

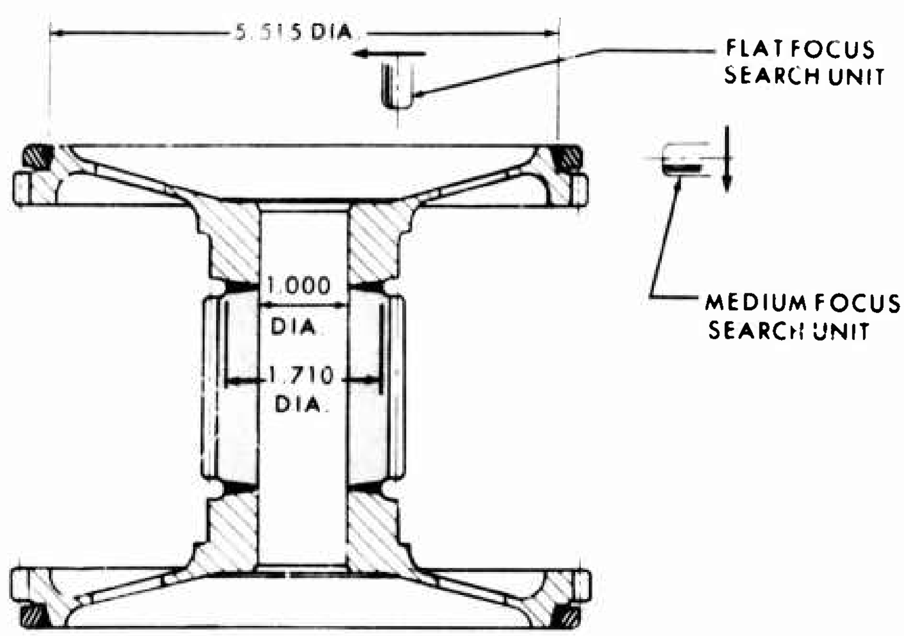
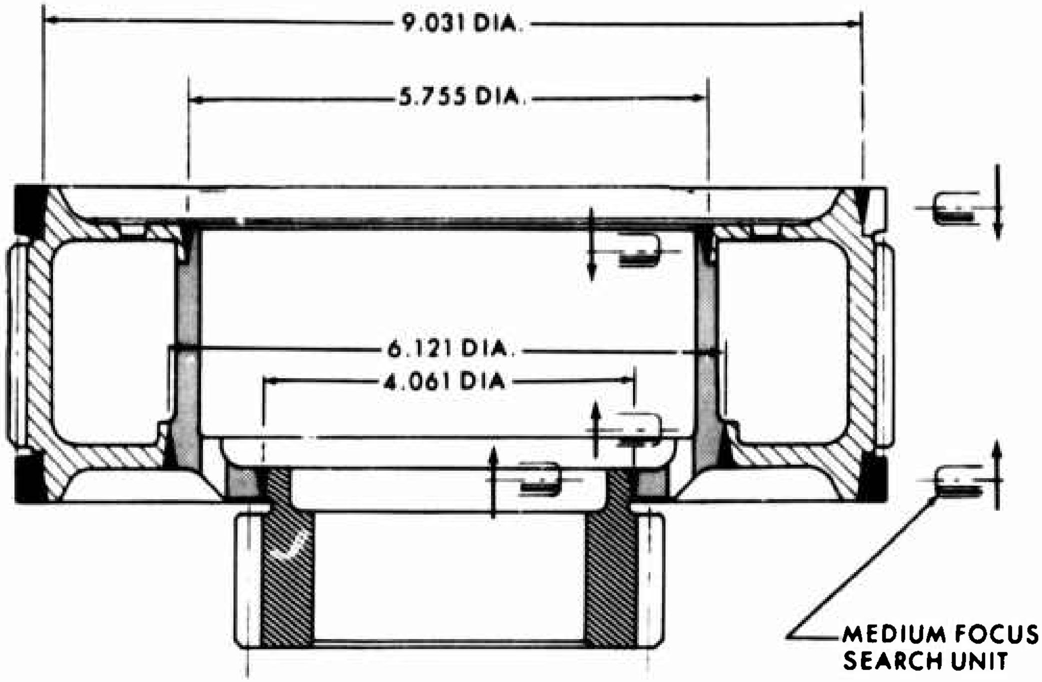


Figure A-4. Ultrasonic Inspection, First-Row Pinion.



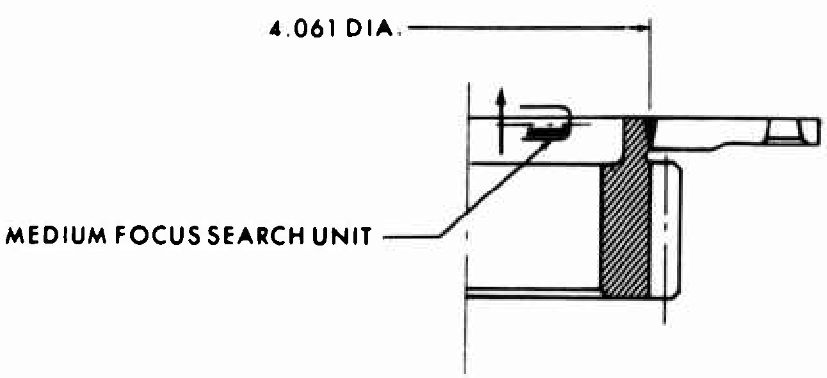


Figure A-5. Ultrasonic Inspection, Second-Row Pinion.

APPENDIX B

COMPONENT LOCATIONS

This appendix is presented as an aid to the reader. Table B-1 in combination with Figure B-1 shows the location of the major components of the roller gear transmission.

TABLE D-1. MAJOR ROLLER GEAR TRANSMISSION COMPONENTS

Nomenclature	Item Number*	Quantity Per Gearbox
Main Hsg. & Liner Ass'y	1	1
Cover & Liner Ass'y	2	1
Rear Cover & Liner	3	1
Housing & Liner Ass'y	4	2
Input Bevel Pinion	5	2
Input Coupling	6	2
Housing & Liner Ass'y, Input	7	2
Input Bevel Gear	8	2
Input Spur Gear	9	2
Freewheel Unit	10	2
Housing & Liner Ass'y, Outer Shaft	11	1
Shaft, Outer	12	1
Spur Gear Input	13	1
Bevel Gear T. T. O.	14	1
Quill - Input Sun	15	1
Main Rotor Shaft	16	1
Lower Housing Assembly	17	1
Sump & Stud Assembly	18	1
Gear-Lub Pump Sump	19	1
Plate - Assembly Upper, Lower	20	1
Shaft - 2nd Row	21	7
Pinion Ass'y - 2nd Row	22	7
Pinion Ass'y - 1st Row	23	7

TABLE B-1. Continued		
Nomenclature	Item Number*	Quantity Per Gearbox
Sun Gear	24	1
Ring Gear Set	25	1
Output Flange	26	1
Spline - Plate	27	1
Gear, Oil Pump Drive Sump	28	1
Housing & Liner Ass'y T. T. O.	29	1
Gear Bevel Pinion T. T. O.	30	1
Quill T. T. O.	31	1
Gear Sput T. T. O.	32	1
Gear Sput T. T. O.	33	1
Quill T. T. O.	34	1
Gear Generator	35	1
Housing Ass'y, Adaptor Box	36	1
Cover Ass'y Box	37	1
Spur - Input	38	1
Spur Output	39	1
Flange T. T. O.	40	1
Coupling T. T. O.	41	1

*Item numbers refer to Figure B-1.

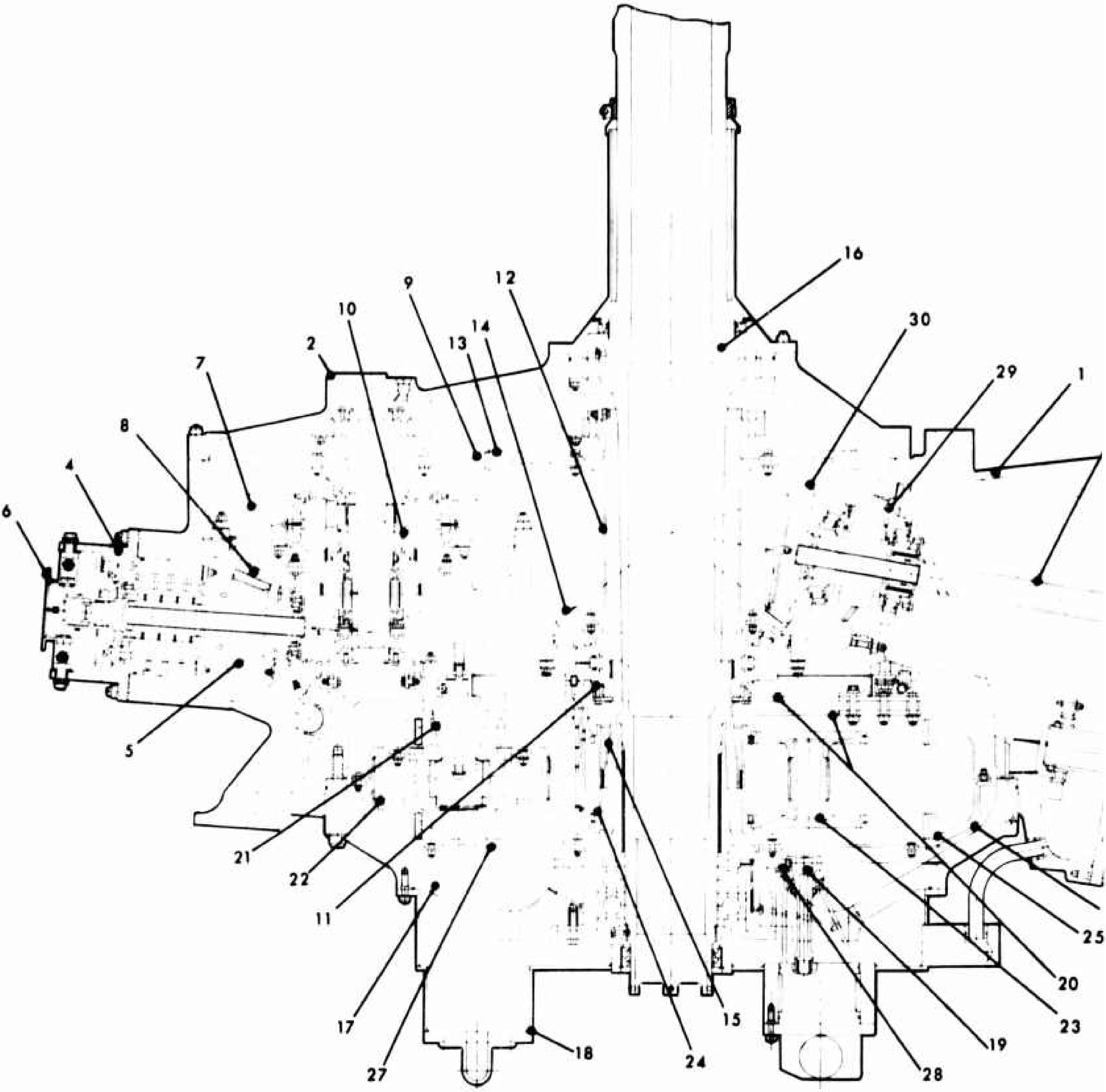
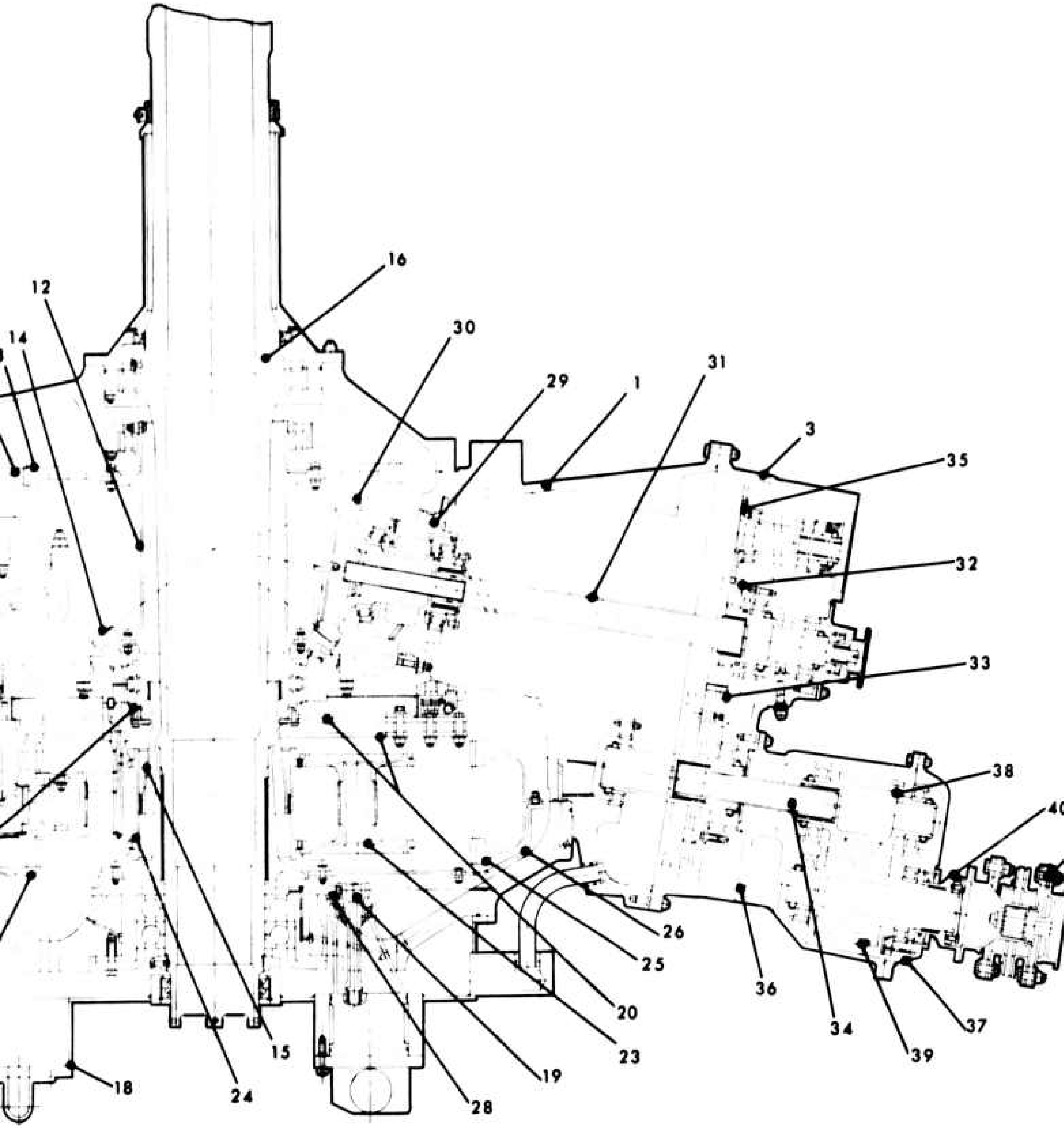


Figure B-1. Major Component Locations,
Roller Gear Transmission.



nt Locations,
ransmission.

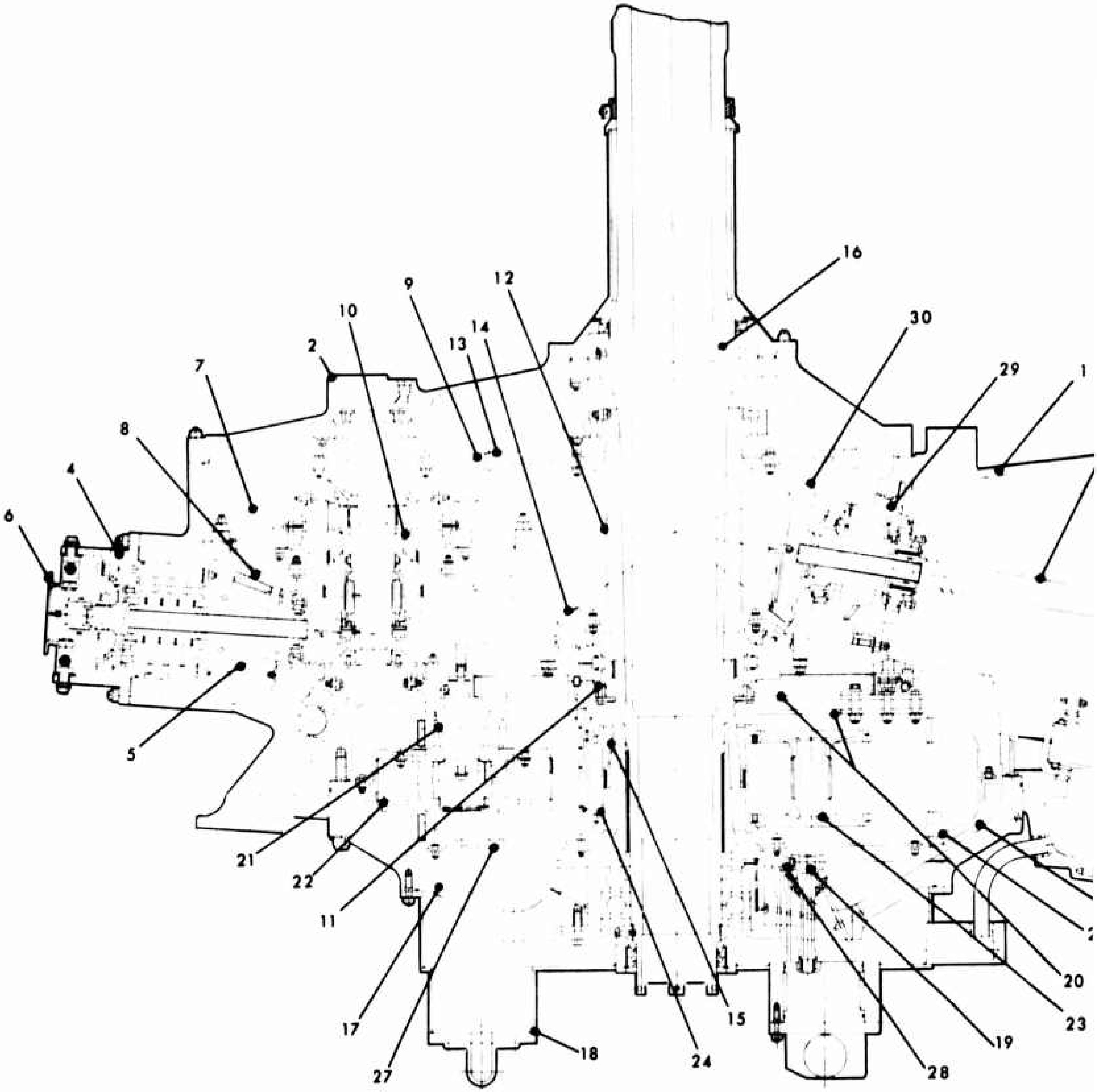
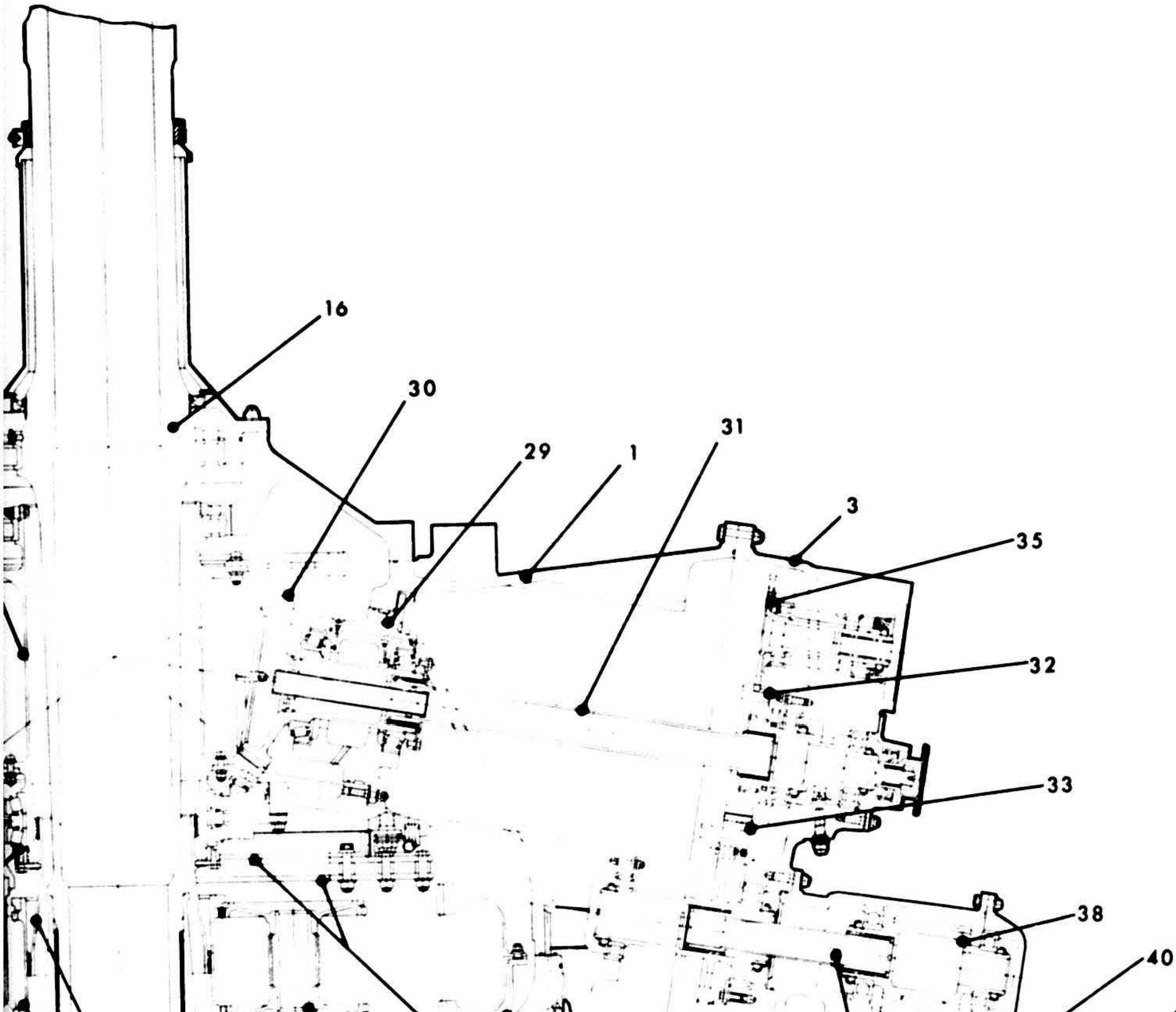


Figure B-1. Major Component Locations, Roller Gear Transmission.



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on.

APPENDIX C

MANUFACTURING PROCEDURE, SECOND-ROW PINION RG351-11181

Presented in this appendix are the step-by-step operating procedures used in the fabrication of the second-row pinion, RG351-11181.

Figure C-1 illustrates the various parts which make up the second-row pinion assembly, and Figure C-2 depicts the production subassemblies which combine to complete the fabrication of the RG351-11181 second-row pinion assembly. The detail drawing is shown at the end of this appendix, Figure C-11.

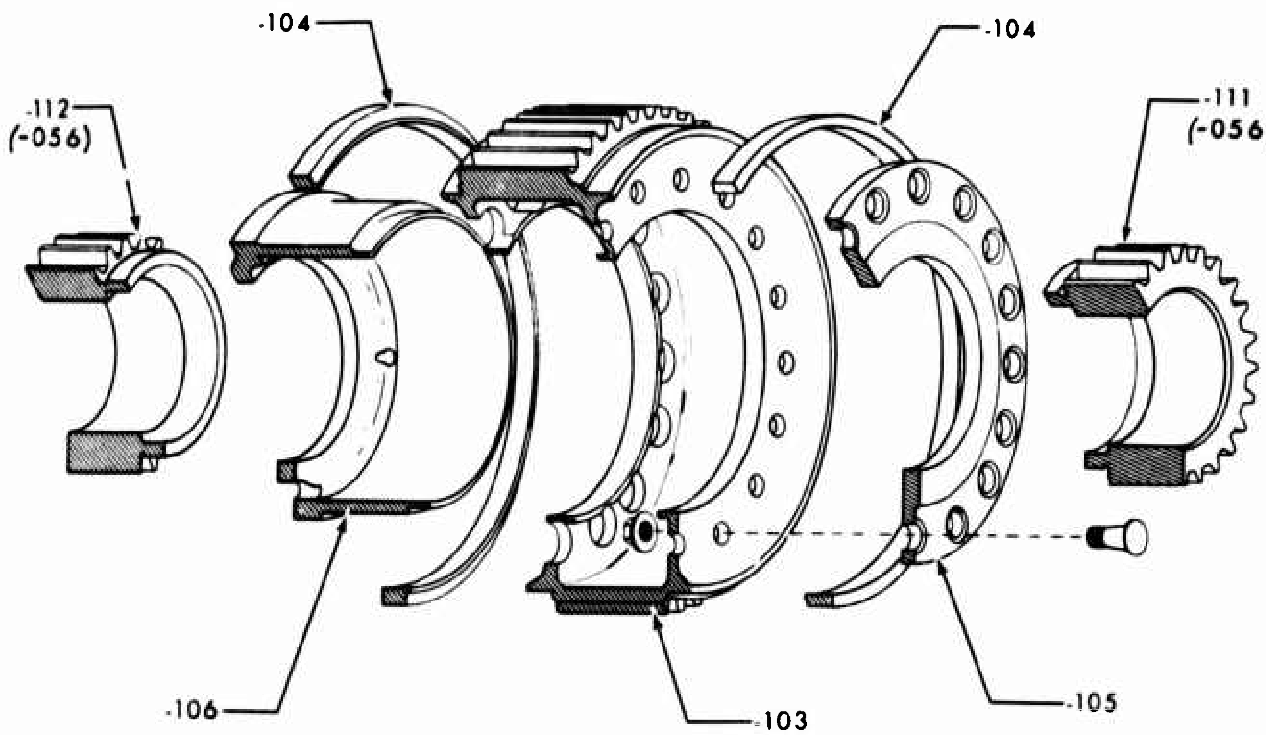

Figure C-1. Second-Row Pinion, Exploded View.

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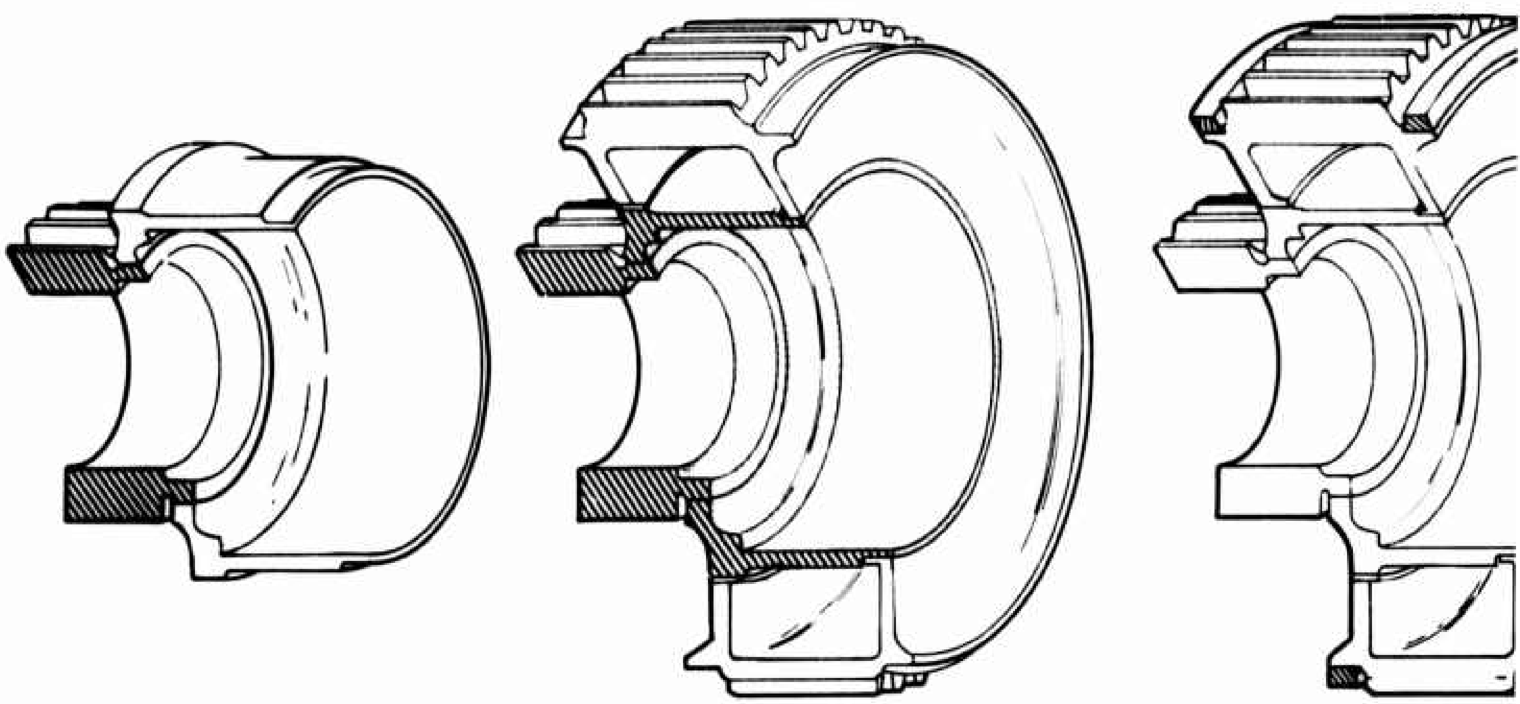

Figure C-2. Second-Row Pinion, Subassemblies.

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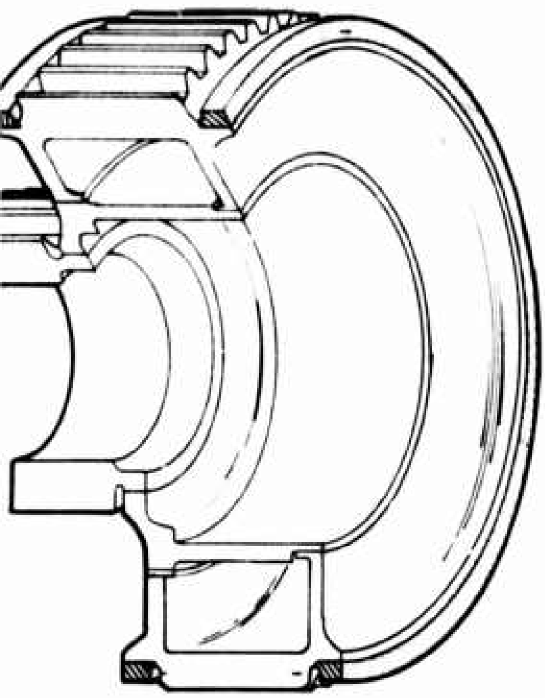
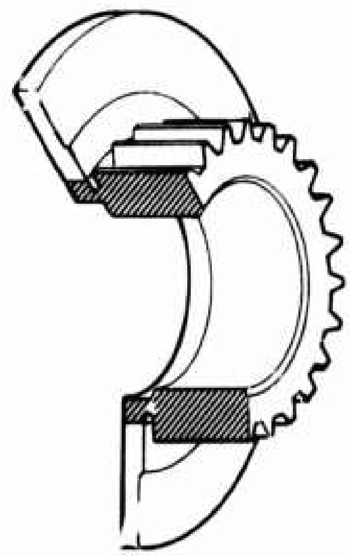
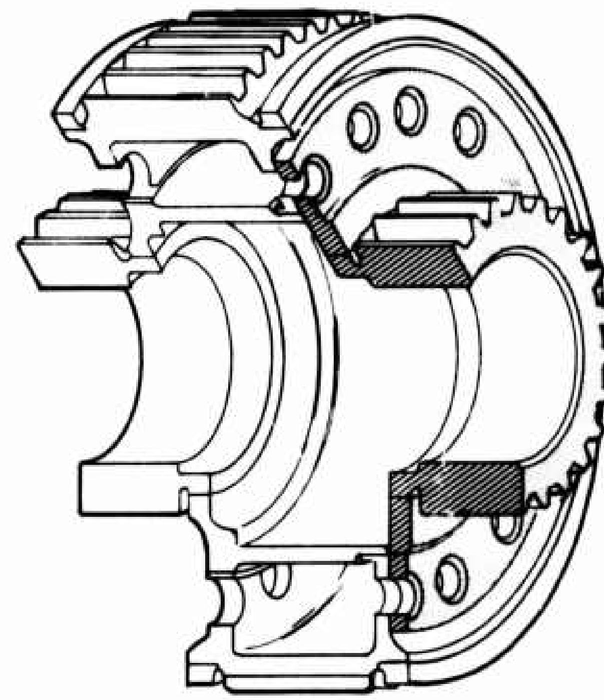


-053



-057



-051

Large Diameter Gear RG351-11181-103

The large diameter gear teeth are machined but not finish ground until this gear is welded to the small gear assembly. The large diameter gear teeth are then finish ground with relationship to the small gear teeth.

Material:	AMS 6265 - 9310 Steel
Type:	Ring Forging

Opr. No.	Description
10	Blank per operation drawing
20	Blank per operation drawing
30	Heat treat for machining
40	Draw to Rc 25-30
50	Blank per operation drawing
60	Blank per operation drawing
70	Magnaflux
80	Surface grind one side to 3.359"/3.357" OAL
90	Surface grind opposite side to 3.353"/3.351" OAL
100	Grind I.D. to 5.625"/5.626" diameter
110	On mag chuck, grind gear O.D. to 9.705"/9.703" diameter - concentric to I.D. within .001" TIR
120	Hob gear, pregrind
130	Deburr
140	Mask gear
150	Copper plate
160	Clean up
170	Carburize to produce .010"/.025" depth of case in finished part (.006" stock)
180	Strip copper

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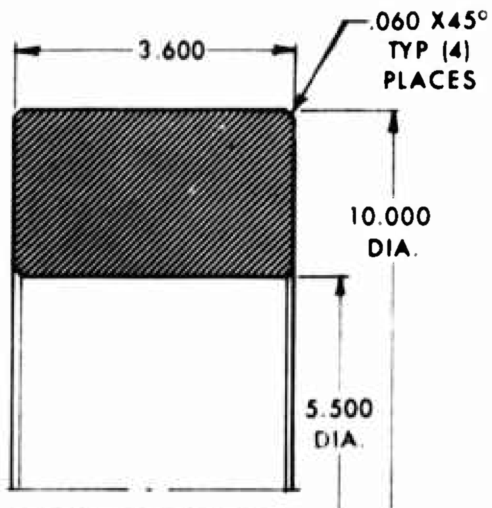
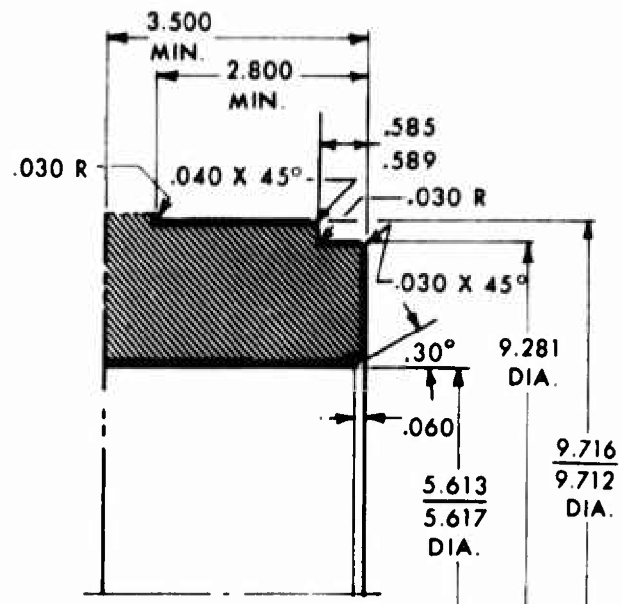
Opr. No.	Description
190	Not used
200	Not used
210	Oxide blast
220	Copper plate all over
230	Harden and quench
240	Freeze
250	Draw to Rc 58-64 case and Rc 30-45 core hardness
260	Strip copper
270	Inspect heat treatment operations and record
280	Surface grind one side to 3.345"/3.343" OAL
290	Surface grind opposite side to 3.337"/3.335" OAL
300	Turn and bore per operation drawing
310	Turn per operation drawing
320	Turn per operation drawing
325	Turn per operation drawing
330	Finish grind I.D. per operation drawing
340	Not used
350	Finish grind I.D. per operation drawing
360	Finish grind O.D. per operation drawing
370	Finish grind O.D. per operation drawing
375	Surface grind gear O.D. to 9.697"/9.695" diameter
380	Nital etch - Note: Gear is not finish ground
390	Deburr - Note: Break edge .005"/.015" radius except outer edges of bores to be .005 maximum - gear teeth are not finished - do not break edges.

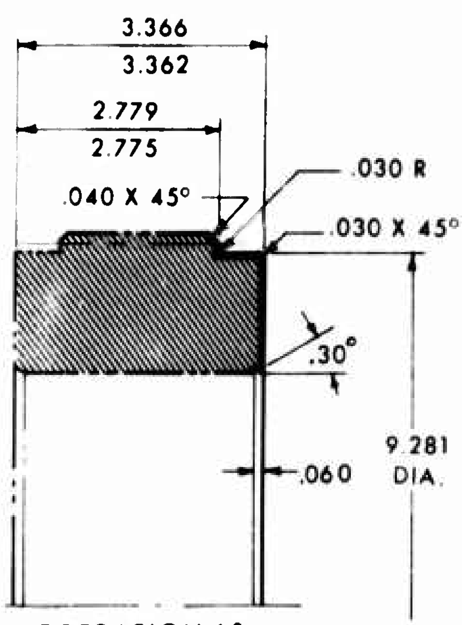
Opr. No.	Description
400	Polish
410	Buff
420	Clean
430	Magnaflux
440	Inspect - Note: Gear O.D. and gear teeth are not finish ground at this time; will be finished under RG351-11181-054 assembly.
450	Visually inspect and identify



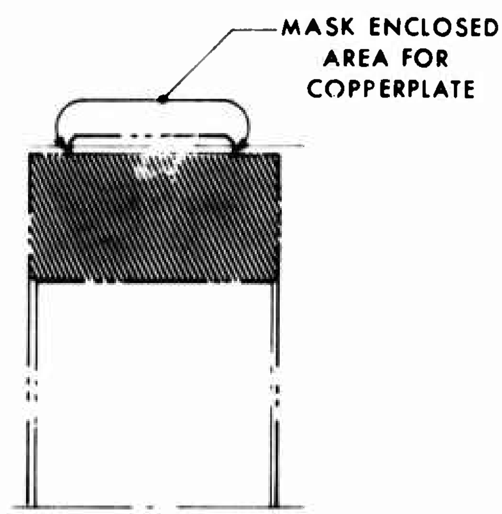
OPERATION 10& 20



OPERATION 50



OPERATION 60



OPERATION 140

Figure C-3. RG351-11181-103 Machine Operation Drawings (Sheet 1 of 3).

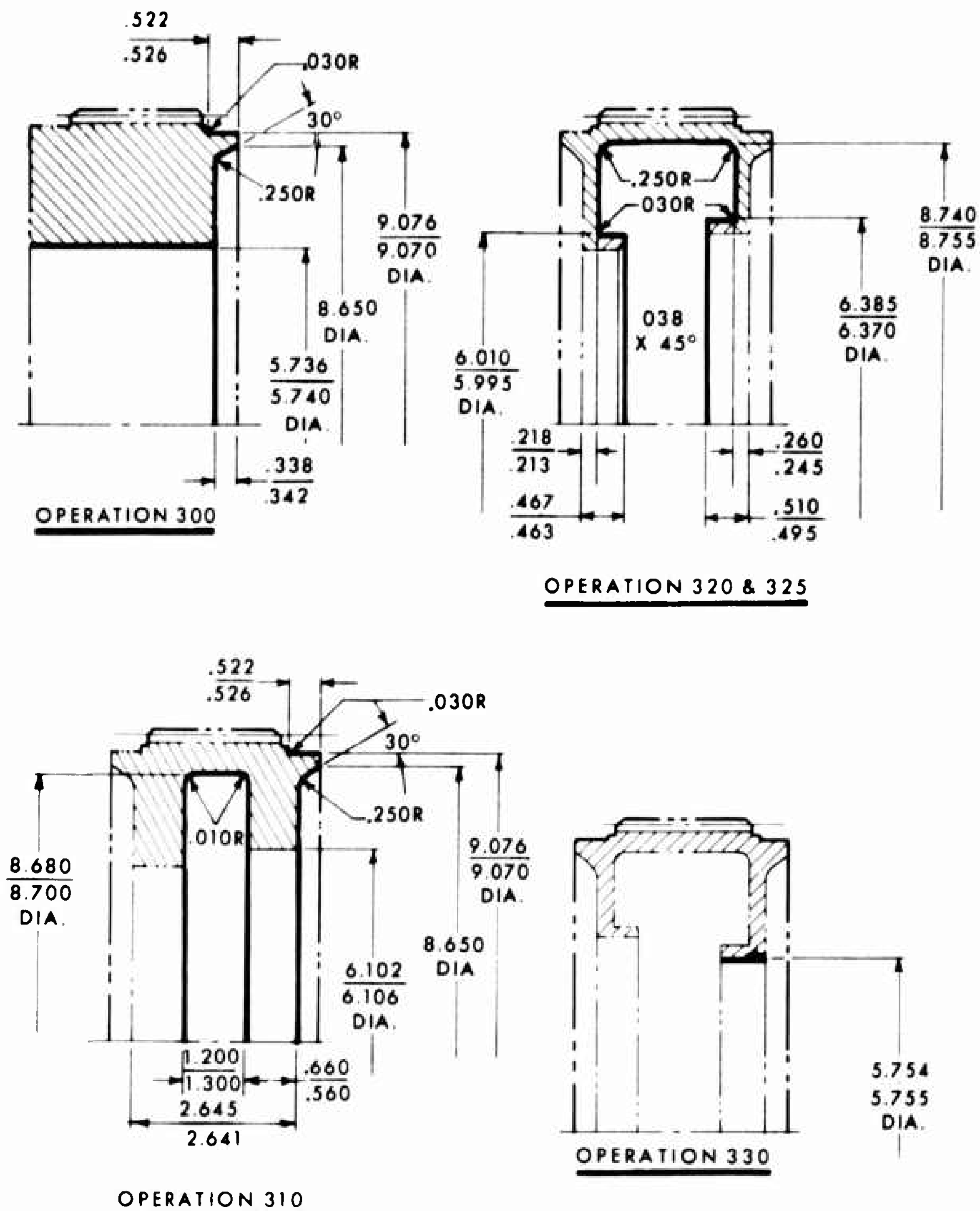
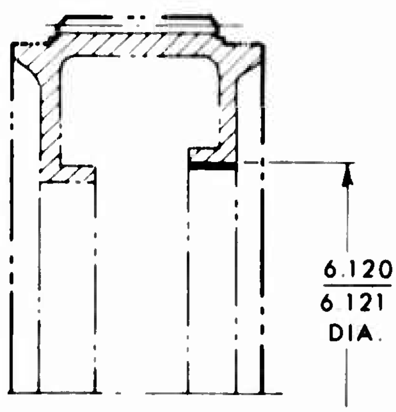
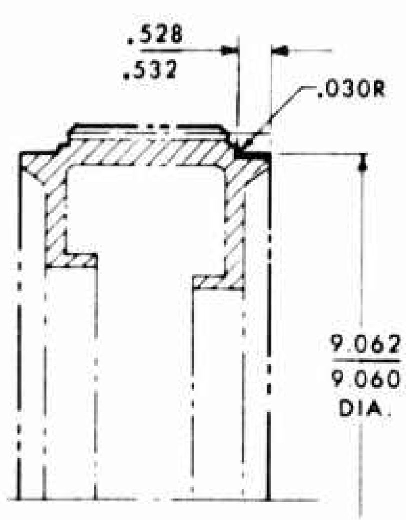


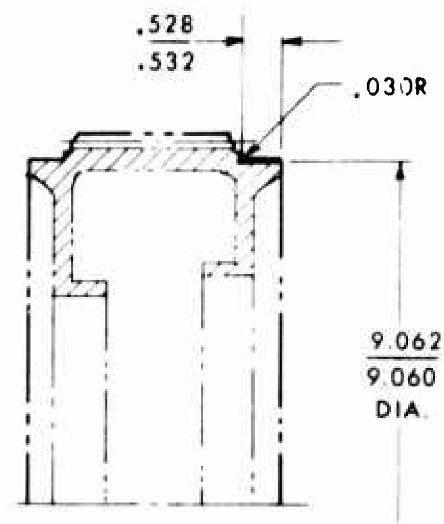
Figure C-3. RG351-11181-103 Machine Operation Drawings (Sheet 2 of 3).



OPERATION 350



OPERATION 360



OPERATION 370

Figure C-3. RG351-11181-103 Machine Operation Drawings (Sheet 3 of 3).

Rollers RG351-11181-104

Two identical rollers are used on each second-row gear assembly. They are machined from a roller-ring forging.

Material: AMS 6265 - 9310 Steel
Type: Multi-Ring Forging

Opr. No.	Description
10	Machine per operation drawing
20	Heat treat for machining
30	Draw to Rc 25-30
40	Machine per operation drawing
50	Face flat side to .557"/.553" OAL and chamfer I.D. to .030" x 45°
60	Deburr
70	Magnaflux
80	Mask
90	Copper plate
100	Clean up
110	Carburize to produce .045"/.060" depth of case in finished part (.008" grind stock)
120	Strip copper
130	Oxide blast
140	Copper plate all over
150	Harden and quench (flat plates)
160	Freeze
170	Draw to Rc 58-64 case and Rc 30-45 core hardness
180	Strip copper
190	Inspect heat treatment operations and record

Opr. No.	Description
200	Bore per operation drawing
210	Lay on flat side - Surface grind chamfered side to .550"/.548" OAL
220	Surface grind flat side to .544"/.542" OAL - parallel to opposite side within .001" TIR
230	Finish grind I.D. to 9.029"/9.030" diameter
240	Finish grind O.D. to 9.556"/9.554" diameter - concentric to diameter "B" (I.D.) within .001" TIR
250	Nital etch
260	Stress relieve
270	Burr - break edges .005"/.015" radius except edge of 9.030" bore to be .005" maximum
280	Clean
290	Magnaflux
300	Inspect
310	Visually inspect and identify

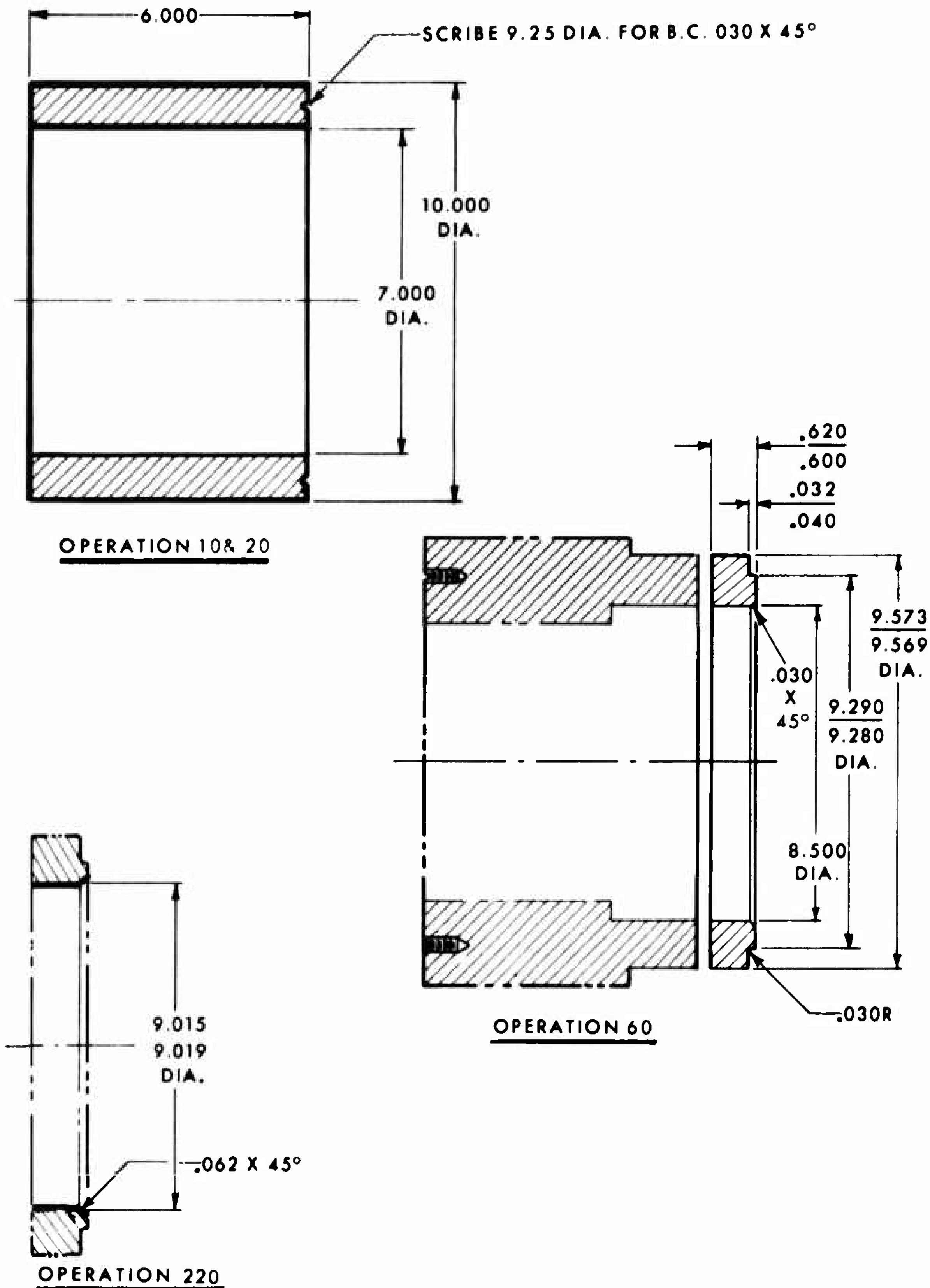


Figure C-4. RG351-11181-104 Machine Operation Drawing.

Flange RG351-11181-105

A single flange is machined from a rolled ring forging which is then welded to a small diameter gear to form a gear/flange assembly.

Material: AMS 6265 - 9310 Steel
Type: Multi-Ring Forging

Opr. No.	Description
10	Blank and cut off per operation drawing
20	Harden
30	Draw to Rc 30-45 core hardness - Note this is finish heat treatment hardness (Reference 300°F)
40	Machine per operation drawing
50	Machine per operation drawing
60	Magnaflux
70	Lay on flat side - surface grind to .320"/.318" OAL
80	Lay on hub side - surface grind to .315"/.311" OAL parallel to opposite side within .001" TIR
90	Finish grind I.D. to 4.060"/4.061" diameter
100	Nital etch
105	Stress relieve
110	Deburr - break edges .005"/.015" radius except edge of bore to be .005" maximum
120	Polish
130	Clean
140	Magnaflux
150	Inspect
160	Visually inspect and identify

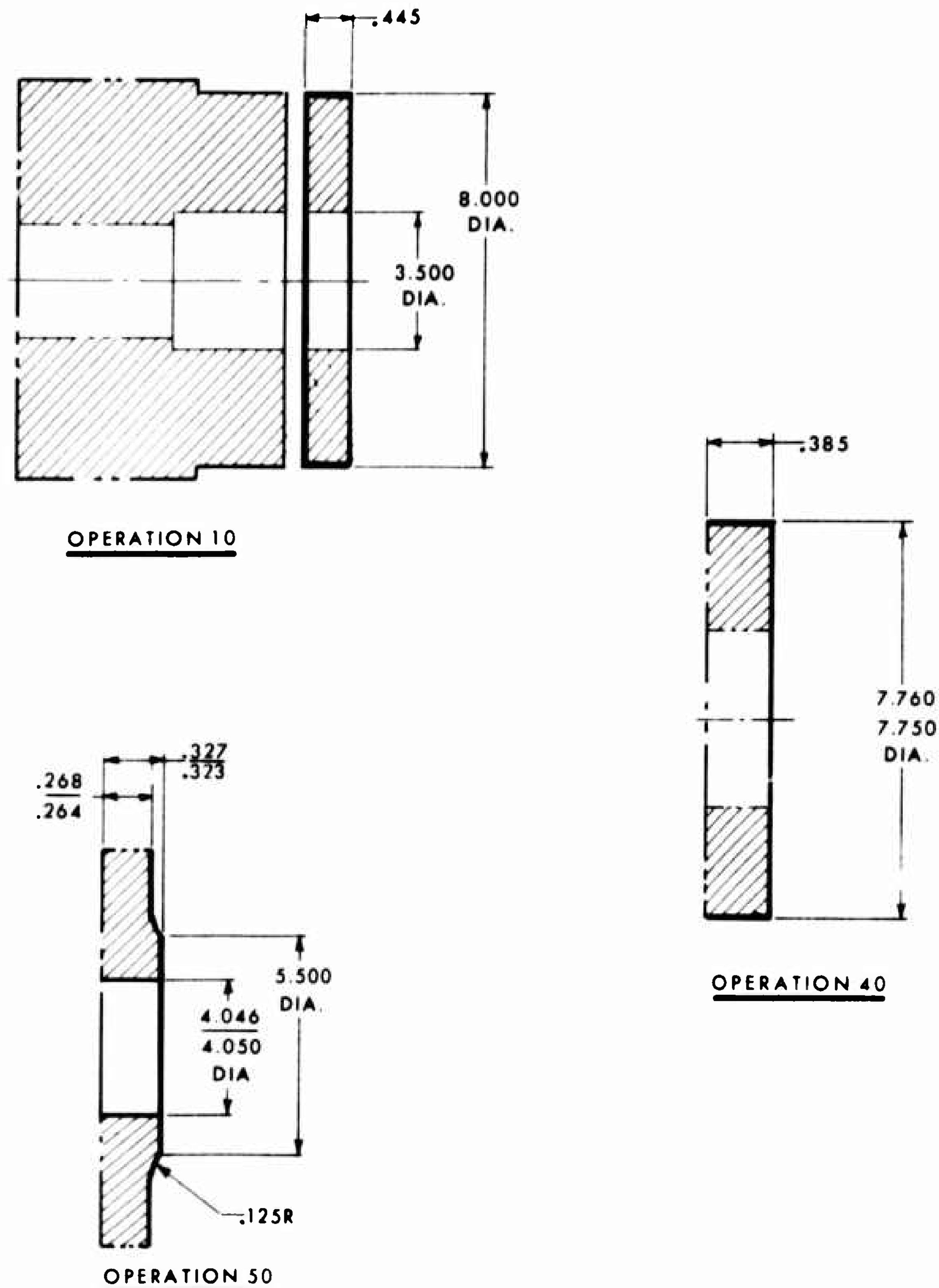


Figure C-5. RG351-11181-105 Machine Operation Drawing.

Shaft RG351-11181-106

The shaft in the central member on which the gears are Electron Beam welded.

Material: AMS 6265 - 9310 Steel
Type: Forging

Opr. No.	Description
10	Not used
20	Not used
30	Heat treat for machining
40	Draw to Rc 25-30
50	Machine per operation drawing
60	Machine per operation drawing
70	Deburr
80	Magnaflux
90	Mask per operation drawing
100	Copper plate
110	Clean up
120	Carburize to produce .025"/.040" depth of case in finished part (.008" grind stock)
130	Anneal
140	Strip copper
150	Drill four .285"/.280" diameter holes equally spaced on 5.156" dia. basic B.C.; true position with diameter "A" within .006" diameter
160	Deburr holes
170	Oxide blast
180	Copper plate all over
190	Harden and quench

Opr. No.	Description
200	Freeze
210	Draw to Rc 58-64 case and Rc 30-45 core hardness
220	Strip copper
230	Inspect heat treatment operations and record
240	Machine per operation drawing
250	Machine per operation drawing
260	Surface grind closed end to 2.962"/2.960" OAL
270	Surface grind open end to 2.954"/2.952" OAL parallel to opposite side within .0005" TIR
280	On mag chuck, finish grind 4.060"/4.061" diameter
290	Finish grind I.D. per operation drawing
300	Finish grind per operation drawing
310	Surface grind O.D.
320	Surface grind O.D.
330	Finish grind face
340	Nital etch
350	Stress relieve
360	Deburr .005"/.015" radius except edge of 4.060" bore to be .005" maximum
370	Polish
380	Clean
390	Magnaflux
400	Inspect - Note: 5.756"/5.755" diameter, 6.122"/6.121" diameter, and .467"/.463" diameter have grind stock left; to finish in -045 assembly
410	Visually inspect and identify

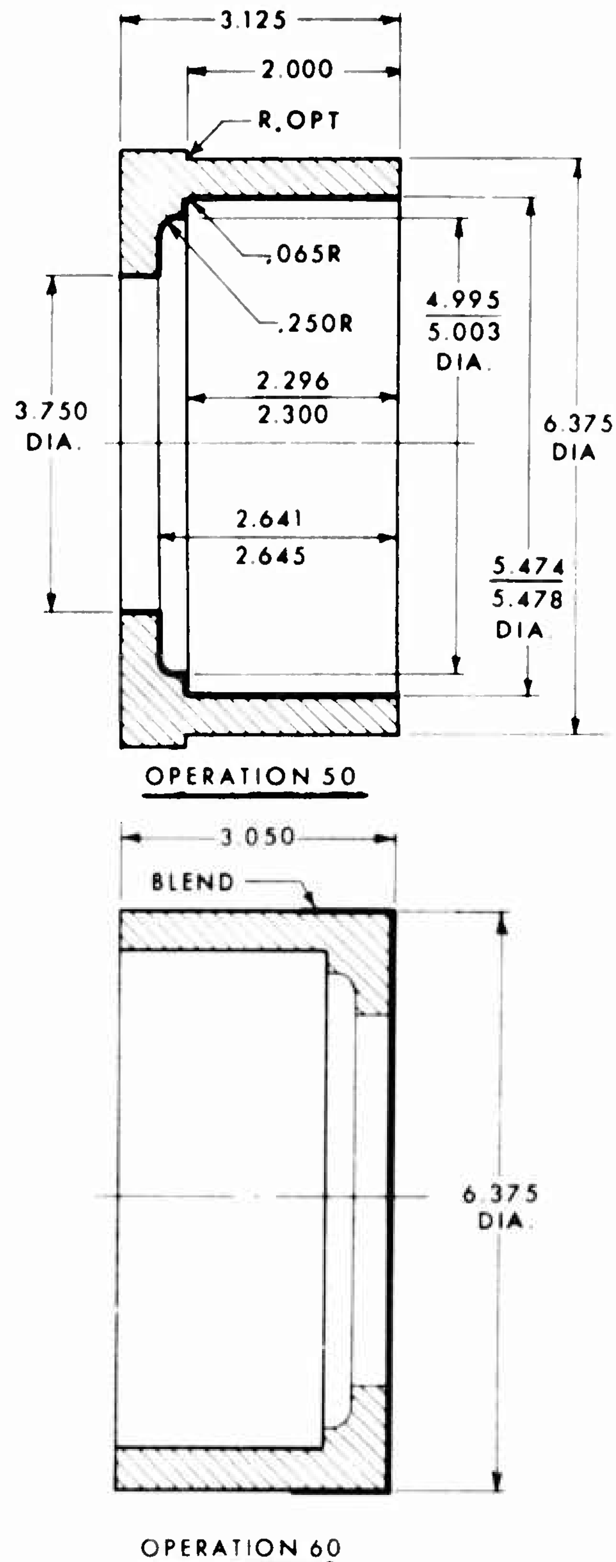


Figure C-6. RG351-11181-106 Machine Operation Drawings (Sheet 1 of 3).

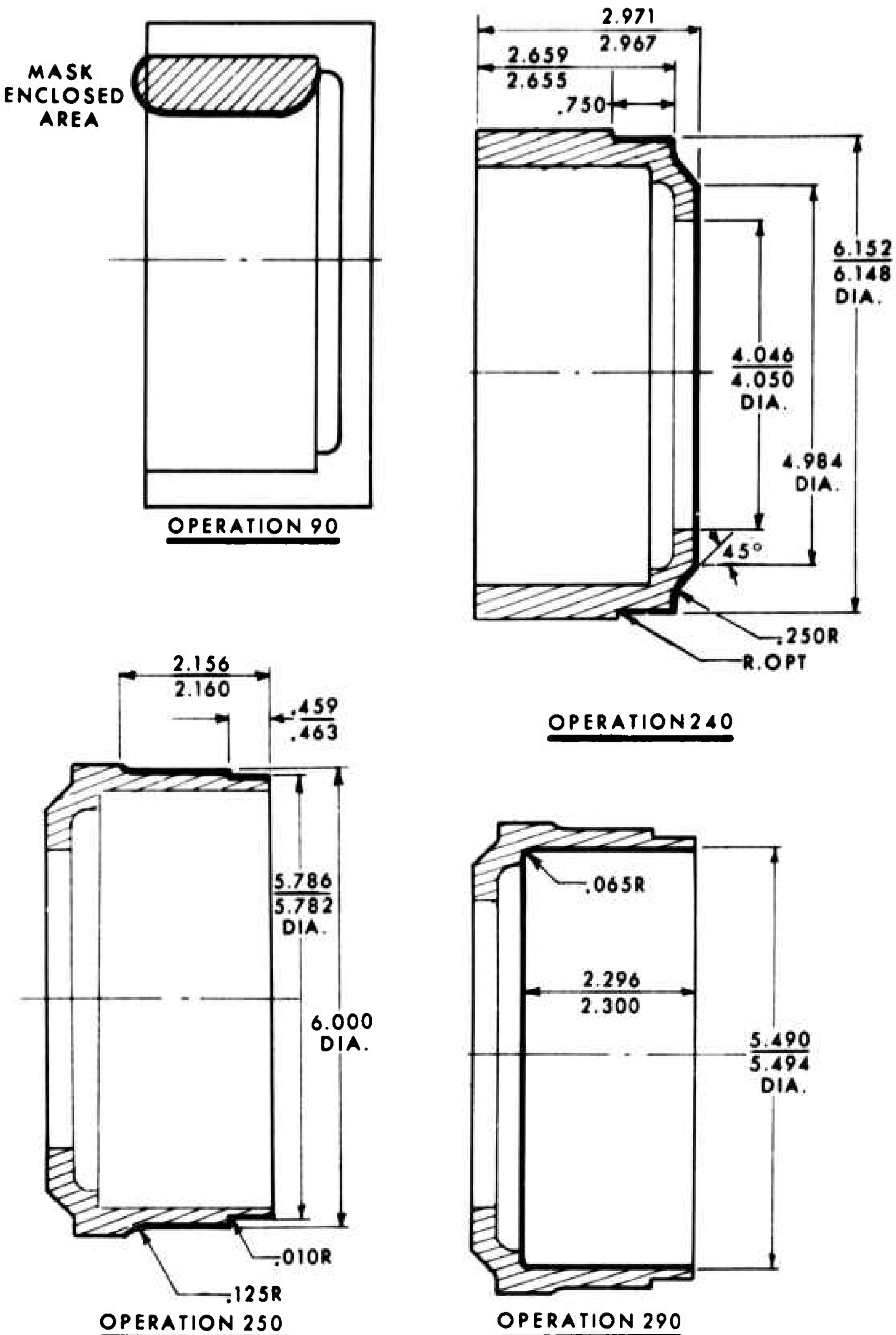
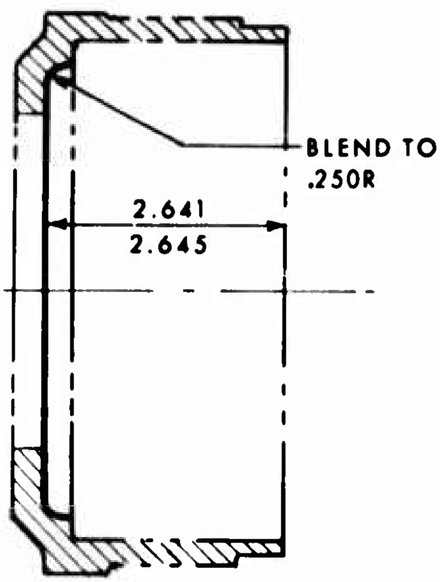
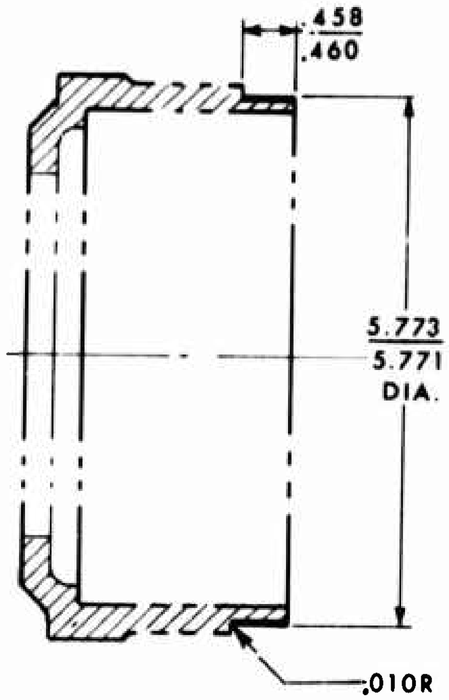


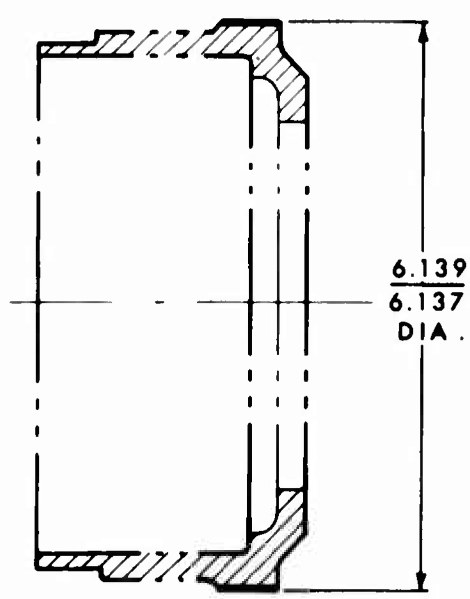
Figure C-6. RG351-11181-106 Machine Operation Drawings (Sheet 2 of 3).



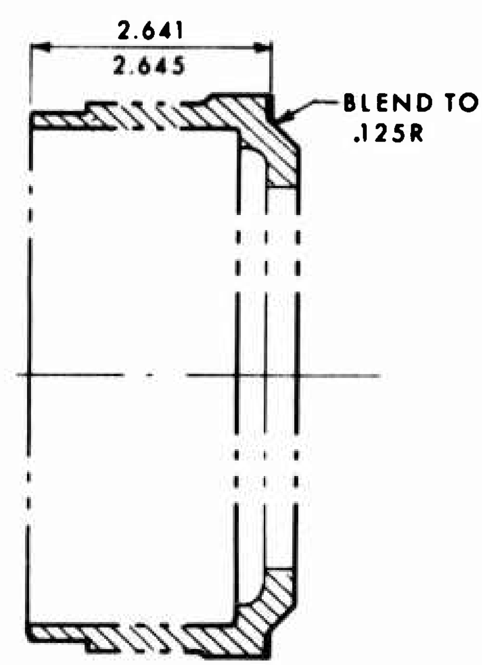
OPERATION 300



OPERATION 310



OPERATION 320



OPERATION 330

Figure C-6. RG351-11181-106 Machine Operation Drawings (Sheet 3 of 3).

Small Diameter Gears RG351-11181-111 and -112

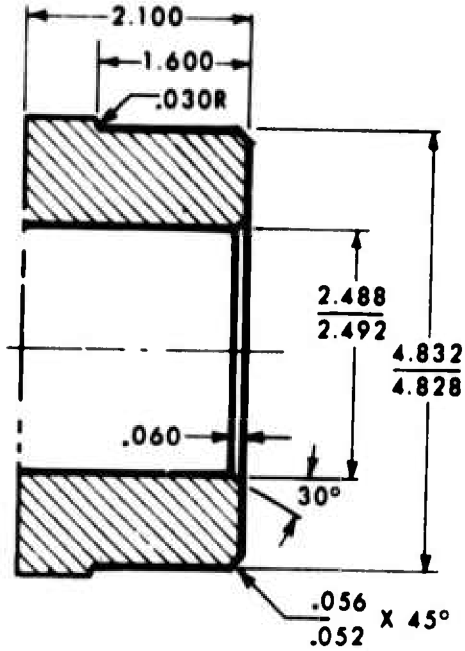
The small diameter gears are manufactured in matched sets whereby the gears are finished ground back-to-back in order to ensure identical concentricity and tooth-to-tooth spacing errors. The gears are identified by numbers RG351-11181-111 and RG351-11181-112.

Material: AMS 6265 - 9310 Steel
Type: 5-1/2" diameter X 2-1/4" overall length bar

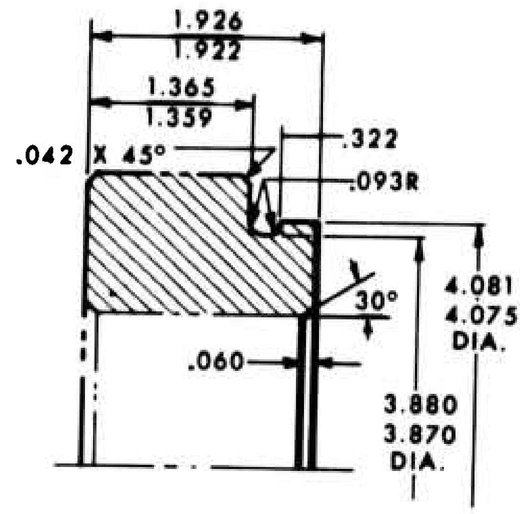
Opr. No.	Description
10	Heat treat for machinability
20	Draw to Rc 25-30
30	Machine per operation drawing
40	Machine per operation drawing
50	Magnaflux
60	Surface grind small hub end to 1.919"/1.917" OAL
70	Surface grind opposite side 1.913"/1.911" OAL
80	Grind I.D. to 2.500"/2.501" diameter
90	On mag chuck, grind gear O.D. to 4.819"/4.817" diameter, true with I.D. within .001" TIR
100	Shape gear, pregrind
110	Deburr - break edges
120	Mask gear teeth
130	Copper plate
140	Clean up
150	Carburize to produce .025"/.040" depth of case in finished part. (.006" grind stock)
160	Strip copper
170	Oxide blast
180	Copper plate all over

Opr. No.	Description
190	Harden and quench
200	Freeze
210	Draw to Rc 58-64 case and Rc 30-45 core hardness
220	Strip copper
230	Inspect heat treatment operations and record; see grind stock and case depth control chart
240	Bore per operation drawing
250	Surface grind small hub side to 1.907"/1.905" OAL
260	Surface grind opposite side to 1.901"/1.899" OAL parallel to opposite side within .0002" TIR
270	Finish grind smallest I.D. to 2.9997"/3.0000" diameter concentric to gear P.D. within .001" TIR and perpendicular to gear face within .0005" TIR
280	Finish grind small O.D. to 4.062"/4.061" diameter concentric to I.D. within .0005" TIR
290	Finish grind gear O.D. to 4.803"/4.801" diameter over odd tooth - concentric within .001" TIR
300	Nital etch
310	Stress relieve
320	Deburr, except corner break of 4.062" diameter to be .005" maximum. Note: gear teeth are not finish ground at this time
330	Polish
340	Clean
350	Magnaflux
360	Inspect to finish dimensions - except gear teeth. Gear teeth will be finish ground at operation #380
370	Identify and route as follows: Split parts into two lots - parts are identical - identify one lot as RG351-11181-111 gears and the other half as RG351-11181-112 gears. Identify with serial numbers. The same serial number is to be assigned to both a -111 gear and a -112 gear.

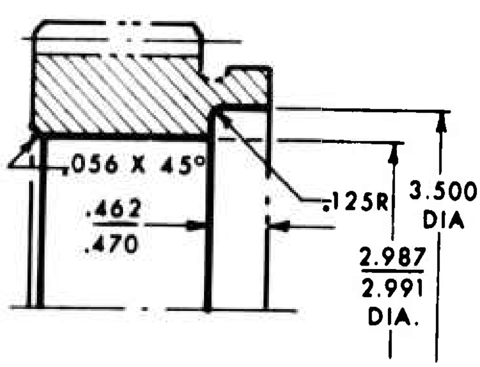
Opr. No.	Description
370 (cont.)	Identify with the letter "Z" on one tooth on both the -111 gears and the -112 gears - any one tooth. Note: etching must be heavy (.001) to carry through following operations.
380	Match one -111 gear and one -112 gear having the same serial number together. Assemble one -111 and one -112 matched gears on arbor - gear face to gear face - line up the two teeth marked with the letter "Z", gears are to be matched ground together. See grind stock and case depth control chart. Note: A profile chart must accompany each gear and must be identified by the same serial number as appears on the corresponding gear.
390	Nital etch
400	Crown etch gear teeth
410	Stress relieve
420	Break gear edges - do not remove identification
430	Buff - do not remove identification
440	Clean
450	Magnaflux
460	Inspect - gear teeth only - verify gear inspection records and check identification and serial numbers - keep in matched sets.
470	Visually inspect and reidentify if necessary



OPERATION 30



OPERATION 40



OPERATION 240

Figure C-7. RG351-11181-111 & -112 Machine Operation Drawing.

Welded Gear/Flange Assembly RG351-11181-057

This assembly consists of the small gear RG351-11181-111 and flange RG351-11181-105.

Opr. No.	Description
10	Clean with MEK and assemble - be careful when cleaning not to remove identification on gear. (1) RG351-11181-111 Gear (1) RG351-11181-105 Flange
20	Inspect assembly - check fit and 1.645"/1.635" mounting distance
30	Electron Beam Weld
40	Stress relieve at 350° ± 15° for 5.0 hours
50	Inspect visually
60	Not used
70	Not used
80	Reinspect gear after Electron Beam Weld for distortion
90	Lap small gear face to clean up 90% minimum
100	Set on gear face and surface grind to 1.887"/ 1.883" OAL
110	Grind flange face to remove weld bead for operation drawing
115	Magnaflux weld joint 100%
120	On mag chuck, grind gear I.D. to 3.0050"/3.0055" diameter, true up gear pitch diameter within .0005" TIR, use one pin in space adjacent to tooth marked "Z" and spread three more pins 90° apart
130	Nital etch
140	Inspect gear and record
150	Deburr
160	Clean

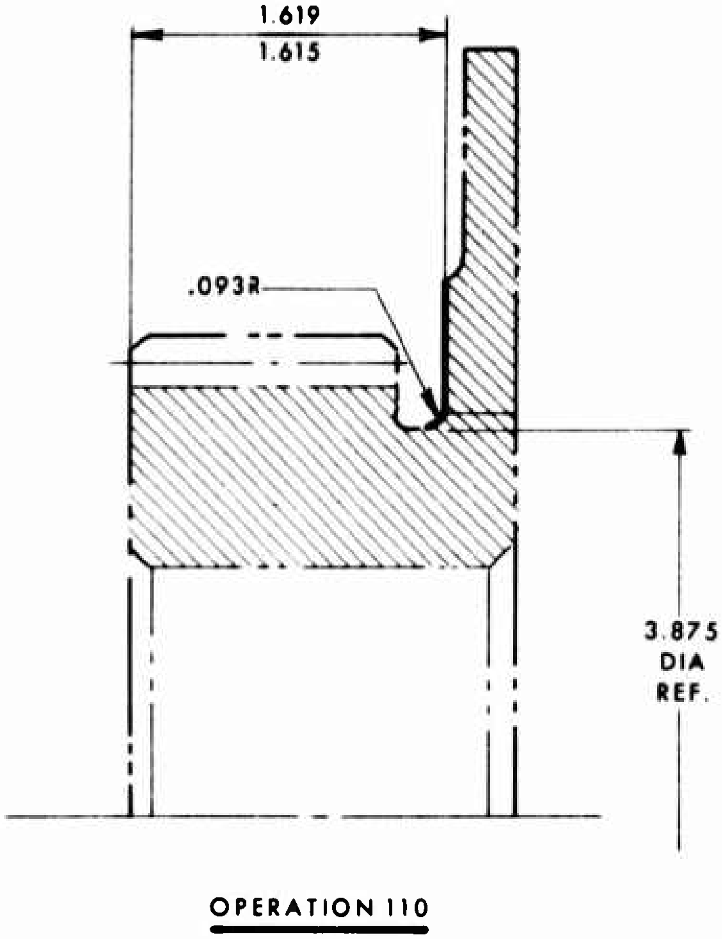


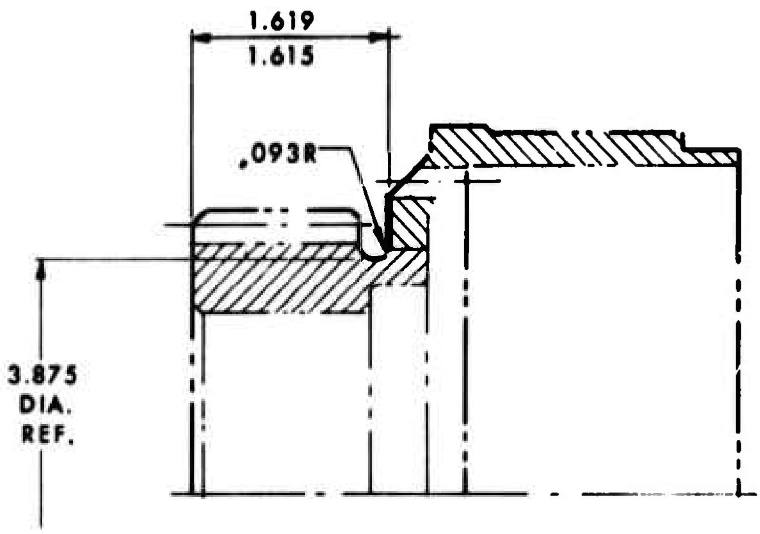
Figure C-8. RG351-11181-057 Machine Operation Drawing.

Welded Gear Assembly RG351-11181-055

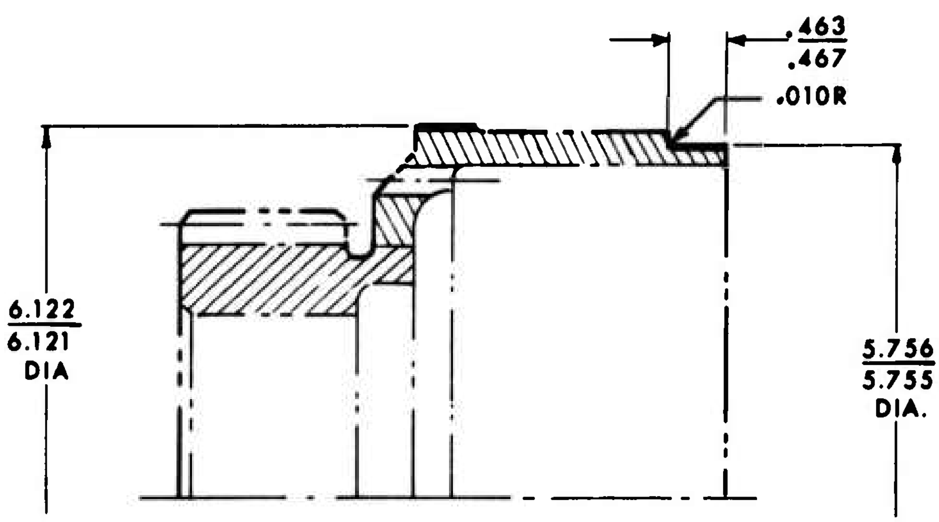
This assembly consists of a small gear RG351-11181-112 and the shaft RG351-11181-106.

Opr. No.	Description
10	Clean with MEK and assemble - be careful when cleaning, not to remove identification on gear. (1) RG351-11181-112 Gear (1) RG351-11181-106 Shaft
20	Inspect assembly - check fit, mismatch and 4.548"/4.538" mounting distance and concentricity
30	Electron Beam Weld
40	Stress relieve at 350° ± 15° for 5.0 hours
50	Inspect visually
60	Not used
70	Not used
80	Reinspect gear after EWB and record
90	Grind flange face to remove weld bead per operation drawing
100	Grind weld bead off flush with adjacent surfaces in counterbore
110	Magnaflux weld bead
120	Grind per operation drawing
130	Grind per operation drawing
140	Nital etch
150	Magnaflux
160	Inspect -055 assembly
170	Visually inspect and identify

Opr. No.	Description
170	Magnaflux
180	Inspect to -057 assembly
190	Visually inspect and identify



OPERATION 90



OPERATION 120 & 130

Figure C-9. RG351-11181-055 Machine Operation Drawing.

Welded Gear Assembly RG351-11181-054

This assembly consists of the gear/shaft assembly RG351-11181-055 and the gear RG351-11181-103.

Opr. No.	Description
10	Drill one hole per operation drawing in RG-351-11181-103 gear
20	Clean with MEK and assemble - be careful when cleaning, not to remove identification (1) RG351-11181-103 Gear (1) RG351-11181-055 Gear Assembly
30	Inspect assembly - check fit and mismatch; gear department to check tooth-to-tooth timing to insure that the teeth are aligned good enough to allow grind stock for gear grind. Note: Seven sets plus two setup pieces must check the same on "X" dimensions within .001" TIR
40	Electron Beam Weld
50	Electron Beam Weld
60	Stress relieve at 350° ± 15° for 5.0 hours
70	Inspect visually
80	Not used
90	Not used
100	Lap small gear face to clean up 90% minimum
110	Surface grind opposite face to clean up 90% minimum
120	On magnetic chuck, grind small gear I.D. to 3.0050"/3.0055" diameter; true up small gear pitch diameter within .005" TIR, use one pin in space adjacent to tooth marked "Z" and spread three more pins 90° apart
130	Check gears for distortion and timing of small gear tooth to large gear tooth to make sure "X" dimension will come in when large gear is ground. "X" dimension must be the same on set of seven pieces.

Opr. No.	Description
140	Burr and polish off weld beads on both sides flush with adjacent surfaces
150	Magnaflux
160	Drill 16 .630"/.624" diameter holes equally spaced on 6.750" diameter basic B.C., except one hole offset .250" basic; true position within .010" diameter. Note: One hole is already in part - drill out to .625" diameter
170	Inspect
180	Finish grind I.D. to 5.5078"/5.5083" diameter with .065" radius, grind seat to 2.649"/2.653" dimension from end face, true with I.D. of small gear within .0002" TIR
190	Finish grind inner face to 8.000" ± .010" diameter with .060" corner radius - to 2.300"/2.296" dimension from seat to inner face; true with I.D. of small gear within .0002" TIR and parallel to end face of large gear within .0002".
200	Grind .050" ± .010" x 45° chamfer on end of 5.5083" diameter bore
210	Finish grind to 9.031"/9.030" diameter with .030" radius, grind seat to .542"/.544" from end of part, true with 5.5078"/5.5083" diameter within .0005" TIR on one end
220	Finish grind opposite end to 9.031"/9.030" diameter with .030" radius, grind seat to .542/.544 from end of part, true with 5.5078"/5.5083" diameter within .0005" TIR
230	Finish grind gear O.D. to 9.685"/9.683" diameter, true with 5.5078"/5.5083" diameter within .001" TIR
240	Inspect
250	Finish grind 126 tooth gear, indicate 5.5083" I.D., true within .0002" TIR, and true up adjacent face within .0002" TIR. Note: Dimension "X" to be held to ± .0002" - tooth-to-tooth timing - record "X" dimension - reference with serial number on small gear

Opr. No.	Description
260	Inspect gear
270	Nital etch
280	Crown etch large gear - Note: mask to include bearing face
290	Inspect large gear crown
300	Stress relieve
310	Burr gear teeth and area machined on -054 assembly except 9.031" diameters to have .005" maximum corner break
320	Buff
330	Clean
340	Visually inspect
350	Magnaflux
360	Inspect -054 assembly
370	Visually inspect and identify

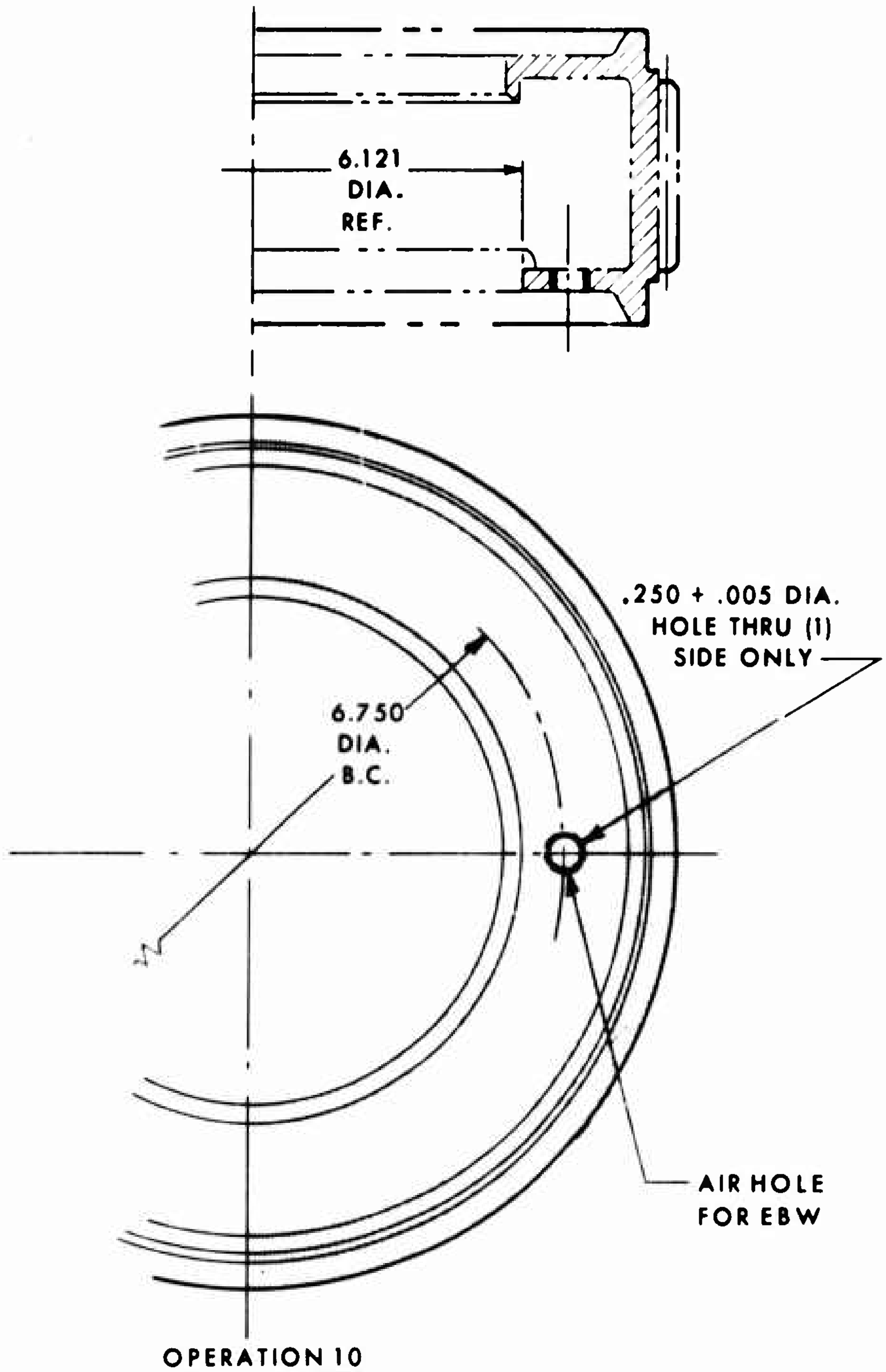


Figure C-10. RG351-11181-054 Machine Operation Drawing.

Gear/Roller Assembly RG351-11181-053

This assembly consists of welded gear assembly RG351-11181-053 and two rollers RG351-11181-104.

Opr. No.	Description
10	Clean with MEK and assemble - be careful when cleaning, not to remove identification (1) RG351-11181-053 Gear Assembly (2) RG351-11181-104 Roller
20	Electron Beam Weld
30	Electron Beam Weld
40	Stress relieve at 350°F $\pm$ 15° for 5.0 hours
60	Inspect visually
70	Grind off weld beads on both sides flush with adjacent surfaces
80	Magnaflux
90	Finish grind top face to 2.640"/2.636" dimension from inner face, true with I.D. of shaft bore within .0005" TIR - 32 micro finish
100	Finish grind lower roller face to 3.313"/3.307" dimension, true with I.D. of shaft bore within .0005" TIR - 32 micro finish
110	Grind roller O.D. to 9.548"/9.543" diameter, true with shaft bore within .001" TIR
120	Nital etch
140	Magnaflux
150	Inspect to -053 assembly Note: Roller diameter is finished at -051 assembly
160	Visually inspect and identify

Matched Gear Assembly RG351-11181-051

This is the final operation whereby the gear/flange assembly is located and fastened to the large gear assembly and the rollers finished. The -051 matched set assembly consists of seven basically identical completed gears.

The RG351-11181-051 Gear Assembly Consists of:
(7) RG351-11181-052 Gear Assemblies
The RG351-11181-052 Gear Assembly Consists of:
(1) RG351-11181-053 Gear Assembly and
(1) RG351-11181-057 Gear Assembly

Opr. No.	Description
10	Withdraw the following parts from finished stores: To make one -052 Assembly (1) RG351-11181-053 gear assembly (1) RG351-11181-057 gear assembly The serial number on the -053 and -057 gear assemblies must be identical. Assemble the two gear assemblies Line up two teeth marked with "Z".
20	Check the tooth-to-tooth alignment 0.000" ± .0002", adjust as required
30	Drill four equally spaced holes on 6.750" diameter B.C., hold drill depth to .050" short of gage dimension. Holes will be undersize
40	Assemble bolts in the four undersize holes and recheck alignment. Secure the bolts
50	Drill and taper ream four holes equally spaced on 6.750" diameter B.C. except one hole offset as shown. Top of function gage to be flush to .010" below surface
60	Disassemble and burr holes
70	Assemble four Briles TL100-5-7 taper bolts and secure
80	Recheck alignment

Opr. No.	Description
90	Taper ream the four undersize holes, drill and taper ream the remaining eight holes. Top of function gage to be flush to .010" below surface.
100	Disassemble and burr holes
110	Recheck alignment and record
120	Inspect, except 9.5335" diameters are semi-finished. Note: -057 assembly to be held in final inspection department until oper. #200.
130	Finish grind roller diameter to 9.5335"/9.5331" diameter and true with -B- bore within .005" TIR - 8 micro finish. Note: Parts to be final inspected and recorded
140	Finish grind .0007"/.0009" x .70" gage point taper on one roller diameter - 8 micro finish. Polish and blend radii. Final inspect and record
150	Finish grind .0007"/.0009" x .070" gage point taper on opposite roller diameter - 8 micro finish. Polish and blend radii. Final inspect and record
160	Finish grind .0007"/.0009" x .460" gage point taper on one roller diameter - 8 micro finish. Polish and blend radii. Final inspect and record
170	Finish grind .0007"/.0009" x .460" gage point taper on opposite roller diameter - 8 micro finish. Polish and blend. Final inspect and record
180	Nital etch. CAUTION - handle with extreme care - 8 micro finish.
190	Stress relieve 1 hour at 300°. CAUTION - handle with extreme care - 8 micro finish.
200	Verify inspection records and match with -057 assembly. CAUTION - handle with extreme care - 8 micro finish.
210	Dulite. CAUTION - handle with extreme care - 8 micro finish.
220	Magnaflux. CAUTION - handle with extreme care - 8 micro finish.

Opr. No.	Description
230	Complete identification and match in sets. Seven -052 assemblies make one -051 assembly. See gear log book. CAUTION - handle with extreme care - 8 micro finish
240	Inspection
250	Ultrasonic inspect

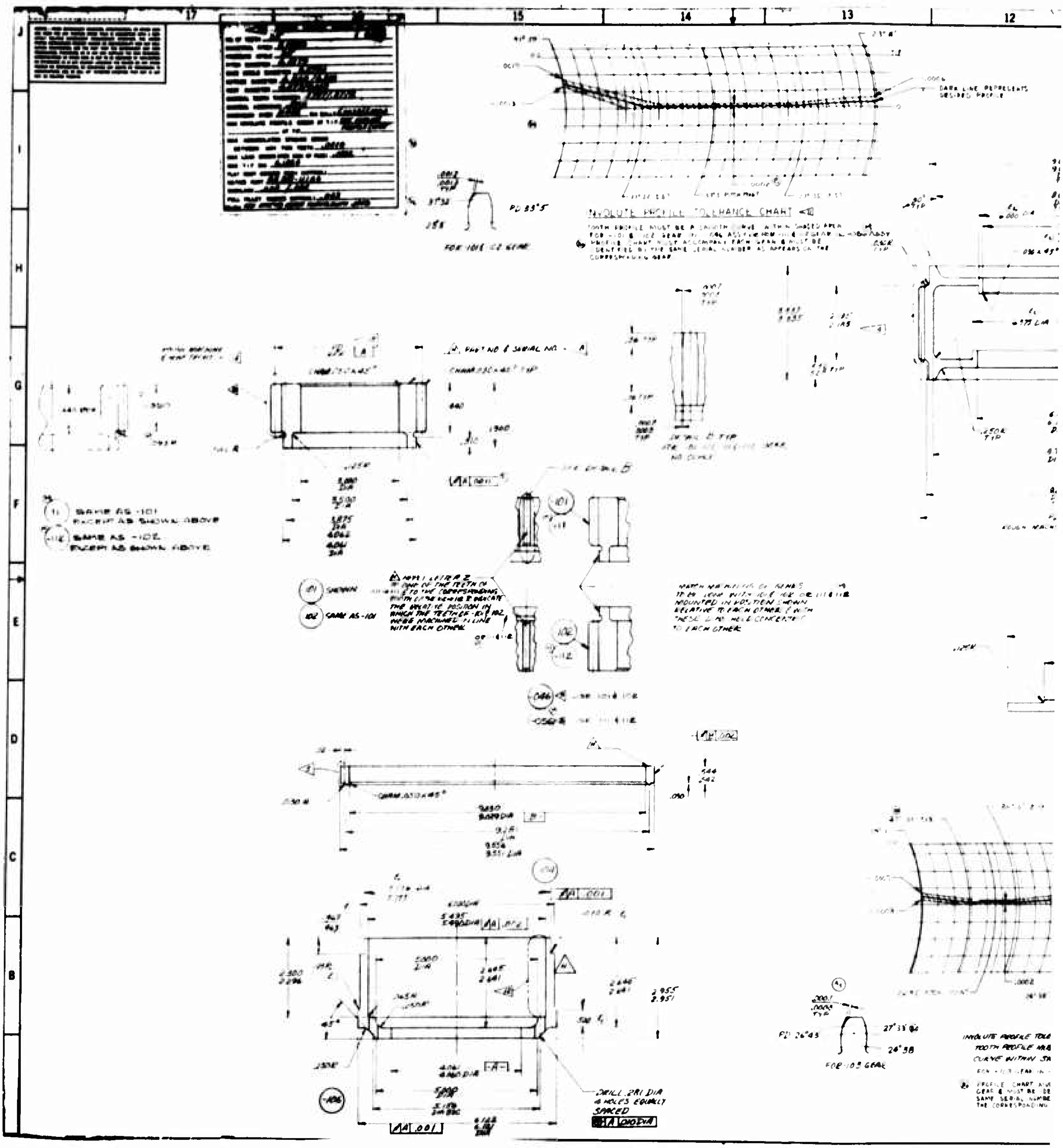


Figure C-11. RG351-11181, Second-Row Pinion Drawing.

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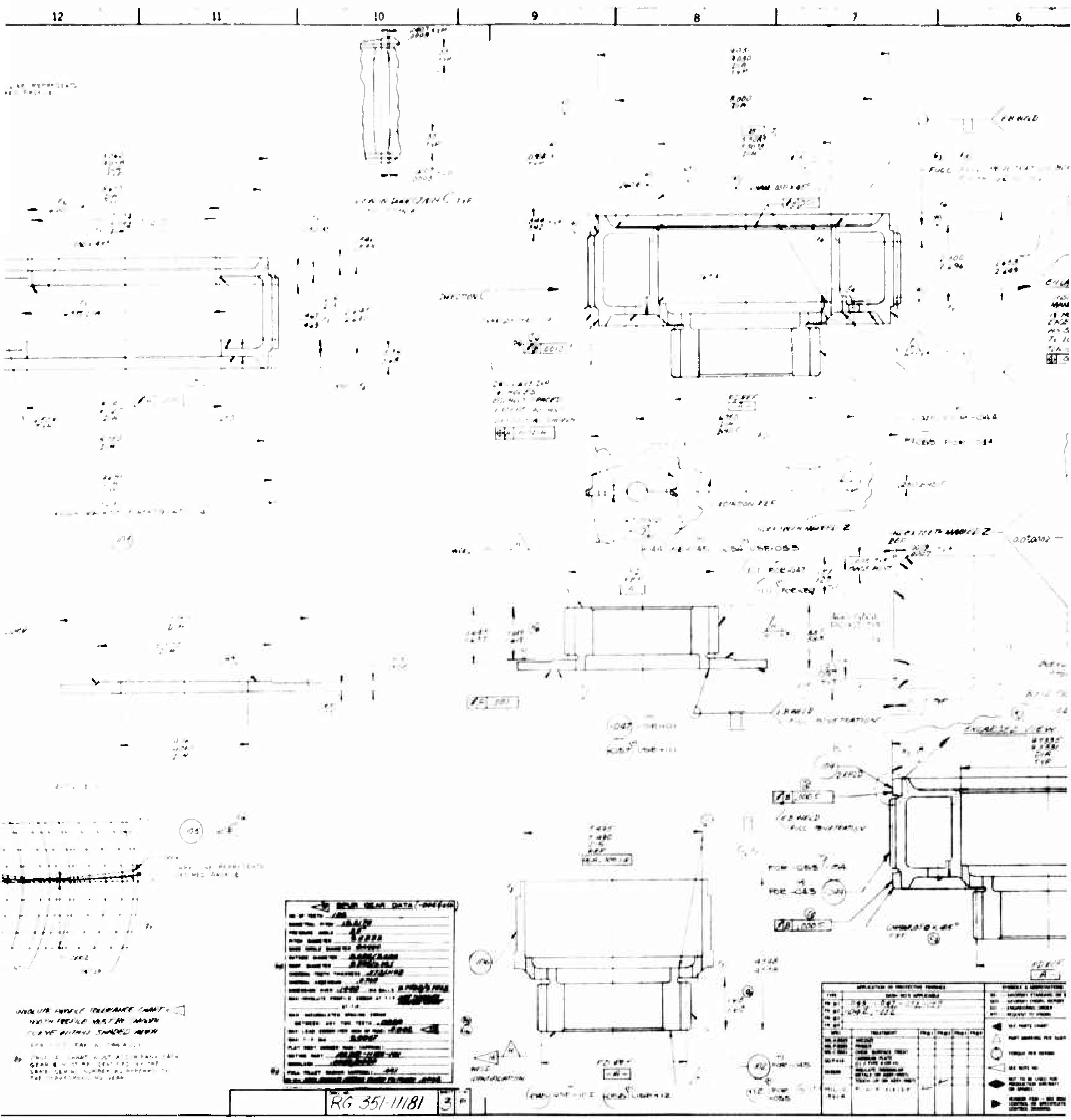
12
11
10
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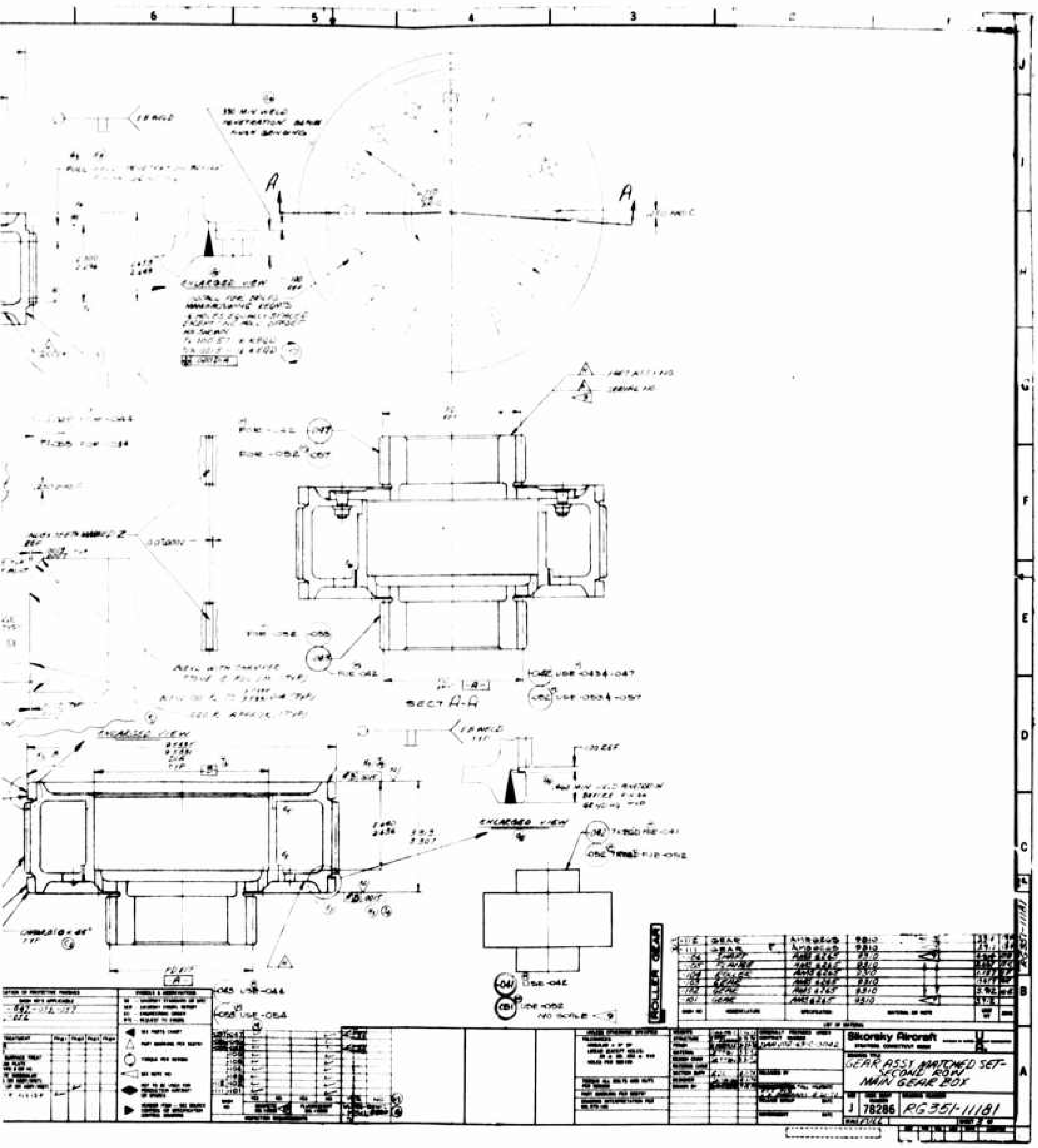
SPUR GEAR DATA
ENLARGED VIEW
RG 351-11181
3



SECT A-A
ENLARGED VIEW
ROLLER GEAR
Sikorsky Aircraft
GEAR ASSY MATCHED SET-
SECOND ROW
MAIN GEAR BOX
J
78286
RG351-11181

APPENDIX D

SECOND-ROW PINION, RG351-11278

This appendix routes the manufacturing process of the second-row pinion matched set assembly, RG351-11278-041. This set, comprising of seven -042 pinions(Figure D-1), is a redesigned version of the second-row pinion RG351-11181 for which the manufacturing process routing is given in the previous appendix.

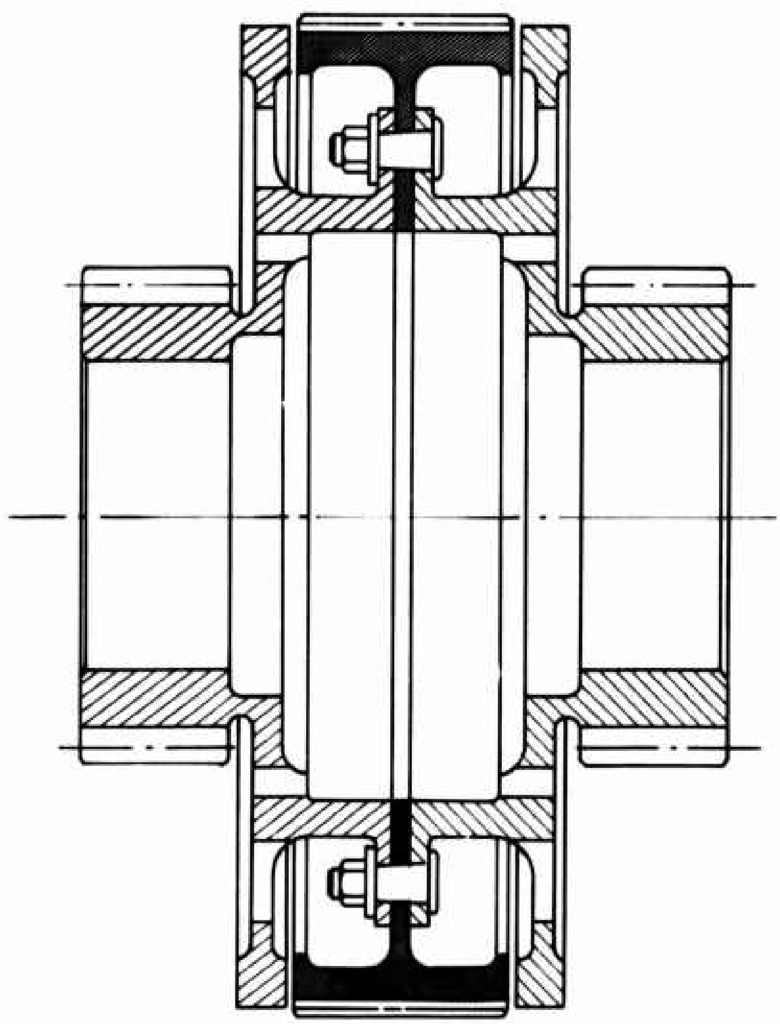


Figure D-1. Second-Row Pinion RG351-11278.

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This redesigned second-row pinion, RG351-11278, stemmed from testing of the roller gear transmission,[6] during which fracture of the originally designed pinion, RG351-11181, occurred. As a result of these tests, the second-row pinion was redesigned to eliminate "blind" electron beam welds.

The RG351-11278 pinion has only two through electron beam welds. Both the entrance face and root exit face of these welds are readily accessible to machining and inspection. The original pinion had a total of six electron beam welds, of which four were blind, i.e., the root exit face was inaccessible to machining and inspection.

Figure D-2, an exploded view of the pinion, depicts the individual parts which comprise the RG351-11278 second-row pinion. The detail drawing is shown in Figure D-3.

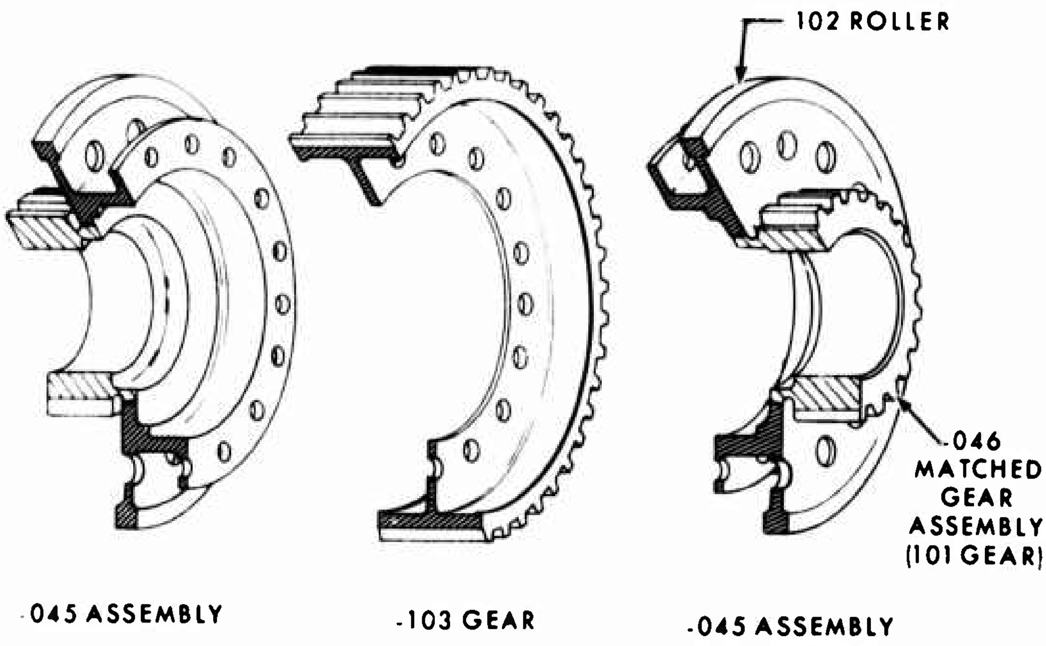


Figure D-2. Exploded View, Second-Row Pinion RG351-11278.

(6) G.F. Gardner and R.E. Haven, Laboratory Bench Test, Volume IV, 3000-HP Roller Gear Transmission Development Program, USAAMRDL-TR-73-98D, USAAMRDL Fort Eustis, Virginia, May 1974.

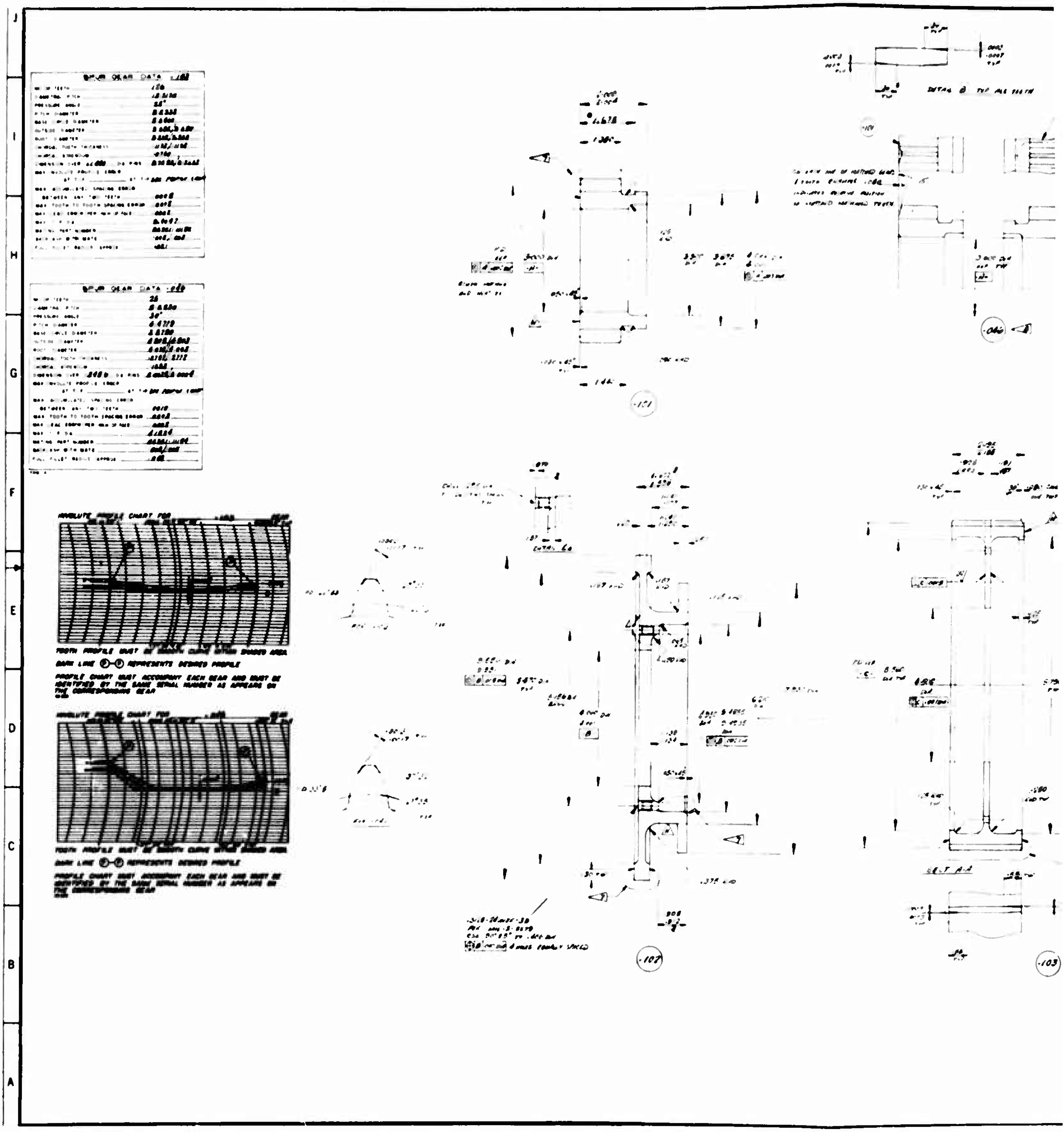
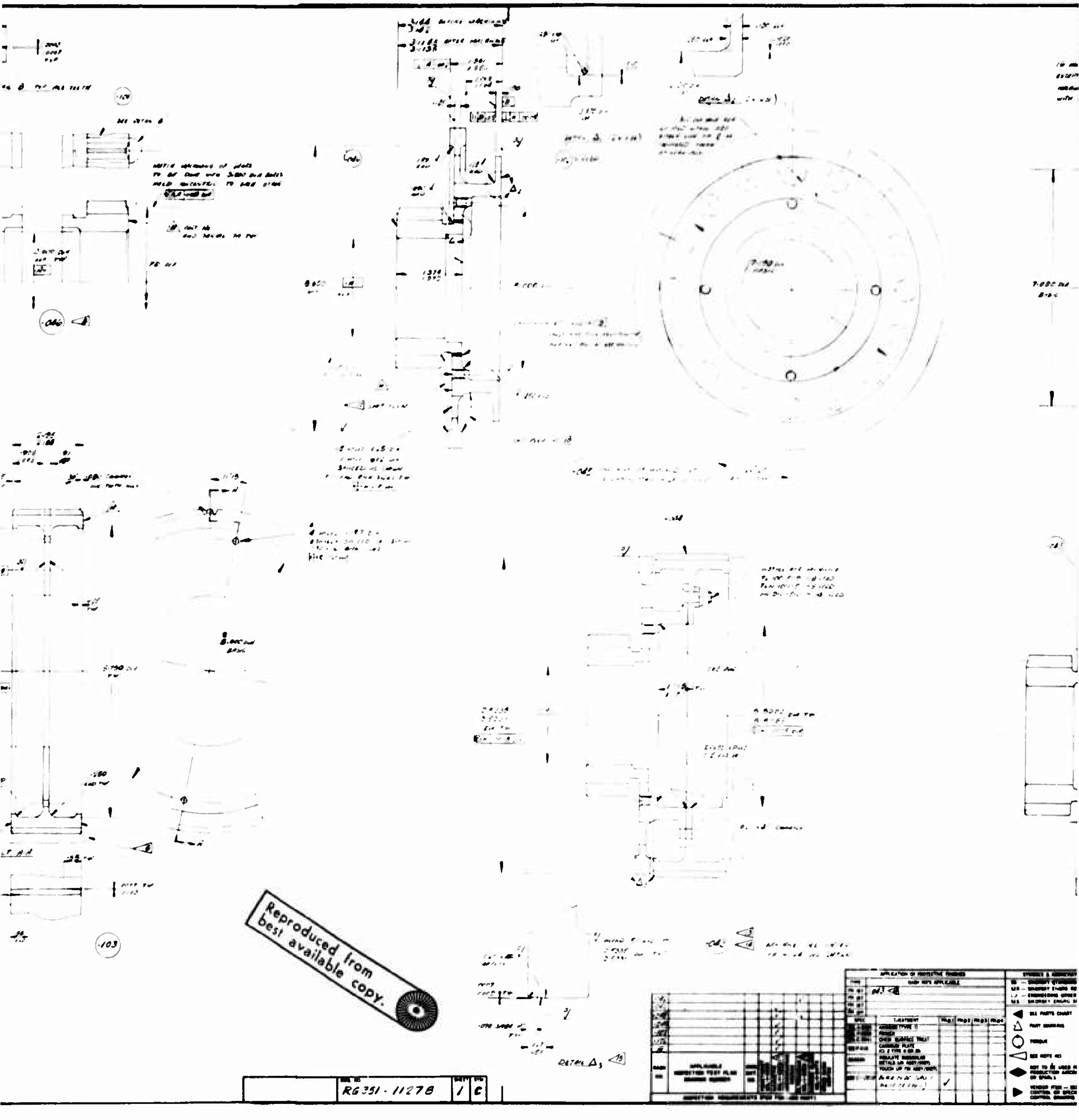
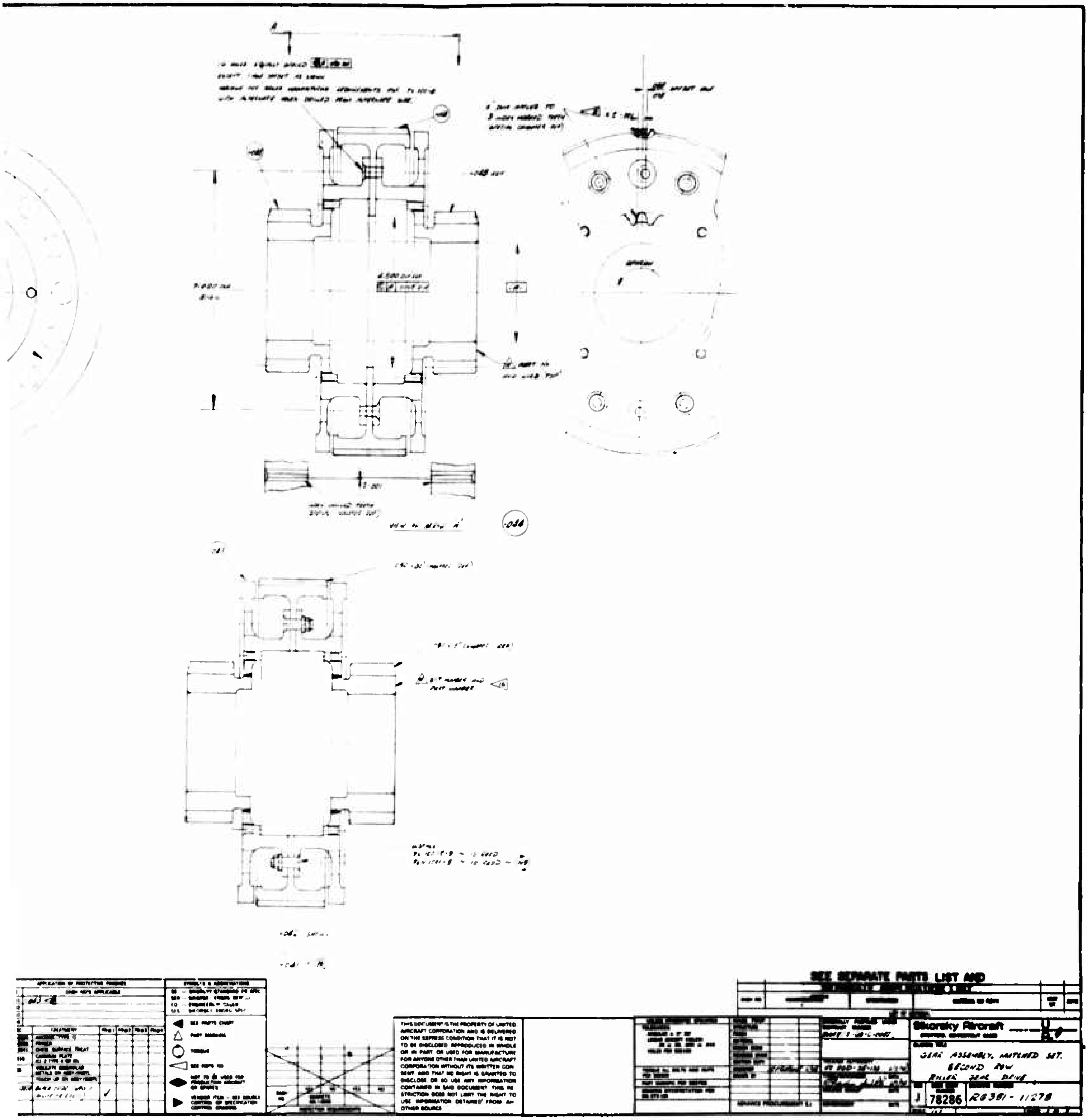


Figure D-3. Second-Row Pinion Drawing.


DETAIL A2
DETAIL A3
-103
-086
-104
RG351-11278
1
C
APPLICATION OF PROTECTIVE FINISHES
TREATMENT
SYMBOLS & ABBREVIATIONS
SEE PARTS CHART
PART MARKING
TORQUE
SEE NOTE NO
VENDOR ITEM — SEE SPECIFICATION CONTROL OR SPECIFICATION CONTROL DRAWING
APPLICABLE INSPECTION TEST PLAN DRAWING NUMBER
INSPECTION REQUIREMENTS SPEC FOR SEE ... ONLY



VIEW IN DIRECTION 'A'
SEE SEPARATE PARTS LIST AND
SYMBOLS & ABBREVIATIONS
SEE PARTS CHART
PART MARKING
TORQUE
SEE NOTE NO.
NOT TO BE USED FOR PRODUCTION AIRCRAFT OR SPARES
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Sikorsky Aircraft
GEAR ASSEMBLY, MATCHED SET, SECOND ROW
PLANET GEAR DRIVE
J
78286
RG351-11278

RG351-11278-102 Roller

Two rollers per gear are required, each roller is fabricated from a ring forging AMS 6205 - 9310 steel. The roller diameters are finished ground at the -041 assembly.

Operation No.	Description
10	Receive and inspect. Steel stamp mill heat code number on one end
20	Blank per operation drawing
30	Blank per operation drawing
40	Heat treat for machinability
50	Draw to Rc 25-30
60	Blank per operation drawing
70	Blank per operation drawing
80	Magnaflux
90	Surface grind large end to 1.6185"/1.6175" OAL
100	Surface grind small end to 1.6125"/1.6115" OAL
110	S.F. grind C'bore per operation drawing
120	Deburr
125	Inspect
130	Mask per operation drawing
140	Clean up
160	Carburize to produce .025"/.040" depth of case in finished part (.006" grind stock)
165	Read hot sample
170	Anneal
180	Strip copper. Add carb load number next to mill heat code no., reference operation no. 70
190	Oxide blast

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RG351-11278-102 Roller

Operation No.	Description
200	Drill four .2719"/.2799" diameter holes equally spaced on 5.156" diameter basic B.C., true position with diameter "B" within .010" diameter. Counter sink 90° + 5° to .401"/.411" diameter. Counter drill .295" $\pm$ .004"/$-$.001" diameter x .070" deep
205	Counter drill four holes .295" + .004"/$-$.001" deep per B/P
207	Tap .312-24UNJF-3B thread per B/P. .2854"/.289" P.D.
210	Deburr four holes
220	Copperplate all over
230	Plug four tapped holes
240	Harden and quench
250	Freeze
260	Draw to Rc 58-64 case and 30-45 core hardness
265	Read final sample
270	Strip copper
280	Inspect heat treat operations and record
290	Turn back web and bore per operation drawing
300	Surface grind per operation drawing
310	Surface grind per operation drawing
320	Surface grind per operation drawing
330	On mag chuck, grind C'bore per operation drawing
340	On mag chuck, grind C'bore per operation drawing
350	On mag chuck, grind I.D. per operation drawing
360	On mag chuck, grind large O.D. to 9.556"/9.551" diameter concentric with I.D. within .001" TIR
370	Nital etch

RG351-11278-102 Roller

Operation No.	Description
380	Stress relieve for one hour at 295°F - 310°F
390	Deburr. Break edges .005"/.019" except edges of 4.060" bore to be .005" maximum
400	Polish. Caution!! Do not remove heat core numbers. Reference operation no. 70
410	Buff
420	Clean
430	Magnaflux
440	Inspect
450	Visually inspect and identify per B/P

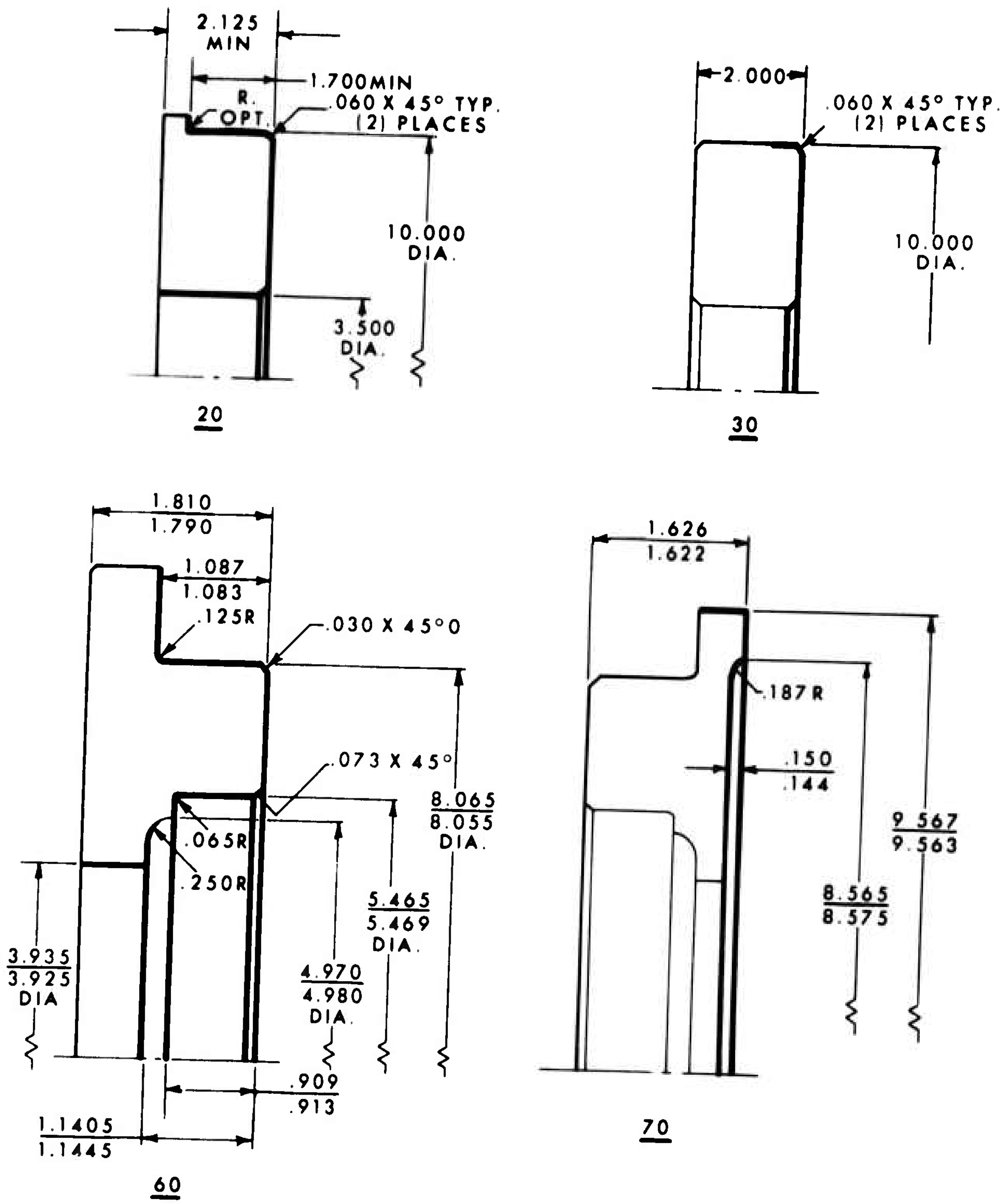


Figure D-4. RG351-11278-102: Machine Operation Drawing (Sheet 1 of 3).

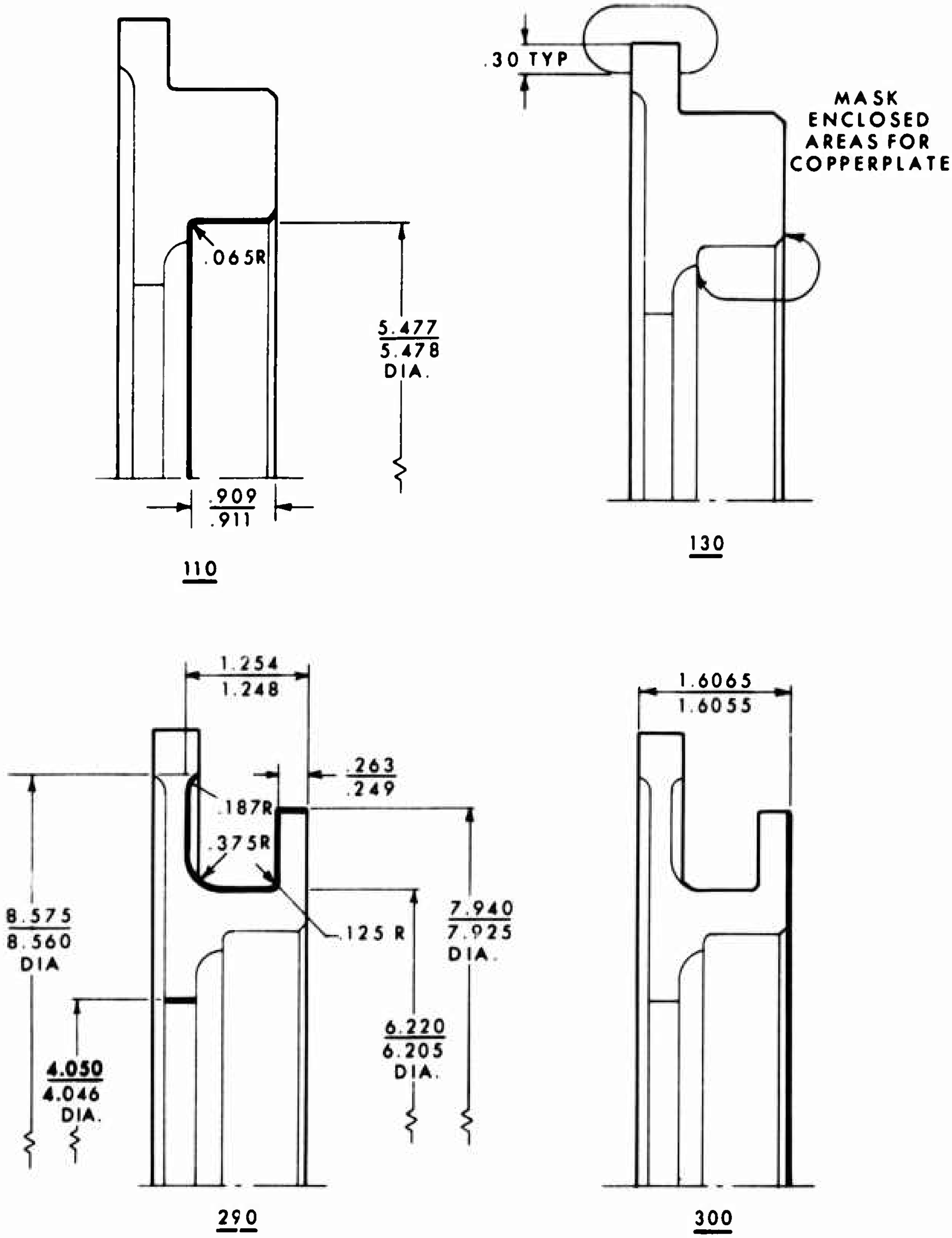


Figure D-4. RG351-11278-102: Machine Operation Drawing (Sheet 2 of 3).

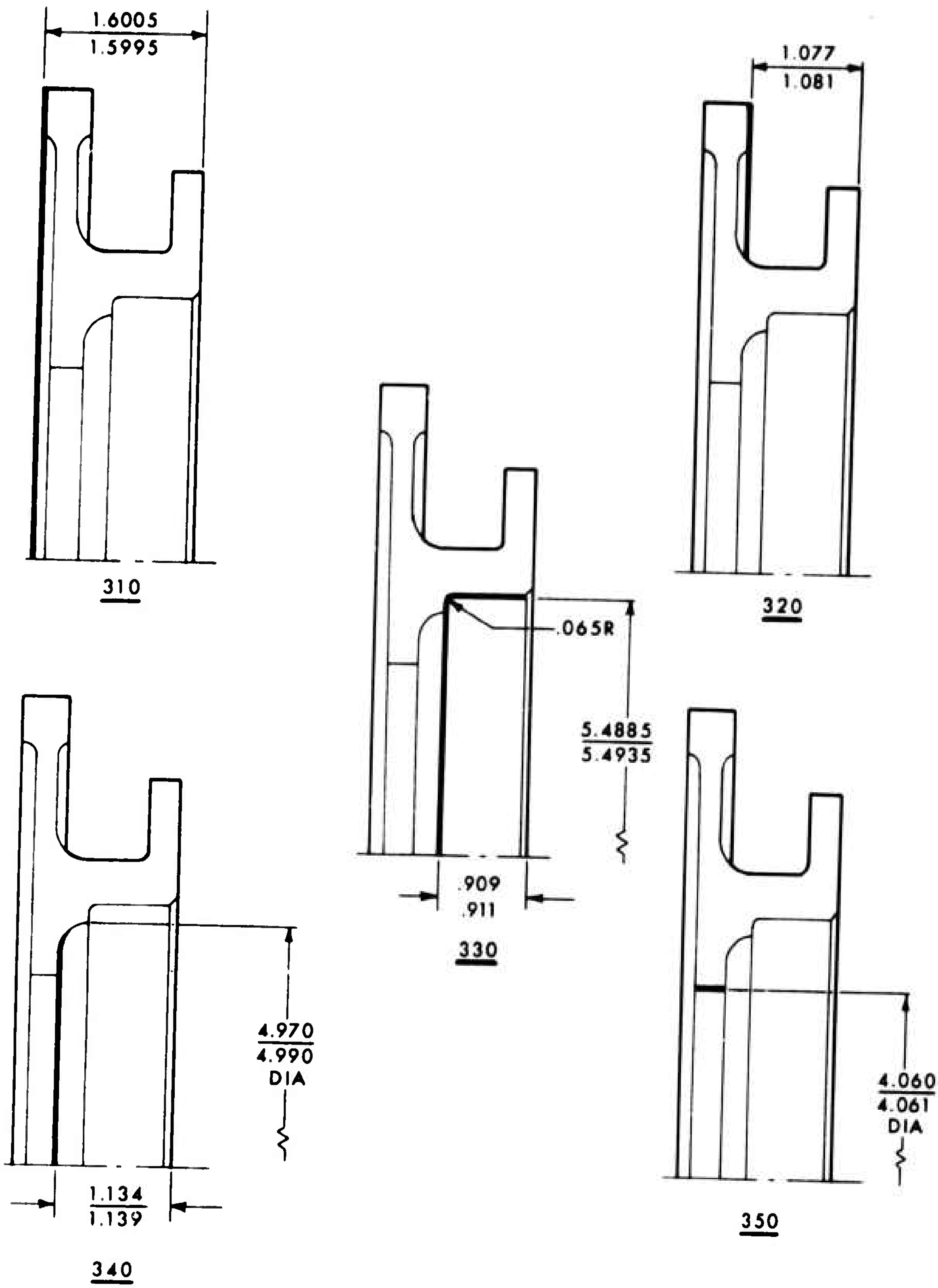


Figure D-4. RG351-11278-102: Machine Operation Drawing (Sheet 3 of 3).

RG351-11278-103 Gear

The gear is fabricated from a ring forging, AMS 6265-9310 steel.

Operation No.	Description
10	Receive and inspect; steel stamp mill heat code no. on one end
20	Blank per operation drawing
30	Blank per operation drawing
40	Heat treat for machinability
50	Draw to Rc 25-30
60	Blank per operation drawing
70	Blank per operation drawing
80	Magnaflux
90	Surface grind the side opposite mill heat code etching to 2.2055"/2.2045" OAL; after grinding, transfer mill heat code no. to this side
100	Surface grind opposite side to 2.2005"/2.1995" OAL
110	Semifinish grind I.D. to 4.350"/4.3505" diameter
120	On mag chuck, surface grind gear O.D. to 9.695"/9.693" diameter - concentric to I.D. within .001" TIR
130	Hob gear pregrind
135	Inspect gear
140	On same end as mill heat code no., mill chamfer on one tooth per B/P. Hold .080" x 30°B/P dimension to .088" ± .010" x 30°
150	Deburr
155	Inspect per check sheet
160	Mask gear
170	Copper plate

RG351-11278-103 Gear

Operation No.	Description
180	Clean up
190	Carburize to produce .010"/.025" depth of case in finished part
195	Read hot sample
200	Strip copper. Add carb load number next to mill heat code number. Reference operation #90
210	Oxide blast
220	Copper plate all over
230	Harden and quench
240	Freeze
250	Draw to Rc 58-64 case and Rc 30-45 core hardness
255	Read final sample
260	Strip copper
270	Inspect H.T. operations and record
280	Turn bore and C'bore one end per operation drawing
290	Turn bore and C'bore opposite end per operation drawing
300	Surface grind one end to 2.1955"/2.1945" OAL, gear face to blue in
310	Surface grind opposite end to 2.1905"/2.1895" OAL, gear faces to be parallel within .0002" (blue in)
320	Grind I.D. to 4.5000"/4.5005" diameter concentric with gear pitch diameter within .001" TIR and perpendicular to gear face within .005" TIR
330	Finish grind flange face one end per operation drawing
340	Finish grind flange face opposite end per operation drawing

RG351-11278-103 Gear

Operation No.	Description
350	On mag chuck, finish grind gear O.D. to 9.685"/9.680" diameter concentric with I.D. within .0003" TIR and perpendicular to gear face within .0005" TIR
360	Nital etch
370	Stress relieve for 1.0 hour at 295°F - 310°F
380	Finish grind gear per B/P
390	Inspect gear and record
400	Nital etch
410	Crown etch gear teeth .0003/.0007 per B/P
420	Inspect crown
430	Stress relieve per SS8705 for 1.0 hour at 295°F - 310°F
440	Drill and ream four .187" ± .010" holes on 8.000" basic bolt circle .020" true position with diameter "C". Note location of one hole in relation with timed tooth marked with 30° angle on face. 90 micro finish
450	Deburr. Note .030" radius on both sides of web holes
460	Polish. CAUTION!! Do not remove heat numbers; reference operation number 280
470	Buff
480	Clean
490	Magnaflux
500	Inspect.
510	Visually inspect and identify

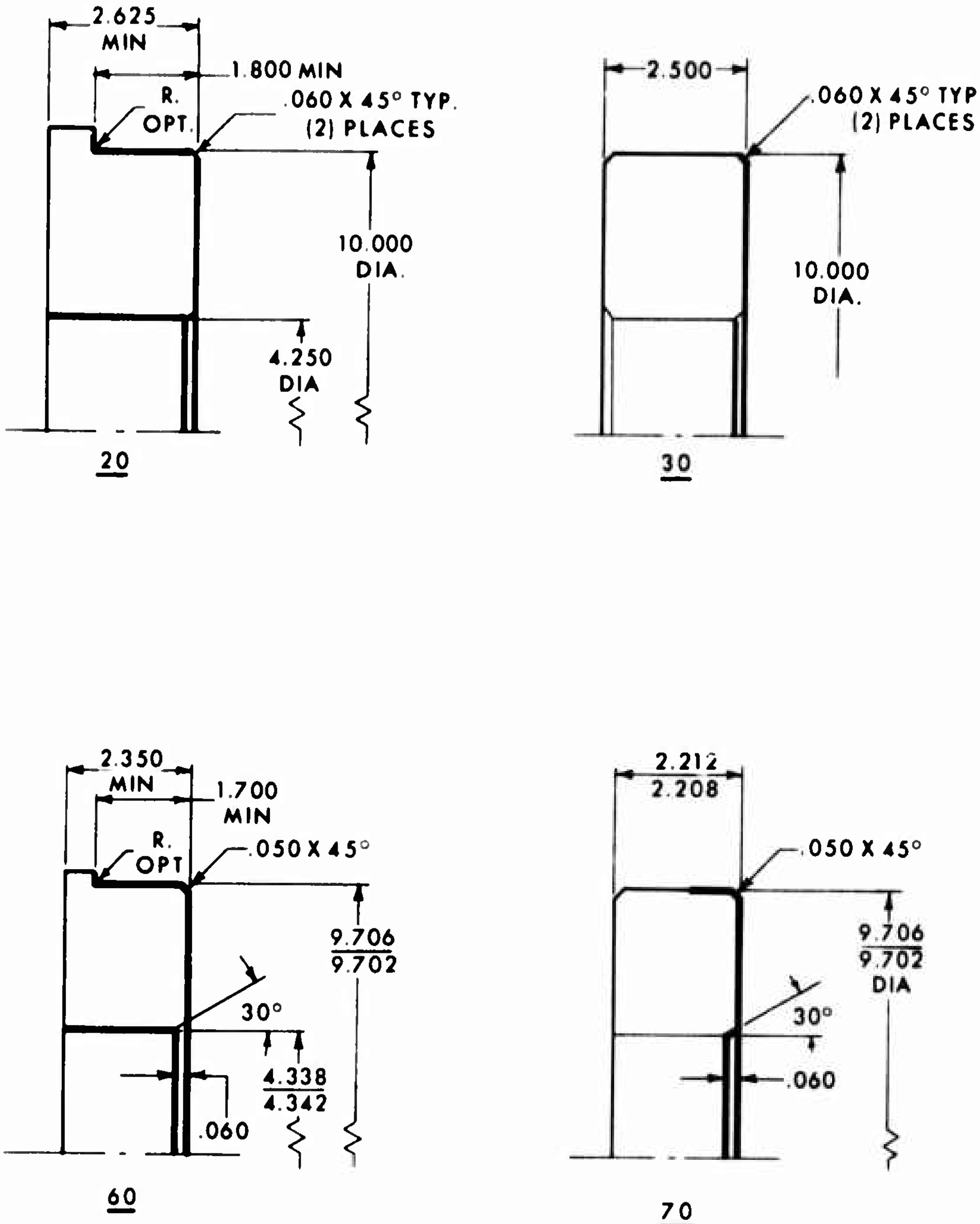


Figure D-5, RG351-11278-103: Machine Operation Drawing (Sheet 1 of 2).

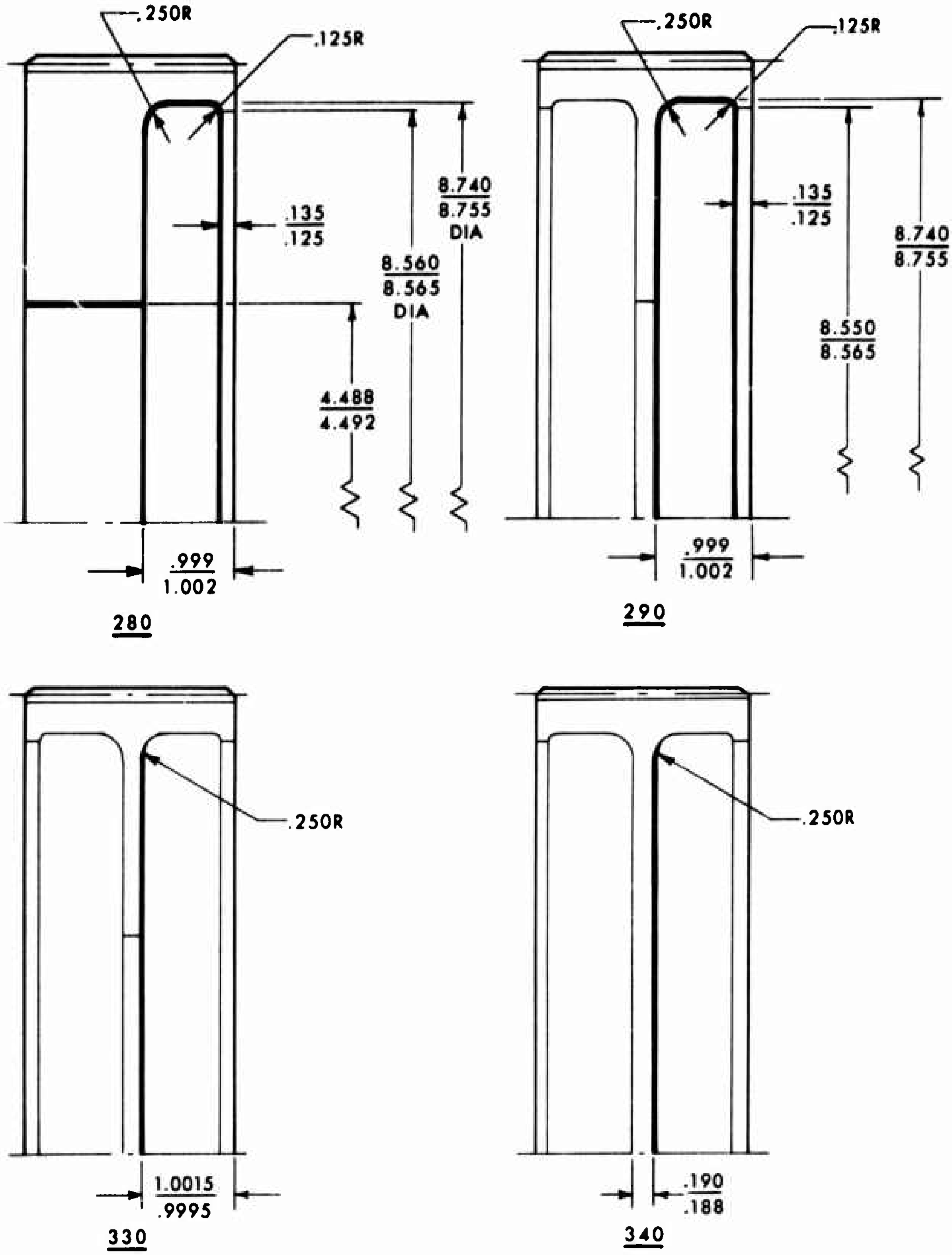


Figure D-5, RG351-11278-103: Machine Operation Drawing (Sheet 2 of 2).

RG351-11274-046 Gear - Matched Set

Two RG351-11278-101 gears, machined from bar stock AMS 6265-9310 steel, are finish ground "in-line" to ensure identical teeth spacing and concentricity tolerance. These two gears are identified with the same serial number to make a -046 matched set.

Operation No.	Description
10	Saw bar to 2-3/8" OAL; steel stamp mill heat code no. on end at 4-1/2" diameter
20	Heat treat for machinability
30	Draw to Rc 25-30
40	Blank per operation drawing
50	Blank per operation drawing
60	Magnaflux
70	Surface grind small hub end to 2.0255"/2.0235" OAL
80	Surface grind opposite side to ~ 0195"/2.0175" OAL
90	Grind I.D. to 2.500"/2.501" diameter
100	On mag chuck, surface grind gear O.D. to 4.819"/4.817" diameter true with I.D. within .001" TIR
110	Shape gear, pregrind
115	Inspect gear
120	Mill chamfer on one tooth. Hold .080" x 15° B/P dimension to .086" ± .010" x 15°
130	Deburr. Break edges per B/P
135	Inspect per check sheet
140	Mask gear teeth per operation drawing
150	Copper plate
160	Clean up
170	Carburize to produce .025"/.040" depth of case in finished part

RG351-11274-046 Gear - Matched Set

Operation No.	Description
175	Read hot sample
180	Strip copper. Add carb load no next to mill heat code number; reference operation #50
190	Oxide blast
200	Copper plate all over
210	Harden and quench
220	Freeze
230	Temper
235	Read final sample
240	Strip copper
250	Inspect heat treat operations and record
260	Bore per operation drawing
270	Surface grind small hub side to 2.0135"/2.0115" OAL
280	Surface grind opposite side to 2.0075"/2.0055" OAL parallel to opposite side within .0002" TIR
290	Finish grind I.D. to 2.9997"/3.0000" diameter concentric to gear pitch diameter within .001" TIR and perpendicular to gear face within .0005" TIR
300	Finish grind small O.D. to 4.062"/4.061" diameter concentric to I.D. within .0005" TIR
310	Finish grind gear O.D. to 4.803"/4.801" diameter over odd tooth concentric to I.D. within .001" TIR (Reference 4.808"/4.803" B/P dimension)
320	Nital etch
330	Stress relieve
340	Deburr. Do not break corner of 4.062" diameter. Note, gear teeth are not finish ground at this time

RG351-11274-046 Gear - Matched Set

Operation No.	Description
350	Polish. Caution!! Do not remove heat number. Ref. operation #260
370	Magnaflux
380	Inspect to finish dimensions, except gear teeth, gear will be ground at operation #400
390	Identify per B/P. The same serial number is to be assigned to two -101 gears, making a -046 set
400	Match two -101 gears having the same serial number together. Assemble matched gears on arbor gear face to gear face. Line up the two teeth marked with the .080" x 15° chamfer. Gears are to be match ground per B/P
410	Inspect gears and record. Identify charts with serial number. Do not lose identification. Keep in matched sets.
420	Nital etch
430	Crown etch gear teeth per B/P. Detail "B"
440	Inspect crown and record
450	Stress relieve
460	Break gear edges per B/P; do not remove identification
470	Buff, do not remove identification
480	Clean
490	Magnaflux
500	Inspect gear teeth only; keep in matched sets
510	Visually inspect and reidentify if necessary

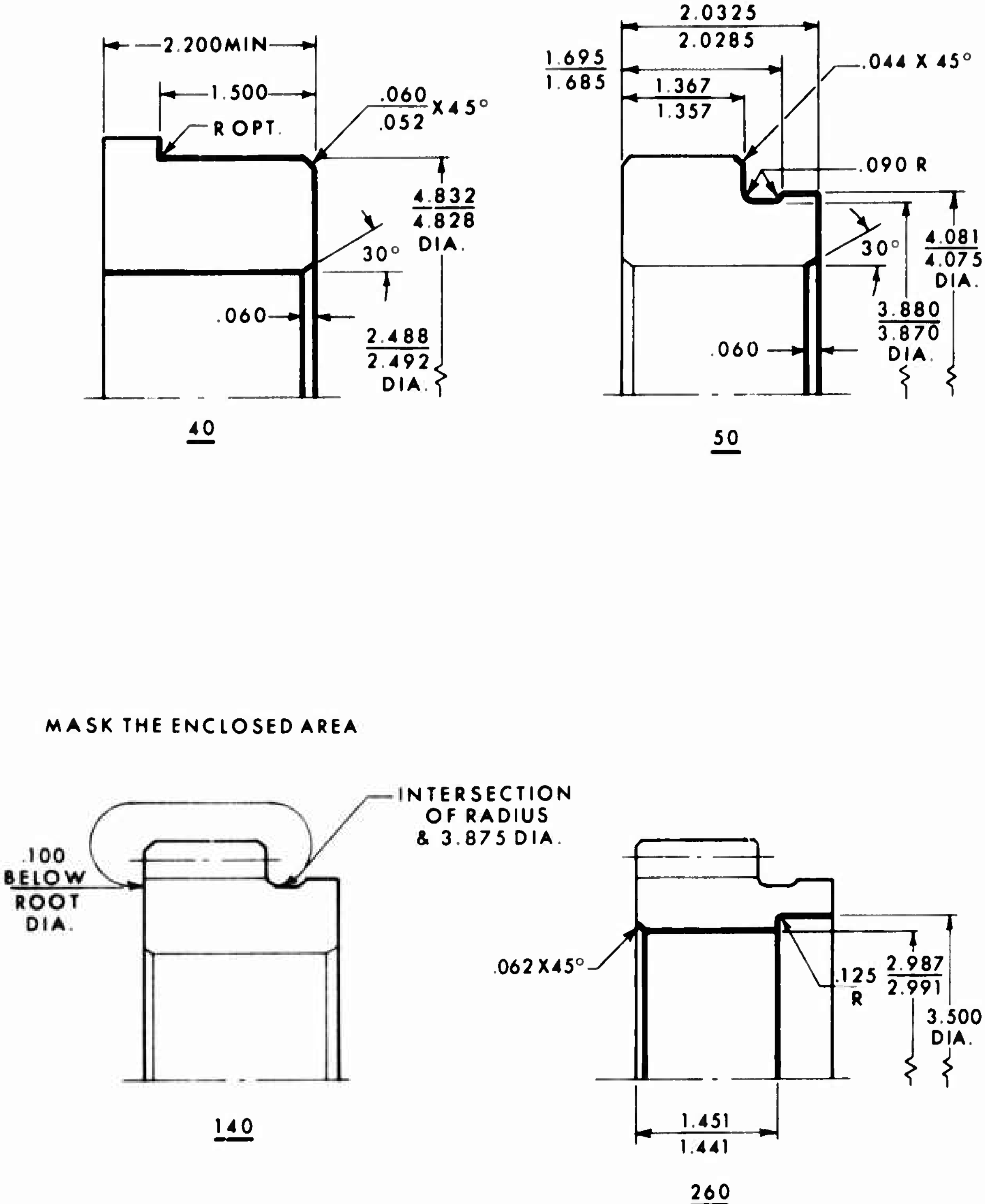


Figure D-6. RG351-11278-046: Machine Operation Drawing.

RG351-11278-045 Welded Gear Assembly

The -046 matched gear assemblies are electron beam welded to the -102 roller to form a -045 welded gear assembly.

Operation No.	Description
10	Clean the following parts with MEK and assemble - be careful when cleaning not to remove identification on gears (1) Set RG351-11278-046 gears (2) RG351-11278-102 rollers
20	Inspect assembly. Check fit and 3.144"/3.142" mounting distance
30	Electron Beam Weld per B/P
40	Stress relieve at 325° ± 10° for 5.0 hours
50	Inspect visually
60	Reinspect gear after Electron Beam Weld for distortion
70	Turn C'bore and flange faces per operation drawing
80	Turn Web per operation drawing
90	Polish per operation drawing
100	Magnaflux weld joint
110	Drill and ream 15 holes .625" ± .010" diameter and 1 hole .812" ± .010" diameter, equally spaced on 7.090" diameter B.C.; true position with diameter "A" within .010" diameter. Also note location of .812" diameter hole with chamfered tooth of gear
120	Break edges of holes, both sides with .030" radius per B/P
130	Shot peen areas indicated on B/P with .012"/.016" intensity
140	Inspect shot peening
150	Surface grind per operation drawing
160	Surface grind per operation drawing

RG351-11278-045 Welded Gear Assembly

Operation No.	Description
170	Surface grind per operation drawing
175	Semifinish grind O.D. per operation drawing
180	Nital etch
190	Stress Relieve
200	Deburr. Break edges .005"/.015" per B/P
210	Clean
220	Magnaflux
230	Inspect per B/P, except roller O.D. is semifinished
240	Visually inspect and identify

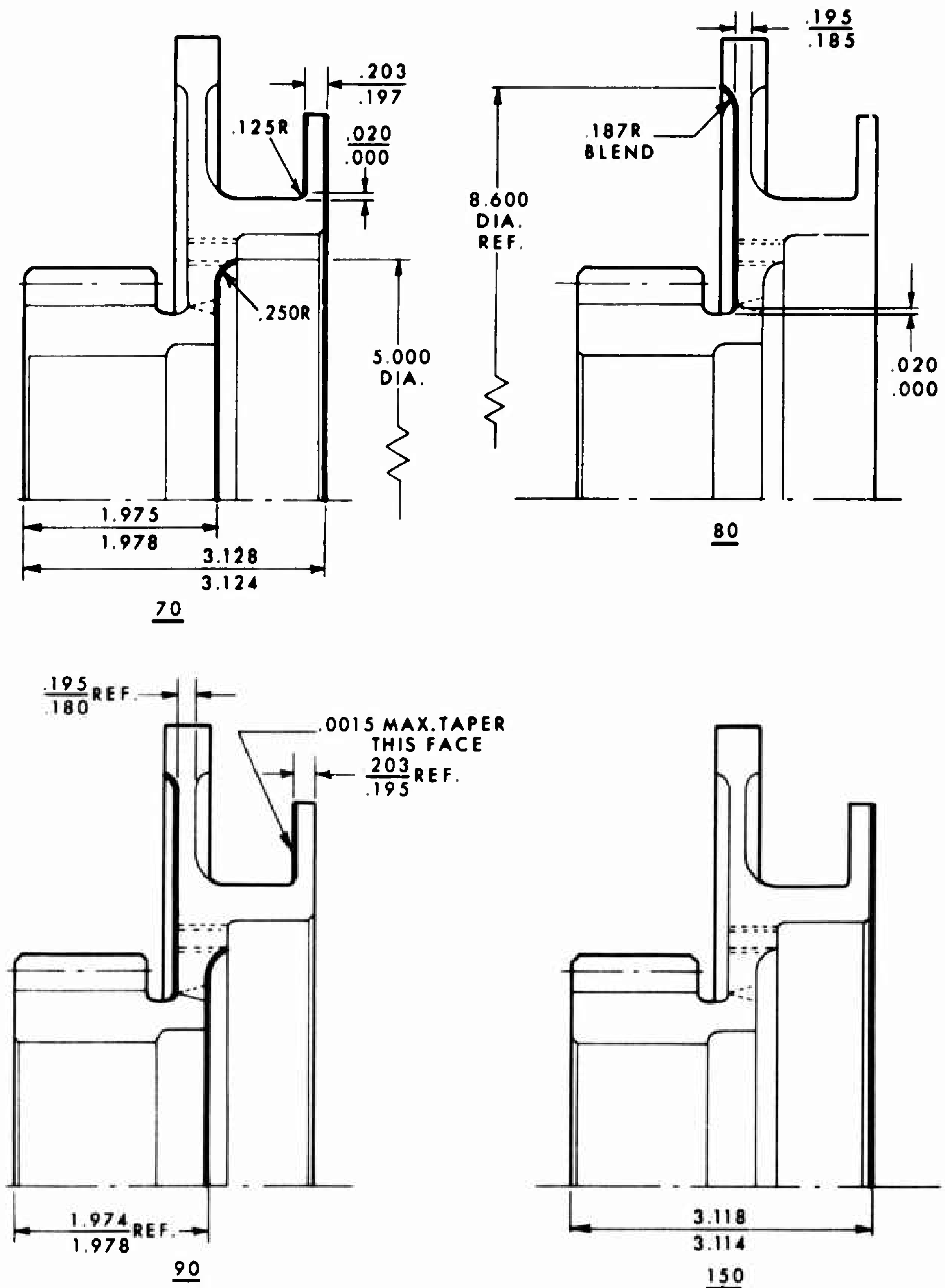


Figure D-7. RG351-11278-045: Machine Operation Drawing (Sheet 1 of 2).

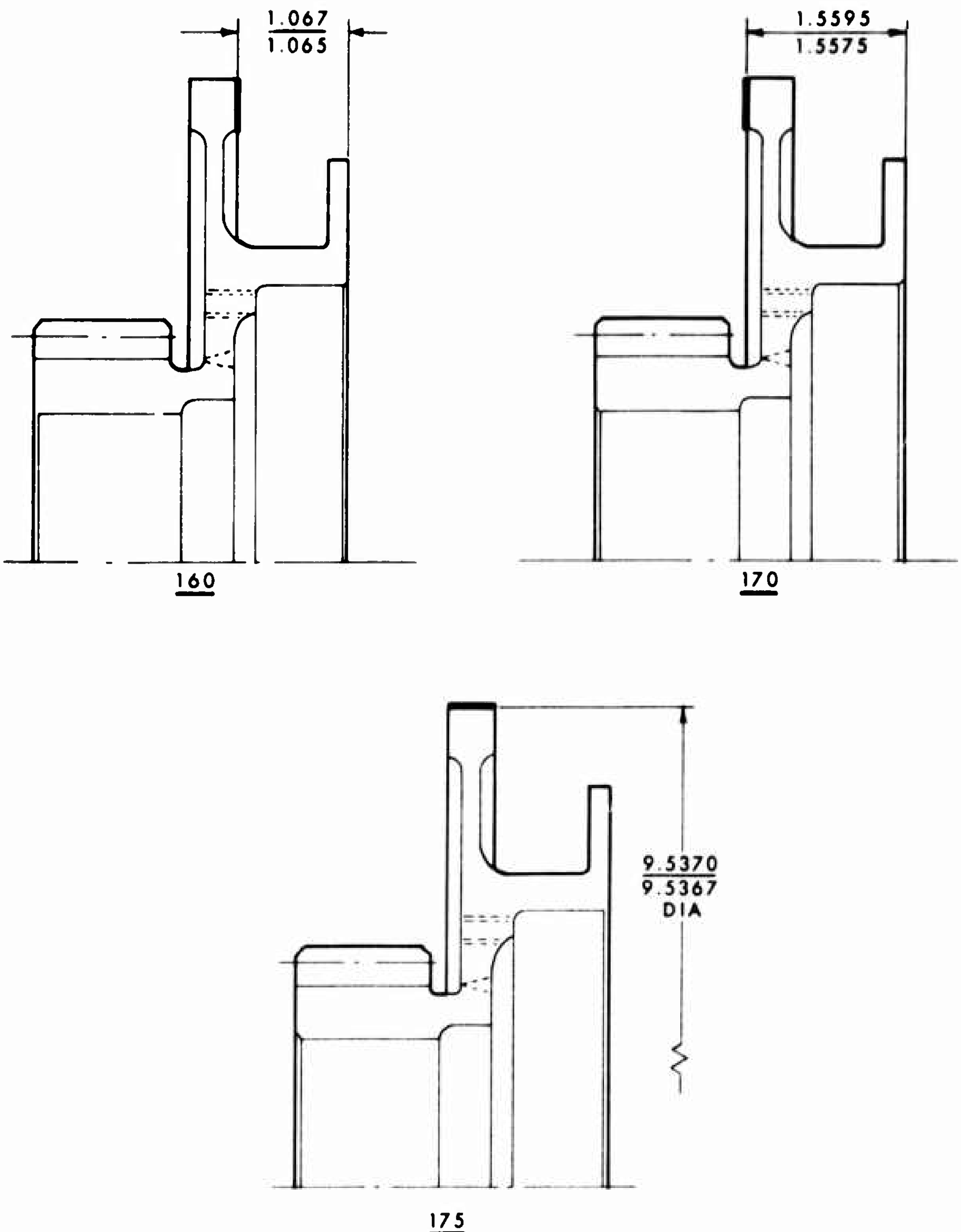


Figure D-7. RG351-11278-045: Machine Operation Drawing (Sheet 2 of 2).

RG351-11278-044 Gear Assembly

This -044 assembly consists of one -103 gear and a -045 welded gear assembly. This assembly lines up the gear teeth on the -101 and -103 gears

Operation No.	Description
10	Install one -103 gear on locating fixture with the chamfered tooth toward the threaded end of fixture. Between centers indicate pitch diameter over a pin true with .0005" TIR and secure. Install one -045 assembly on same end as chamfered tooth on the -103 gear. Adjust the chamfered teeth to the proper "X" dimension and secure. Vibro etch the work "top" on -045 web on this end. Install one -045 assembly (with the same serial number) on the opposite end. Adjust the chamfered tooth to the proper "X" dimension and secure. Note: .001" alignment of the -045 gears. Record by set number being same as the -045 serial number. Also record the serial number of -103 gear used in this assembly
20	Locate in fixture with end marked "top" down. Drill four equally spaced tapered holes on 7.090" diameter B.C. teeth. Hold drill depth to .050" short of gage dimension. Holes will be undersize
30	Assembly bolts in the four undersize holes and recheck alignment. Secure the bolts
40	Locate in fixture with end marked "top" down. Drill and taper ream four holes equally spaced on 7.090" diameter B/C, exept one hole to be offset as shown per B/P
50	Disassemble
55	Deburr holes
60	Assemble four Briles TL100-5-9 taper bolts and secure
70	Recheck alignment per B/P
80	Locate in fixture with end marked "top" down. Taper ream the remaining four holes per B/P

RG351-11278-044 Gear Assembly

Operation No.	Description
90	Locate in fixture with end marked "top" up. Drill and taper ream eight holes equally spaced on 7.090" diameter B.C. and located per B/P
100	Disassemble
110	Deburr holes
120	Assemble 16 Briles TL100-5-9 taper bolts and secure
130	Recheck alignment per B/P and record
140	Disassemble
150	Magnaflux
160	Inspect to -044 assembly
170	Visually inspect and identify per B/P

RG351-11278-041 Matched Gear Assembly

Seven RG351-11278-042 assemblies constitute a -041 matched gear assembly. Each -042 assembly consists of the -043 gear assembly whereby the counterbore and roller diameters are finish machined.

Operation No.	Description
10	Send the RG351-11278-103 gears to lathe department for operation #20. Hold the RG351-11278-045 set of assemblies at assembly department
20	Turn bore per operation drawing
30	Assemble the top half of RG351-11278-045 matched set with the RG351-11278-103 gear per operation drawing. Both parts must be identified with the same assembly number
40	Grind center bore per operation drawing
50	Disassemble
60	Assemble the RG351-11278-103 gear with the bottom half of RG351-11278-045 matched set per operation drawing. Both parts must be identified with the same assembly number
70	Grind center bore per operation drawing
80	Disassemble
90	Finish grind roller diameters to 9.5335"/9.5331" diameter and true with -A- bore within .005" TIR, 8 micro finish. Note: Parts to be final inspected and recorded
100	Final inspect operation #90 and record
110	Finish grind .0007"/.0009" x .070" gage point taper on one end of roller diameter, 8 micro finish. Polish and blend radii per B/P. Final inspect and record
120	Final inspect operation #110 and record
130	Finish grind .0007"/.0009" x .070" gage point taper on opposite end of roller diameter, 8 micro finish. Polish and blend radii per B/P. Final inspect and record

RG351-11278-041 Matched Gear Assembly (cont'd)

Operation No.	Description
140	Final inspect operation #130 and record
150	Nital etch. Caution!! Handle with extreme care. 8 micro finish
160	Stress relieve for 1.0 hour at 295°/310°. Caution!! Handle with extreme care. 8 micro finish
170	Magnaflux. Caution!! Handle with extreme care. 8 micro finish
180	Verify inspection records. Caution!! Handle with extreme care. 8 micro finish
190	Dulite. Caution!! Handle with extreme care. 8 micro finish
200	Magnaflux. Caution!! Handle with extreme care. 8 micro finish
210	Complete identification and match in sets per B/P notes 13 and 16. Seven -042 assemblies make one -041 assembly. See gear log book. Withdraw 16 TL100-5-9 bolts and 16 TLN1001-5 nuts for each -042 assembly. Package and send with parts. Do not assemble
220	Ultrasonic inspect

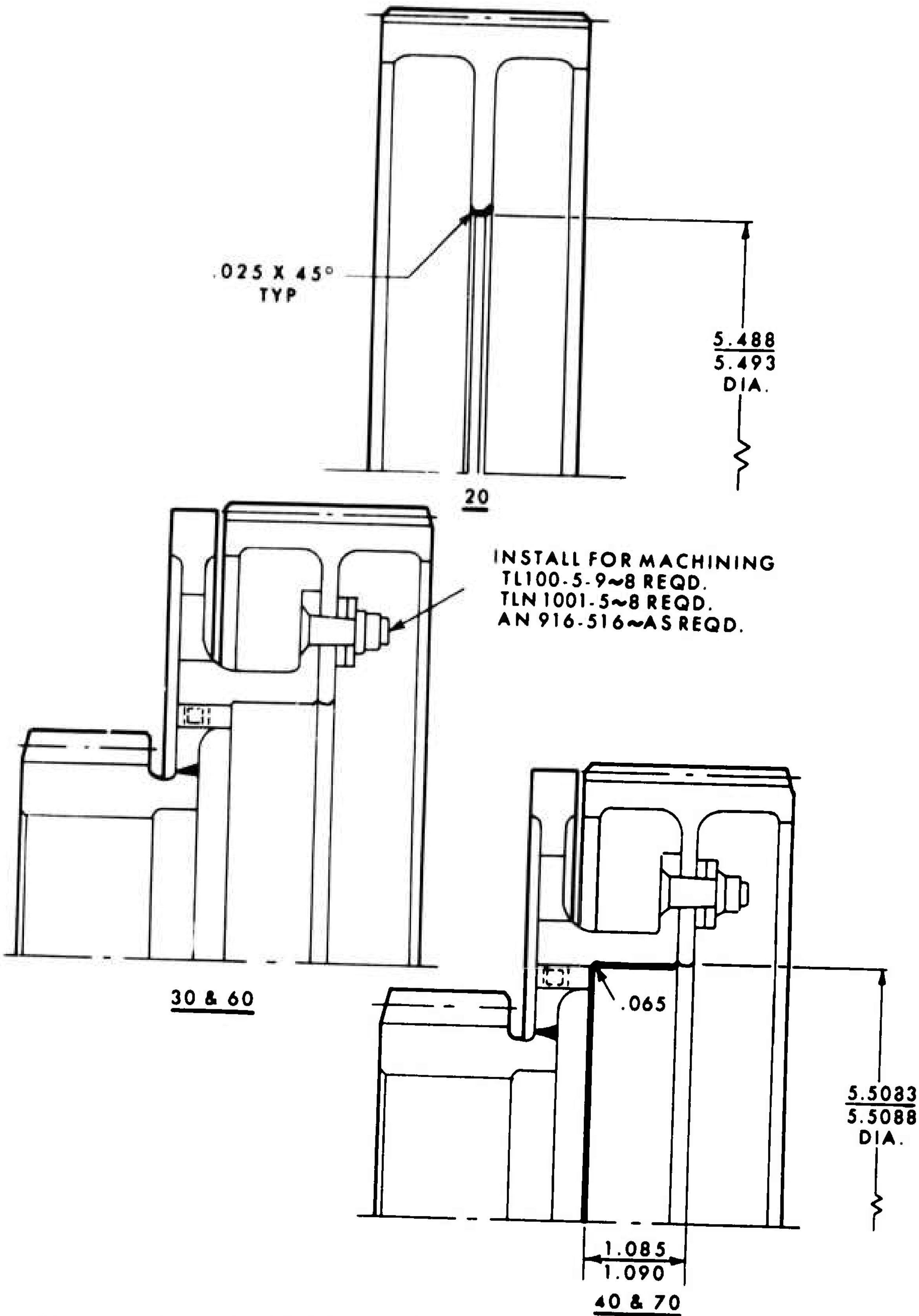


Figure D-8, RG351-11278-041: Machine Operation Drawing.

APPENDIX E

MANUFACTURING PROCEDURE, FIRST-ROW PINION, RG351-11182

Presented in this appendix are the manufacturing procedures used in the fabrication of the first-row pinions, RG351-11182. The pinions are fabricated in matched sets of seven pinions per set, wherein each pinion has the same dimension between the stepped gears with ± .0002 inch.

Figure E-1 depicts the individual parts of the first-row pinion. The detail drawing is shown in Figure E-7.

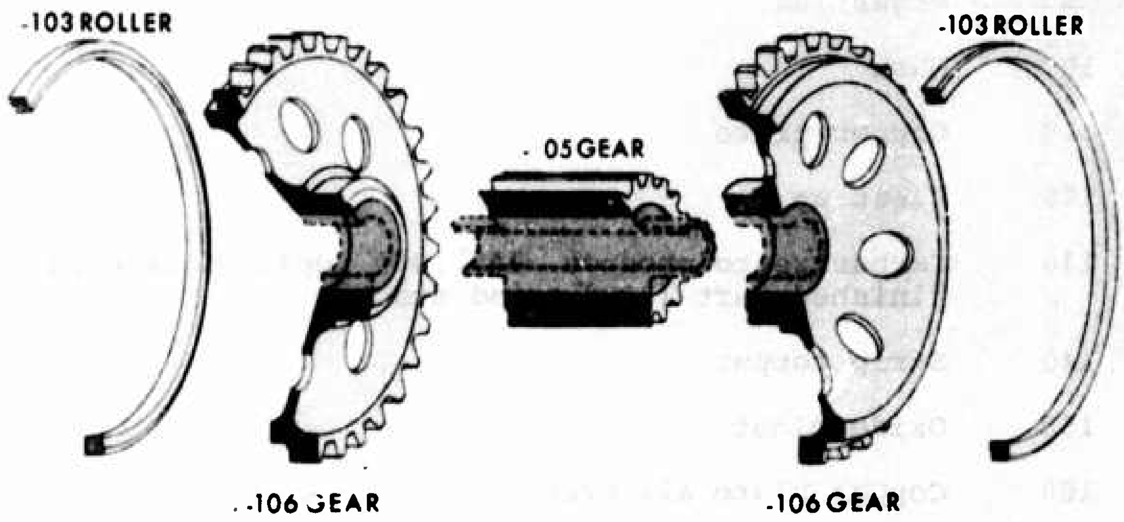


Figure E-1. Exploded View, First-Row Pinion RG351-11182.

RG351-11182-103 Roller

Two rollers per assembly are each fabricated from an AMS-6265-9310 steel forging.

Operation No.	Description
10	Blank per operation drawing
20	Blank per operation drawing
30	Heat treat for machinability
40	Draw to Rc 25-30
50	
55	Drill four holes, equally spaced, on a 6.000" bolt circle diameter in one end. Drill 5/16" diameter x 9/16" tap 3/8"-16 x 1/2" deep, Ref. operation drawing 60
60	Blank and cut off per operation drawing
70	Face flat side to .277"/.273" OAL and chamber I.D. to .030" x 45°
80	Deburr
90	Magnaflux
100	Mask
110	Copper plate
120	Clean up
130	Carburize to produce .045"/.060" depth of case in finished part (.008" grind stock)
140	Strip copper
150	Oxide blast
160	Copper plate all over
170	Harden and quench (flat plates)
180	Freeze
190	Draw to Rc 58-64 case and Rc 30-45 core hardness

RG351-11182-103 Roller

Operation No.	Description
200	Strip copper
210	Inspect H.T. operations and record
220	Bore per operation drawing
230	Lay on flat side. Surface grind chamfered side to .268"/.266" OAL
240	Surface grind flat side to .260"/.258" OAL Parallel to opposite within .001" TIR
250	Finish grind I.D. to 5.513"/5.514" diameter
260	Finish grind O.D. to 6.164"/6.160" diameter concentric to diameter "B" (I.D.) within .001" TIR
270	Nital etch
280	Stress relieve
290	Burr. Break edges .005"-.015" rad max.
300	Clean
310	Magnaflux
320	Inspect
330	Visually inspect and identify

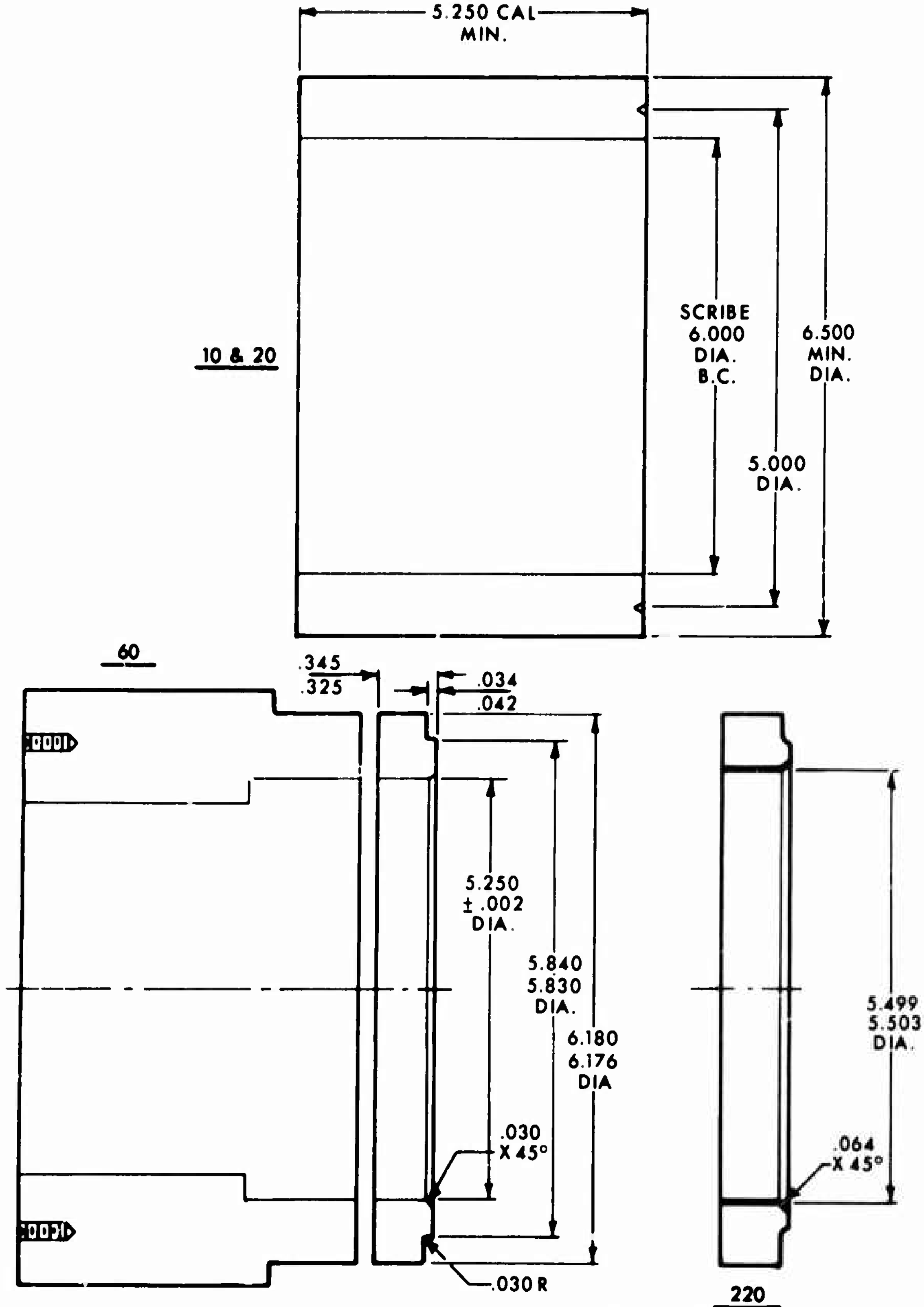


Figure E-2. RG351-11182-103, Machine Operation Drawing.

RG351-11182-105 Spur Gear

The gear is fabricated from bar stock, AMS 6265-3310 steel. The gear teeth are carburized, heat-treated and finish ground.

Operation No.	Description
10	Saw bar to 3.875" OAL per Pc
20	Harden for machinability
30	Draw to Rc 25-30
40	Blank per operation drawing
50	Blank per operation drawing
60	Magnaflux
70	Hob 27 tooth gear pregrind
75	Inspect gear
80	Deburr
90	Mask gear per operation drawing
100	Copper plate
110	Clean up
120	Carburize to produce .010"/.025" depth of case in finished part
130	Strip copper
140	Oxide blast
150	Copper plate all over
160	Harden
170	Freeze
180	Draw to Rc 58-64 case and Rc 30-45 core hardness
190	Strip copper
200	Inspect heat treat operations
210	Bore and blank per operation drawing one end

RG351-11182-105 Spur Gear

Operation No.	Description
220	Form center and blank per operation drawing opposite end
230	Grind centers, both ends, to .090" x 30° true with pitch diameter of gear within .0005" TIR
240	
250	Finish grind .7998" diameter per operation drawing #250-A one end. Finish grind 1.800" diameter per operation drawing #250-B opposite end
260	
270	Finish grind 1.800" diameter per operation drawing #270-A one end. Finish grind 1.800" diameter per operation drawing #270-B opposite end
280	
285	Finish grind gear O.D. to 2.191"/2.189" diameter over odd tooth
290	Finish grind 27 tooth gear per B/P off centers
300	Inspect gear
310	Nital etch
315	Crown etch gear teeth .0003"/.0006" x .472" from end
317	Inspect crown 100%
320	Stress relieve
330	Deburr .005"/.015" corner break except 1.800" diameters to have .005" max. corner break
340	Buff
350	Clean
355	Visually inspect
360	Magnaflux
370	Inspect
380	Identify. Mark the letter "Z" on one tooth

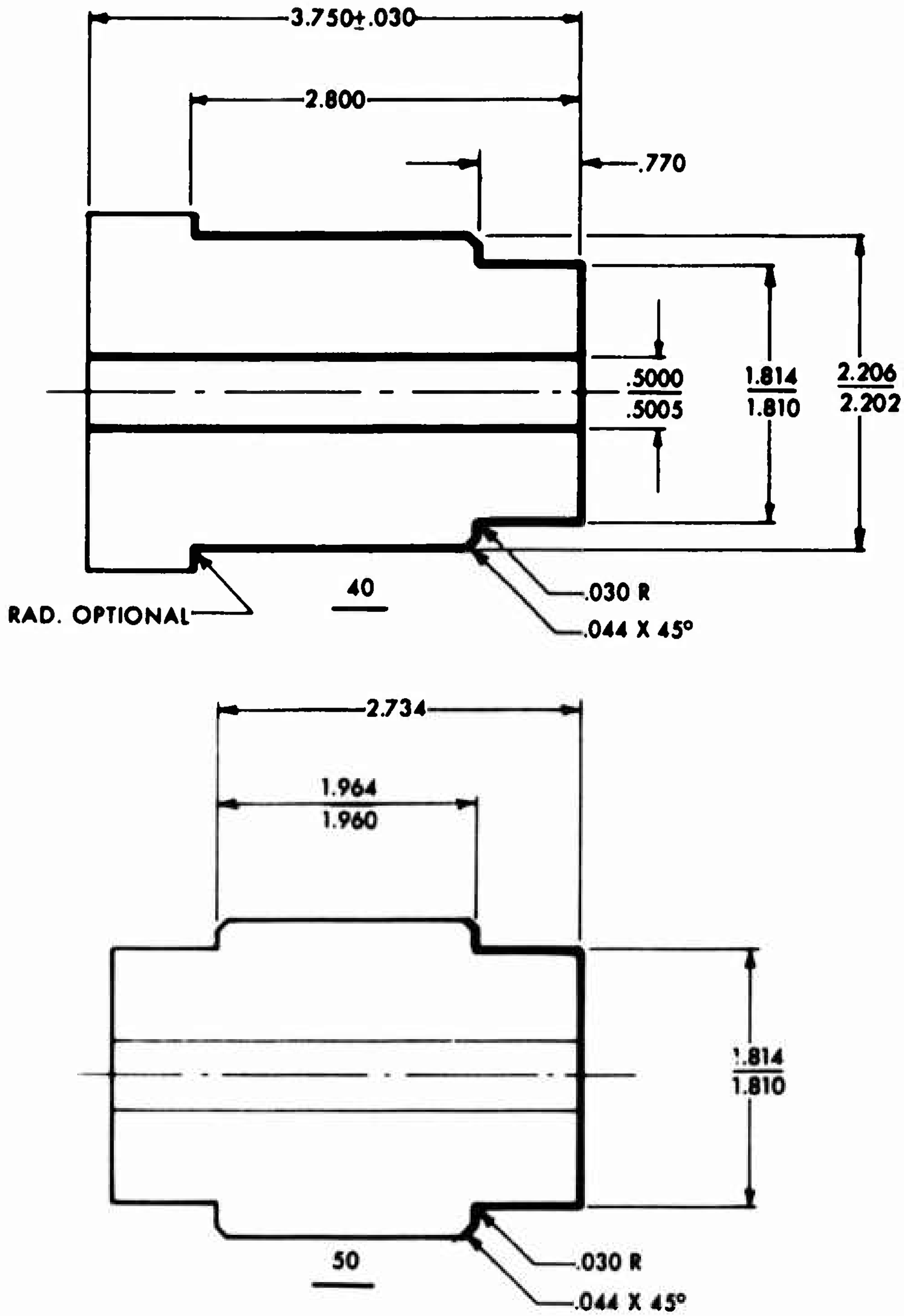
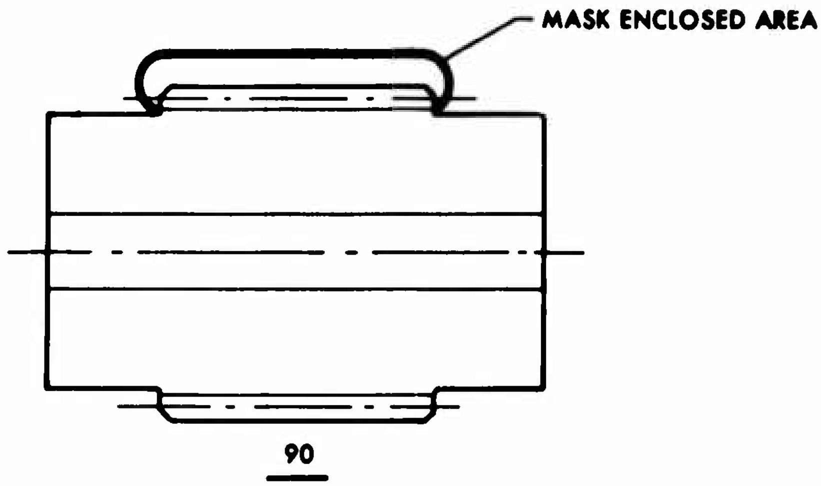


Figure E-3. RG351-11182-105, Machine Operation Drawing. (Sheet 1 of 4.)



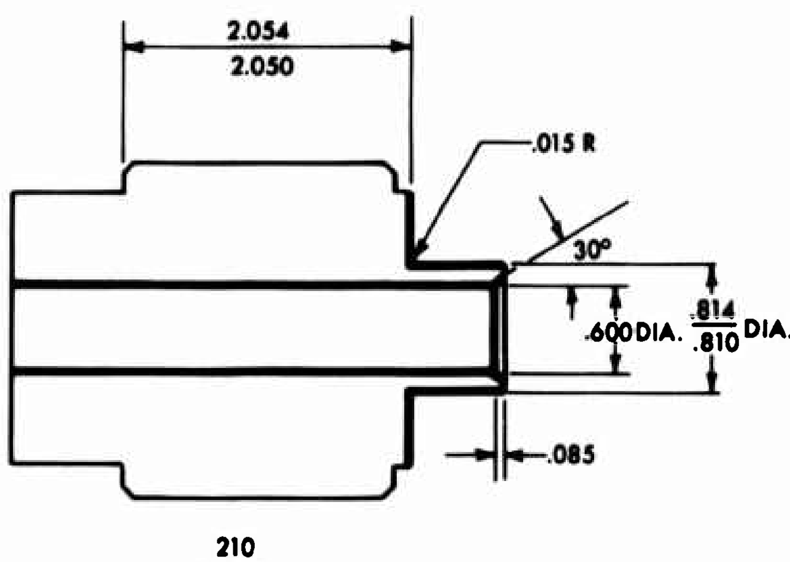
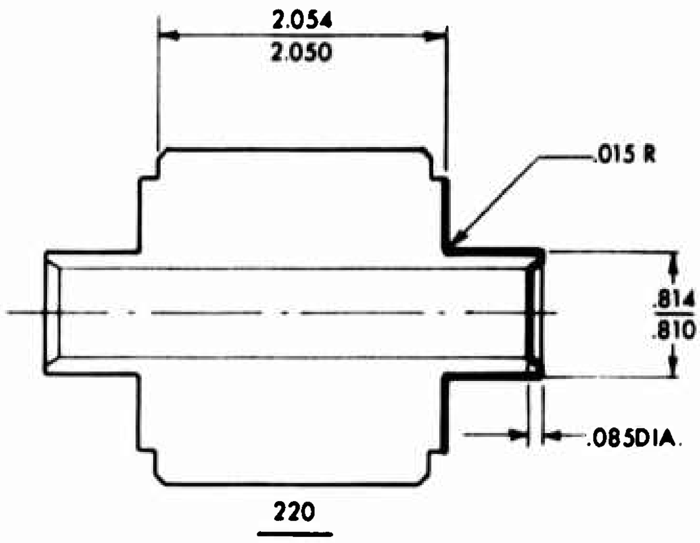


Figure E-3. RG351-11182-105, Machine Operation Drawing. (Sheet 2 of 4).



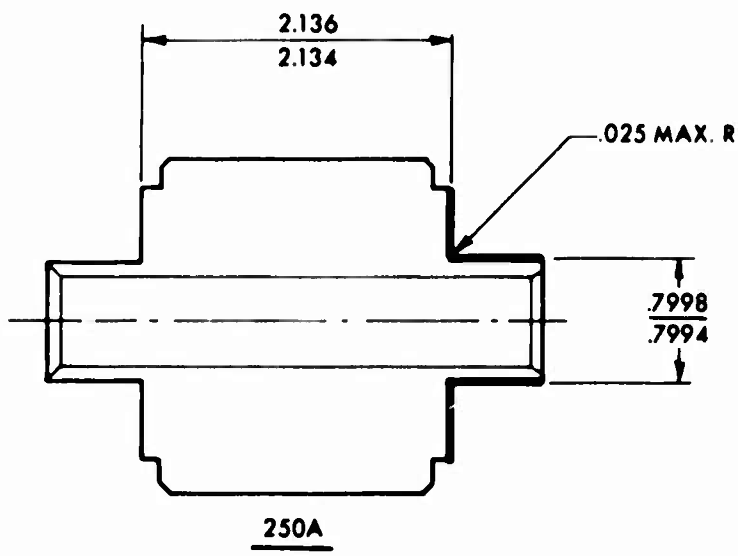


Figure E-3. RG351-11182-105, Machine Operation Drawing. (Sheet 3 of 4).

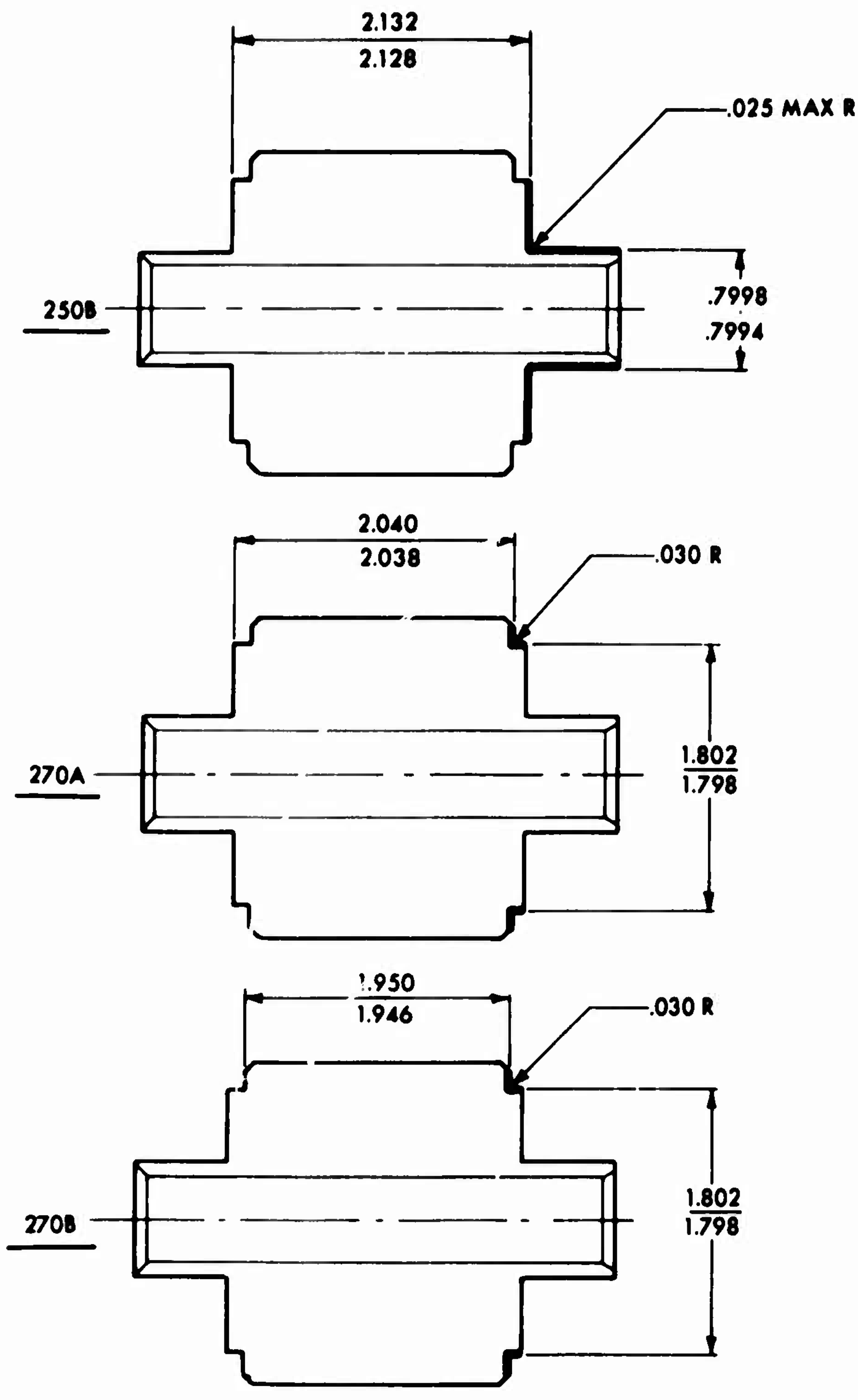


Figure E-3. RG351-11182-105, Machine Operation Drawing. (Sheet 4 of 4).

RG351-11182-106 Gear

Operation No.	Description
10	Heat treat for machinability. Steel stamp mill H.T. code no. on one side of forging
20	Draw to Rc 25-30
30	Blank per operation drawing
35	Blank per operation drawing
40	Blank per operation drawing
50	Magnaflux
60	Surface grind per operation drawing
70	Surface grind per operation drawing
80	Grind I.D. to .6003"/.6007" diameter concentric to bearing O.D. within .002" TIR
90	On magnetic chuck, grind gear O.D. to 6.365"/6.363" diameter concentric to I.D. within .0005" TIR
100	On magnetic chuck, surface grind bearing diameter to 2.079"/2.077" diameter with .030" rad concentric to I.D. within .001" TIR. Hold .582"/.578" dim to .581"/.579" from end of part
110	Hob 58 tooth gear pregrind
115	Inspect gear
120	Deburr
130	Mask 2.068" bearing diameter
140	Copper plate
150	Clean up. Note: Double carb cycle (1st carb)
160	Carburize to produce .090"/.105" depth of case in finished part. Note: This is for 2.068" bearing diameter only
170	Strip copper. Vibro etch carb load no. next to mill H.T. code no. on face

RG351-11182-106 Gear

Operation No.	Description
180	Mask bearing diameter and gear
190	Copper plate
200	Clean up
	Note: 2nd carb
210	Carburize to produce .015/.030 depth of case in the finished part. (Gear) and to produce .090/.105 depth of case in the finished bearing diameter
220	Strip copper
230	Oxide blast
240	Copper plate all over
250	Harden. Quench between flat plates
260	Freeze
270	Draw to Rc 58-64 case - Rc 30-45 core
280	Strip copper
290	Inspect heat treat operations
300	Trace web and bore per operation drawing
310	Turn per operation drawing
315	Turn per operation drawing
320	Trace web per operation drawing
330	Polish webs. Do not remove mill H.T. and carb load no's. reference operation drawing
334	Vibro etch serial numbers lightly in web
335	Inspect
340	Drill eight .750" ± .010" diameter web holes through on 3.750" ± .010" diameter bolt circle, equally spaced
350	Surface grind per operation drawing

RG351-11182-106 Gear

Operation No.	Description
360	Surface grind per operation drawing
370	Surface grind per operation drawing
380	Finish grind I.D. to .8000"/.8004" diameter concentric to P.D. of gear within .001" TIR
385	Grind face per operation drawing
390	Grind O.D. per operation drawing
400	Finish grind bearing diameter to 2.068"/2.067" diameter with .030 rad. Bump seat to .578"/.582" from end of part. Concentric to I.D. within .001" TIR
410	Grind 1.800" diameter to 1.802"/1.798" diameter with .030 rad. Bump seat to .085"/.987" dim from end of part. Concentric to I.D. within .001" TIR
420	Nital etch
430	Stress relieve
440	Burr. Note: Gear is not finish ground. Hold .005" max break around end of 1.800" hub O.D.
450	Polish. Hold .005" max break around end of 1.800" hub O.D.
460	Clean
465	Visually inspect
470	Magnaflux
480	Inspect. Note: These dim's to be finished in the -053 weld assembly. Gear O.D., .664"/.666" dim, .407"/.405" dim, 5.515"/5.514" diameter, and gear to be finish ground under -053 assembly. Stock is left on front face and gear to allow for shrinkage and distortion during EBW. Web ref. operation drawing no. 300 and 310
490	Identify. Remove vibro etched nos. from web. Ref. operation drawing no. 300 and 310

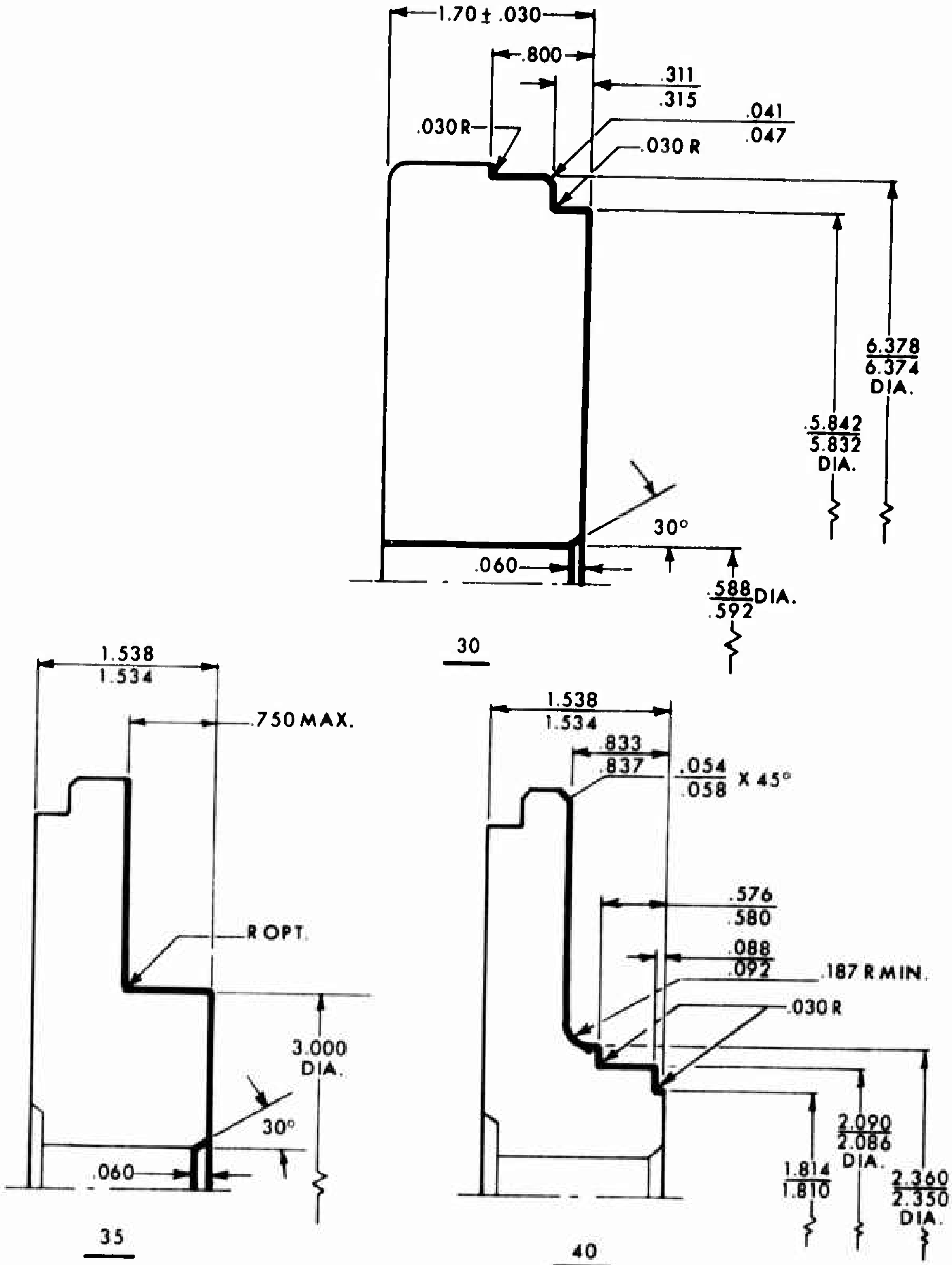


Figure E-4. RG351-11182-106, Machine Operation Drawing. (Sheet 1 of 4).

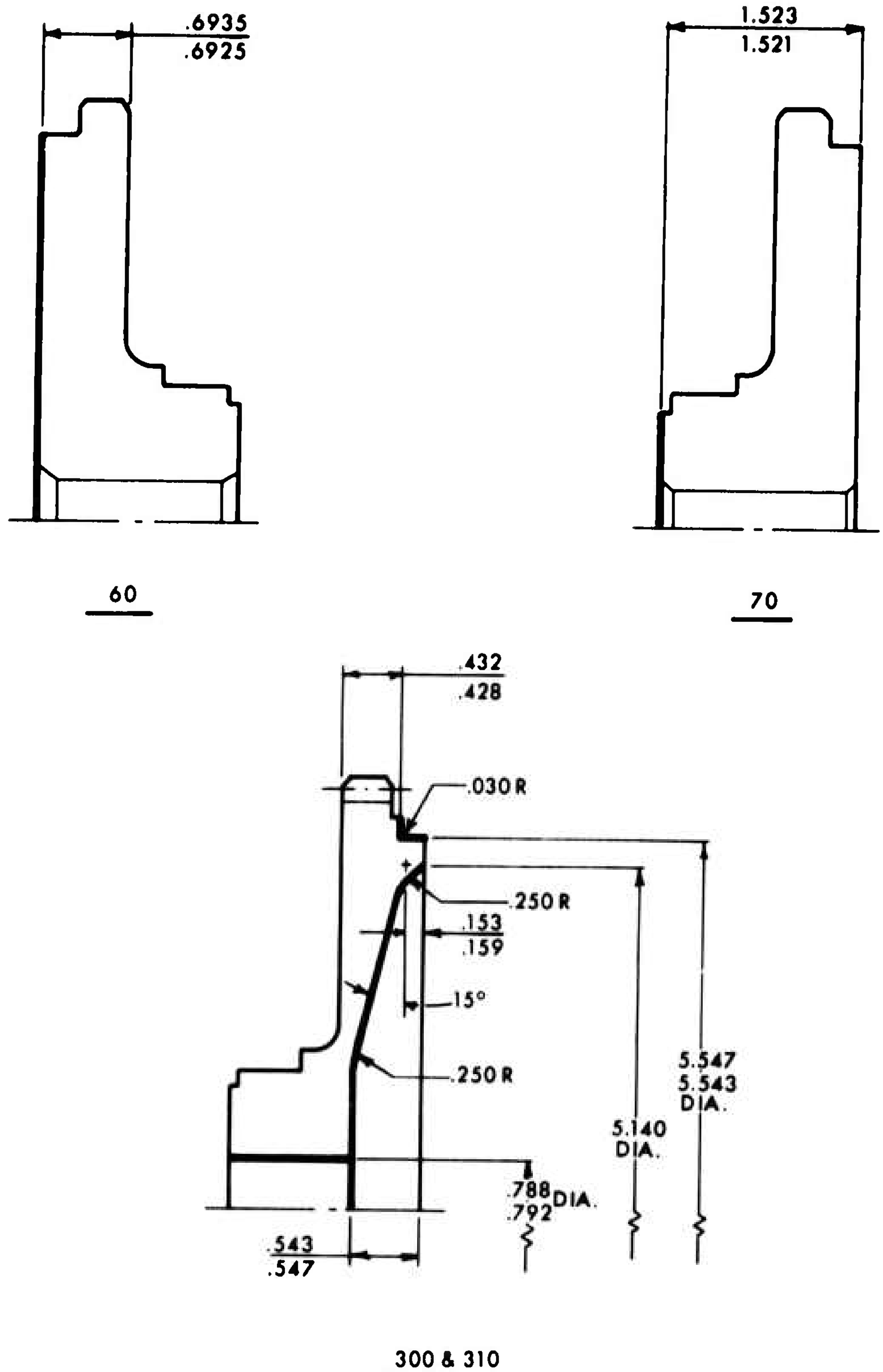
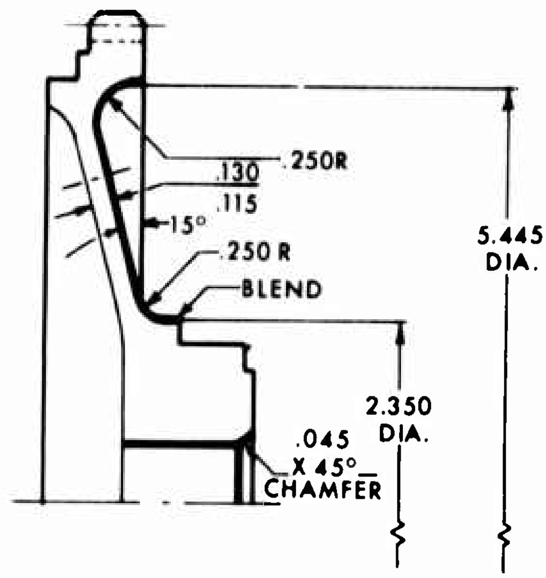
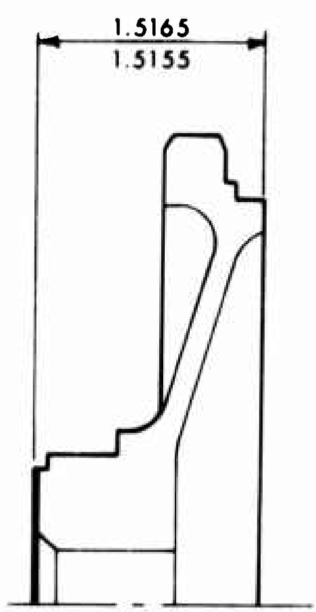


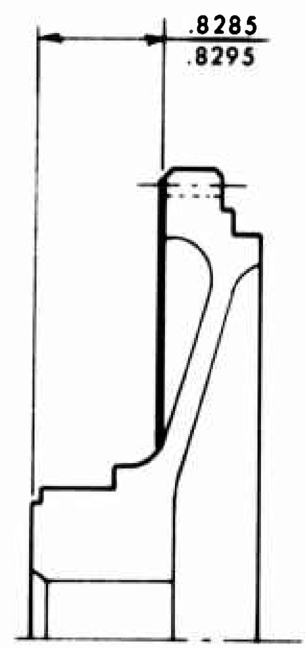
Figure E-4. RG351-11182-106, Machine Operation Drawing. (Sheet 2 of 4).



315 & 320



350



360

Figure E-4. RG351-11182-106, Machine Operation Drawing. (Sheet 3 of 4).

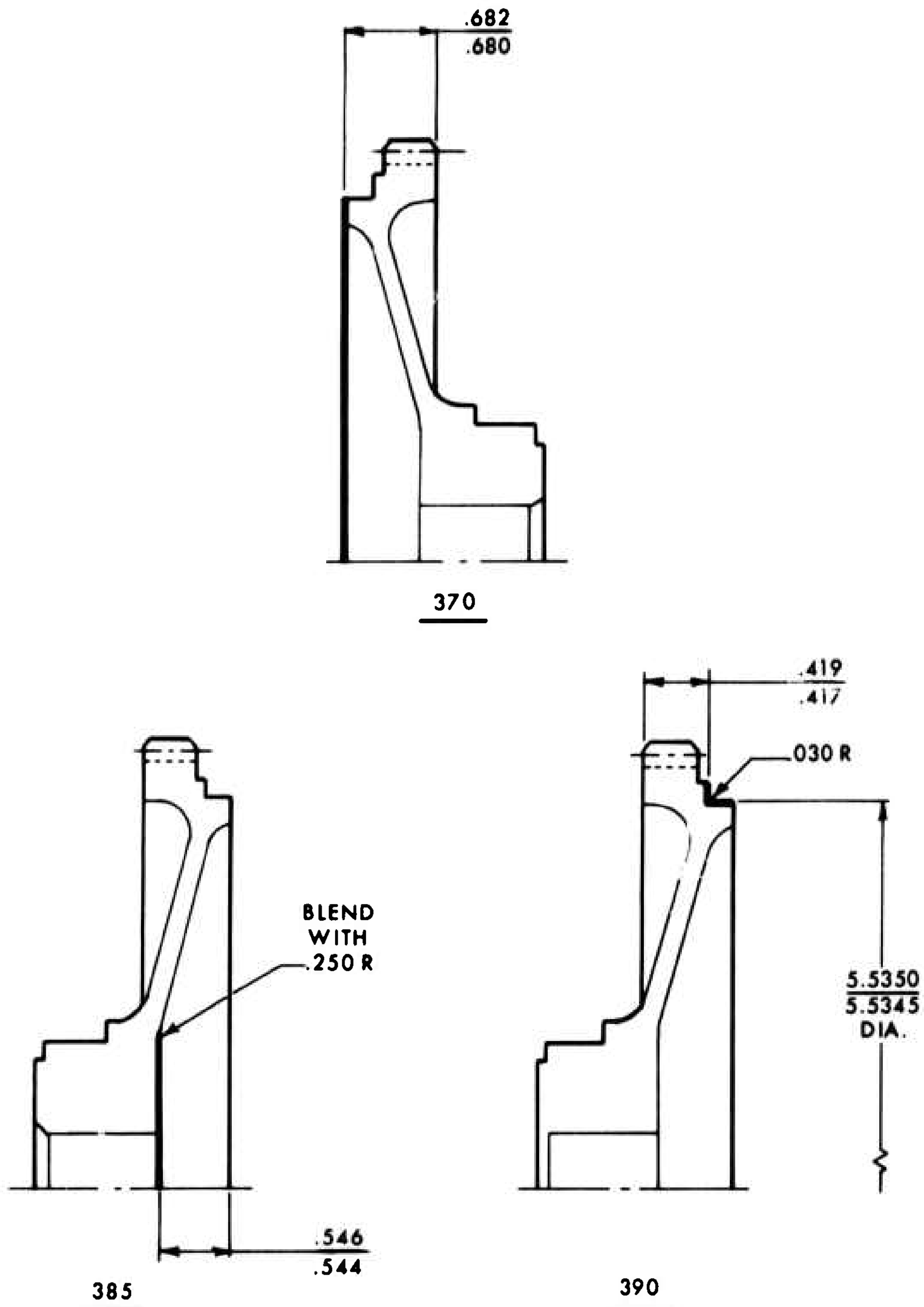


Figure E-4. RG351-11182-106, Machine Operation Drawing. (Sheet 4 of 4).

RG351-11182-063 Welded Gear Assembly

This gear assembly consists of two RG351-11182-106 gears electron-beam-welded to an RG351-11182-105 small diameter gear

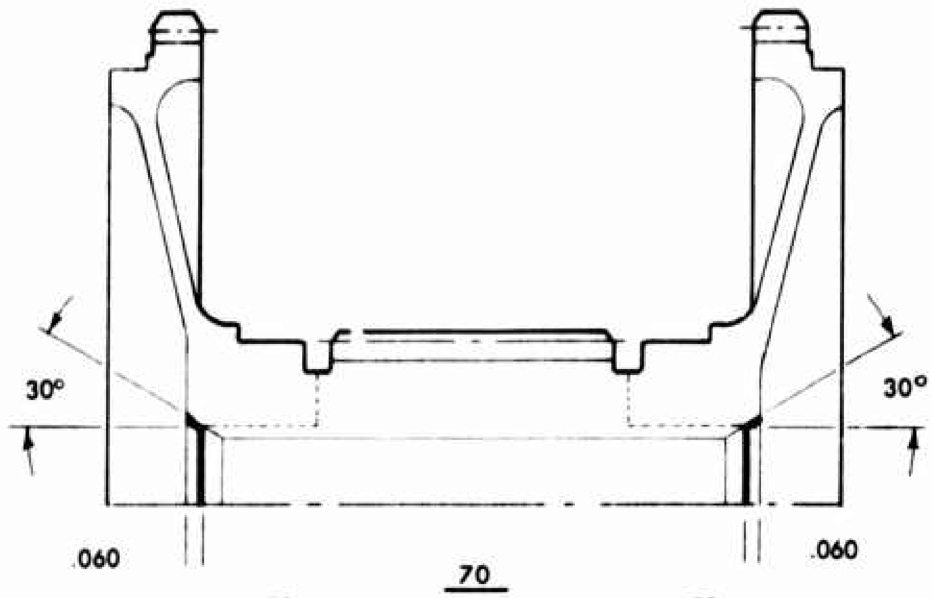
Operation No.	Description
10	Clean with MEK, assemble one RG351-11182-105 gear and two RG351-11182-106 gears on fixture. Note: Timing. -106 gears to be timed with -105 gear. Timing to be the same on seven sets within .001" TIR
20	Inspect assembly. Tooth-to-tooth timing to be the same within .002" total; the teeth are to be aligned good enough to allow grind stock for gear grind. Note large gears are cut pregrind at this time. Check face runout on each end of large gears. Not to exceed .002" TIR
30	EBW one end
40	EBW opposite end
50	Stress relieve at 325° ± 10° for 5.0 hours
60	Inspect visually
70	Grind centers per operation drawing
80	Off centers of large gears. Inspect concentricity and lead of small gear. P.D. to be concentric within .005" TIR
90	Semifinish grind per operation drawing
100	Semifinish grind per operation drawing
110	Grind 1.720" x .217" dim per operation drawing
120	Grind 1.720" x .217" dim per operation drawing
130	Grind .030" x 45° chamfer both ends of small gear
140	Magnaflux weld joints
150	Bore per operation drawing
160	X-ray weld joints
170	Bore and center per operation drawing

RG351-11182-063 Welded Gear Assembly

Operation No.	Description
180	Center per operation drawing
190	Grind bore per operation drawing
200	Grind both faces per operation drawing
210	Grind center per operation drawing
220	Grind center per operation drawing
230	Inspect gears and record
240	Grind end face per operation drawing
250	Grind end face per operation drawing
260	Grind face per operation drawing
270	Grind face per operation drawing
280	Grind gear O.D. per operation drawing
290	Grind gear O.D. per operation drawing
300	Grind 5.515" diameter per operation drawing
310	Grind 5.515" diameter per operation drawing
320	Finish grind 58 tooth gears. To be ground in set. Note: "X" dim must be held and recorded
330	Inspect gear teeth and "X" dim. Record and mark tooth with letter Z
340	Nital etch
350	Stress relieve
360	Burr. Break 5.515" diameter on front edge .005" max. Break edges of large gears .005"/.015". Break end edges of small gear .015"/.025"
370	Polish
380	Clean

RG351-11182-063 Welded Gear Assembly

Operation No.	Description
390	Magnaflux
400	Inspect
410	
420	Visually inspect and identify



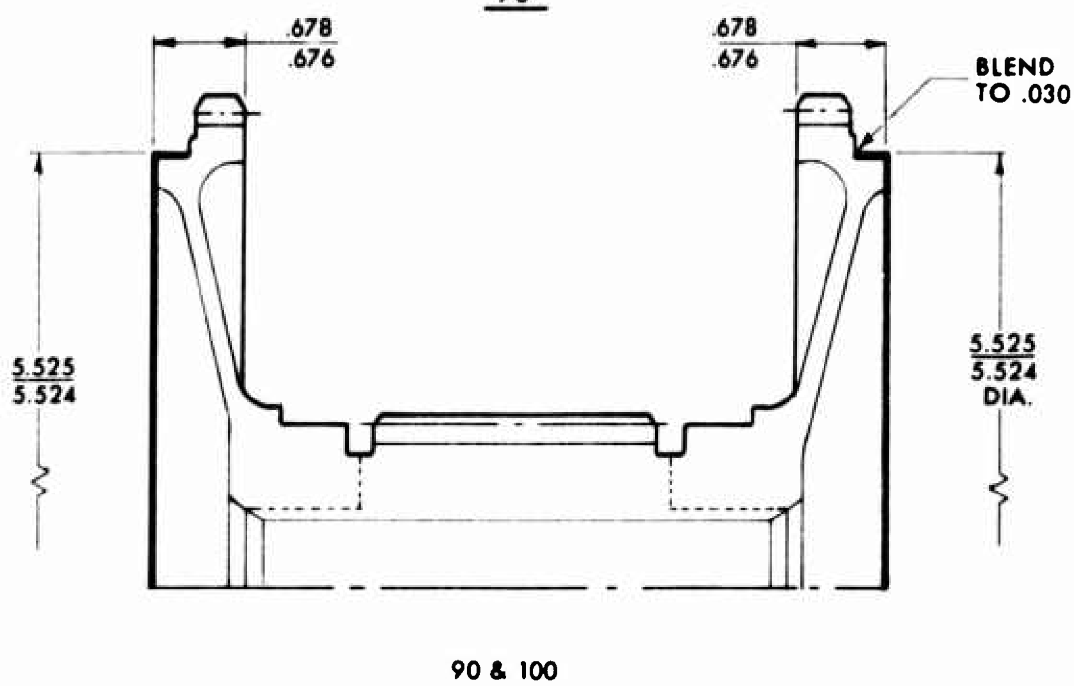
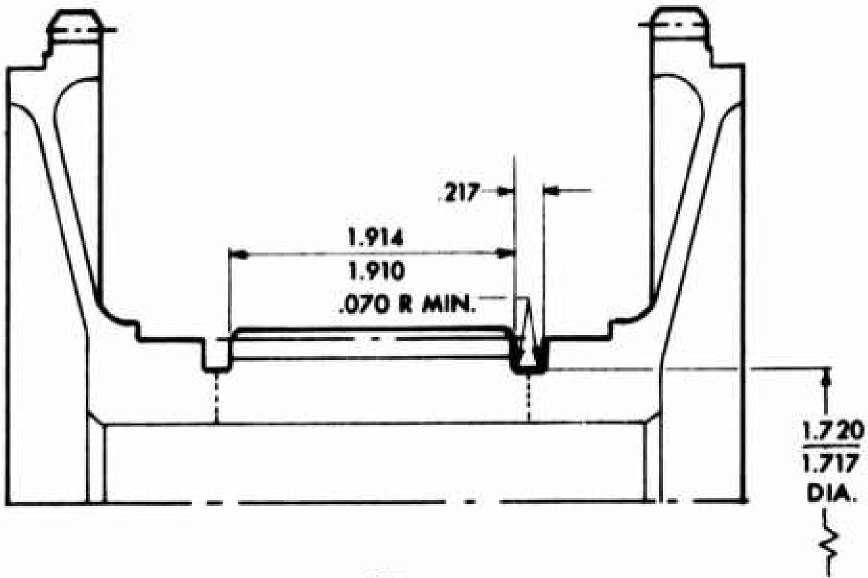


Figure E-5. RG351-11182-063, Machine Operation Drawing.
(Sheet 1 of 7).



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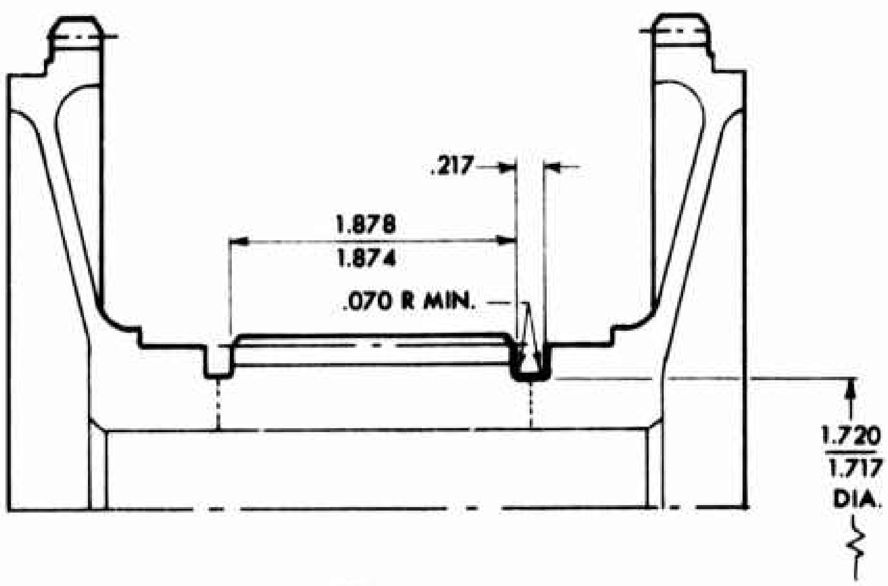
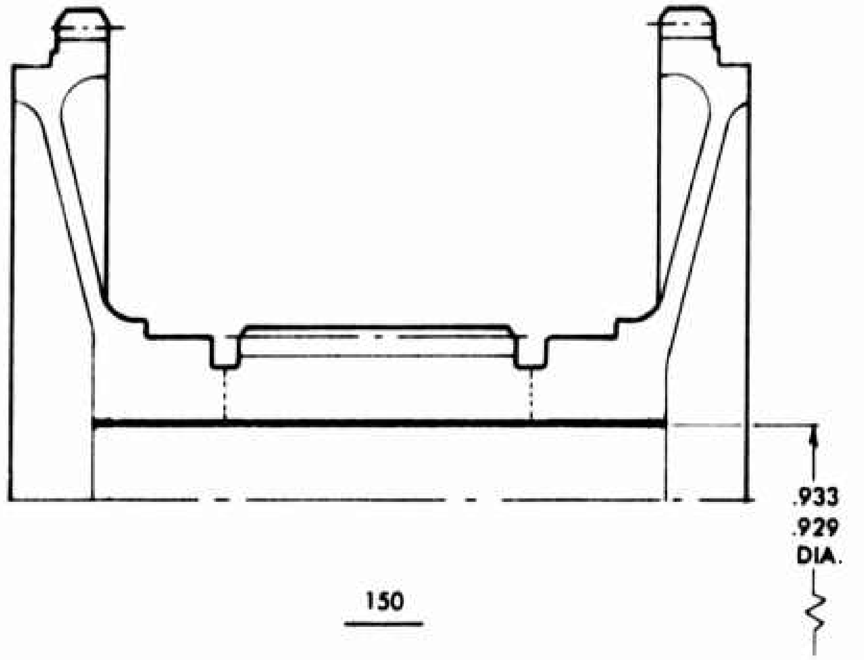


120

Figure E-5. RG351-11182-063, Machine Operation Drawing. (Sheet 2 of 7).



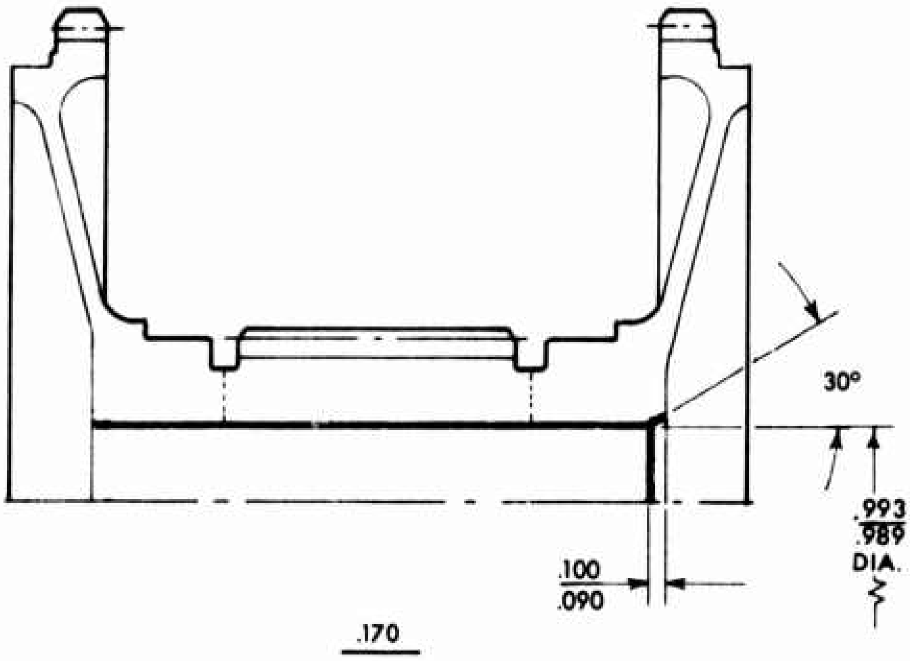
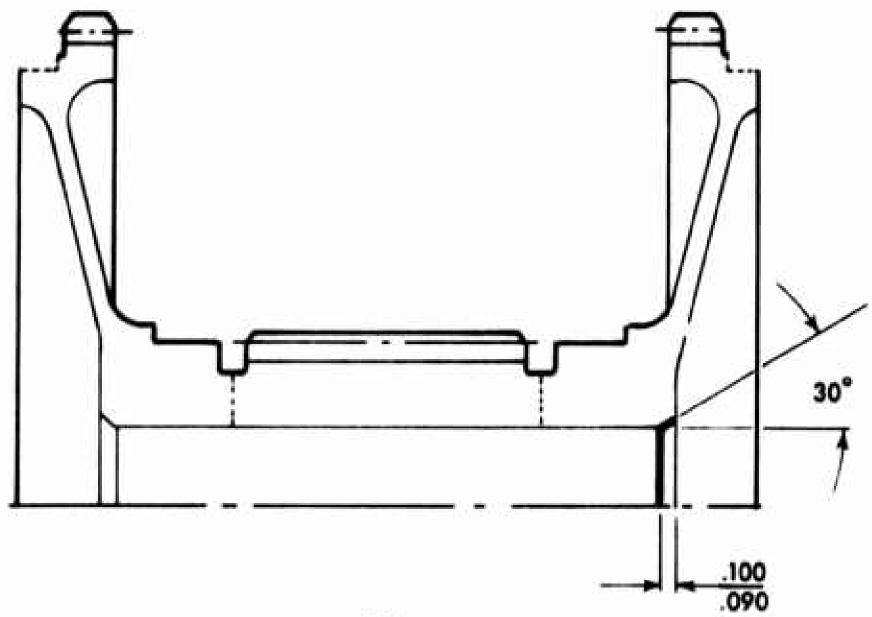


Figure E-5. RG351-11182-063, Machine Operation Drawing. (Sheet 3 of 7).



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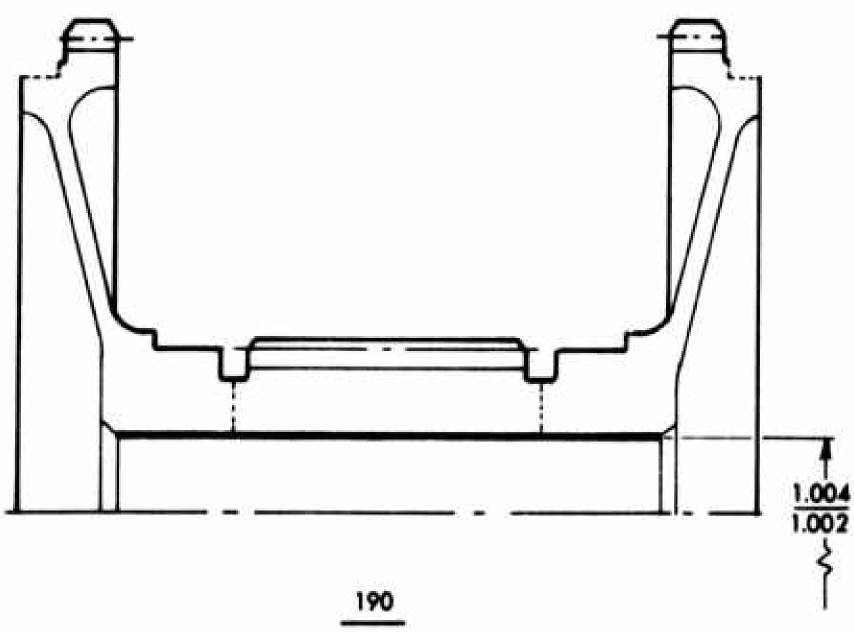

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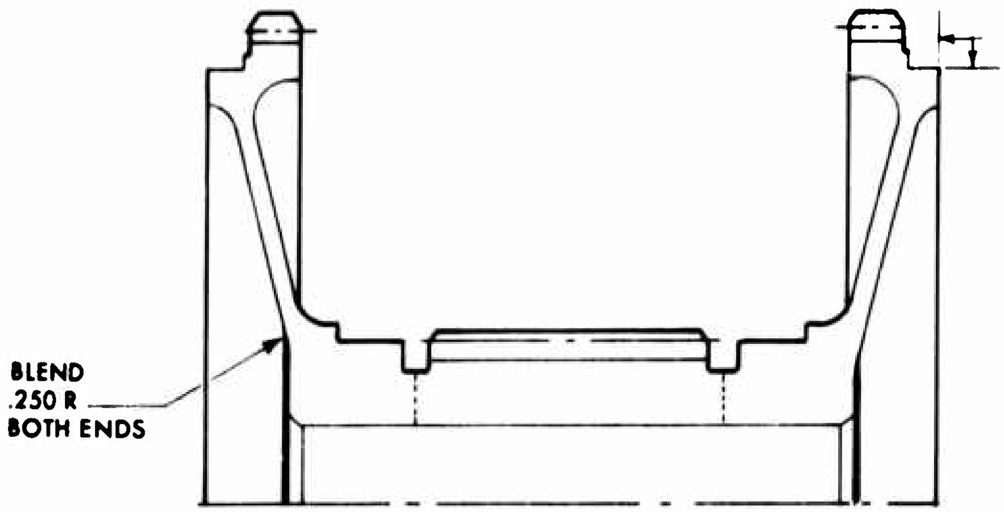
Figure E-5. RG351-11182-063, Machine Operation Drawing. (Sheet 4 of 7).



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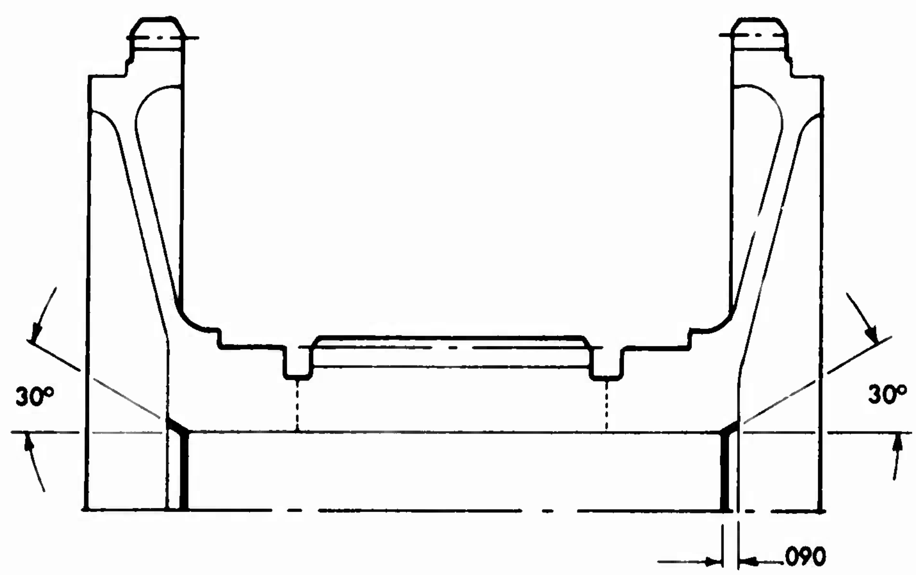
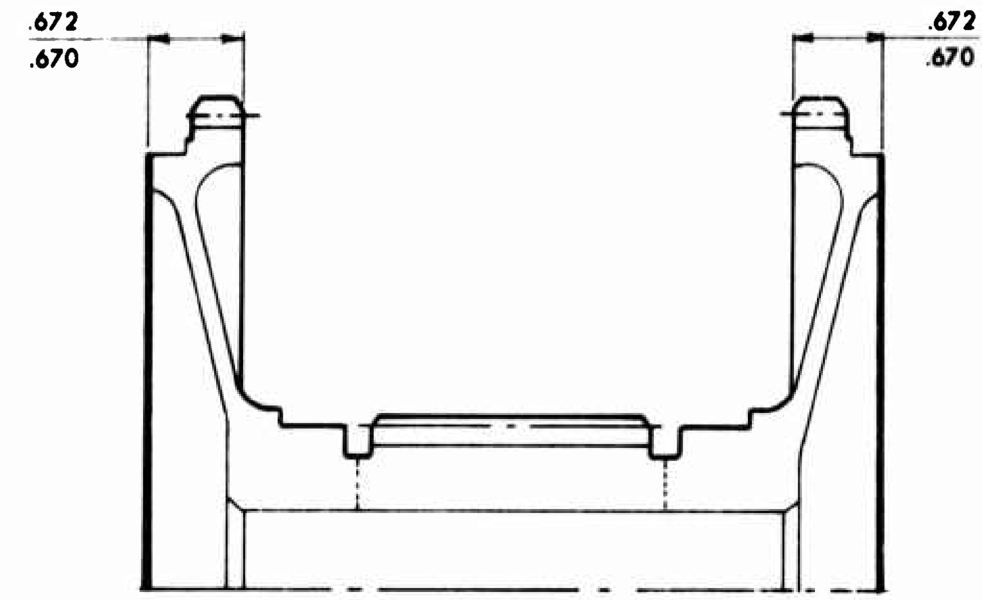
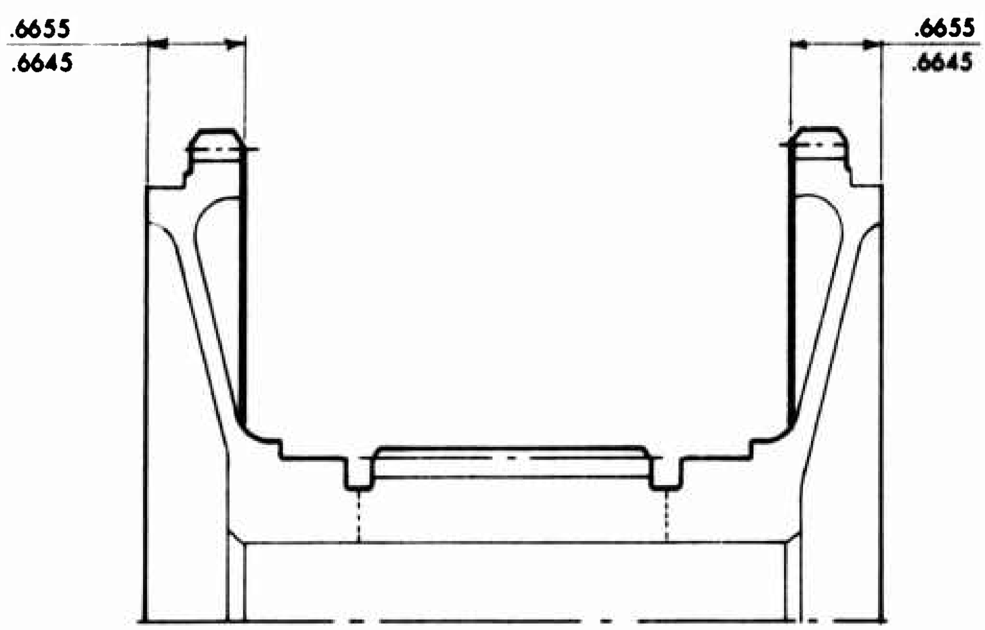


210 & 220

Figure E-5. RG351-11182-063, Machine Operation Drawing. (Sheet 5 of 7).

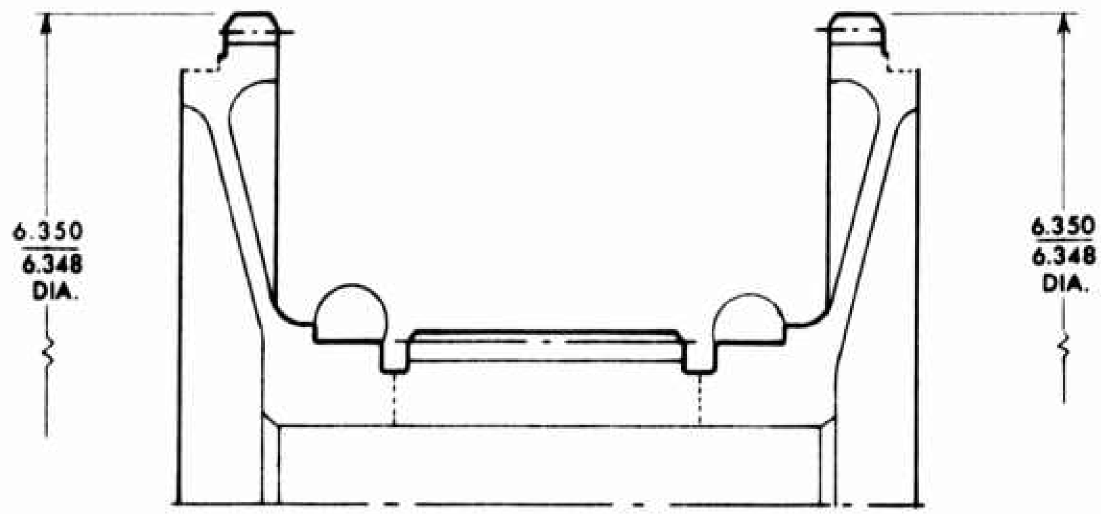


240 & 250

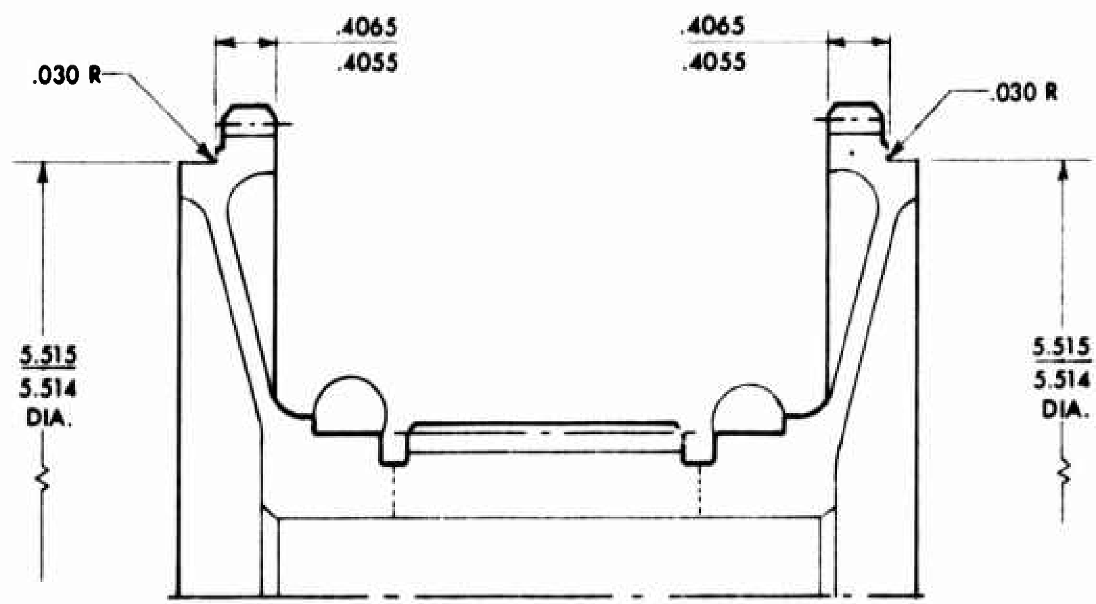


260 & 270

Figure E-5. RG351-11182-063, Machine Operation Drawing. (Sheet 6 of 7).



280 & 290



300 & 310

Figure E-5. RG351-11182-063, Machine Operation Drawing. (Sheet 7 of 7).

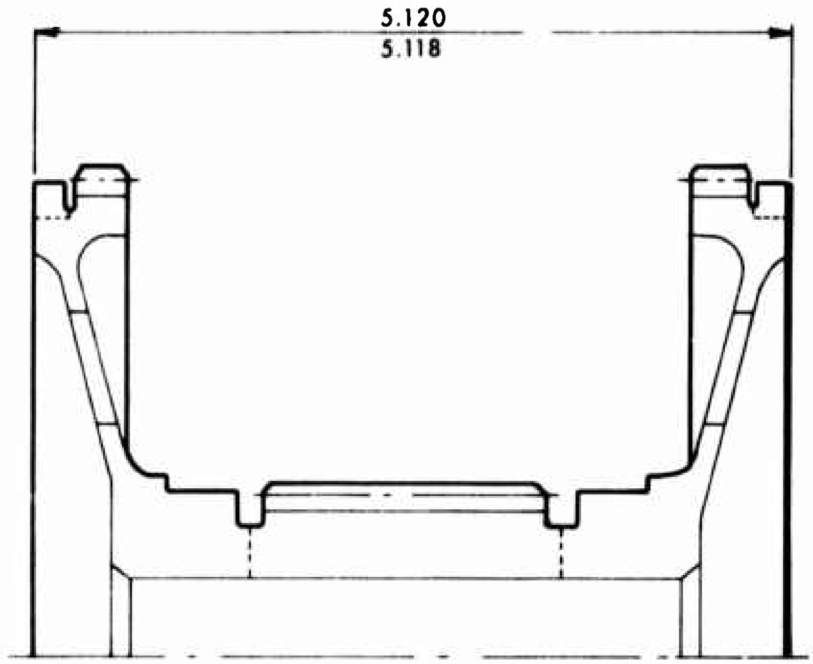
RG351-11182-061 First-Row Pinion Assembly

Each RG351-11182-061 assembly consists of seven RG351-11182-062 assemblies fabricated as a matched set. Each RG351-11182-062 assembly consists of two RG351-11182-103 rollers welded to an RG351-11182-062 gear assembly

Operation No.	Description
10	Withdraw the following parts from finished stores, clean with MEK and assemble. Do not remove identification when cleaning one RG351-11182-063 gear assembly two RG351-11182-103 rollers To make one RG351-11182-062 gear assembly, keep as matched sets - seven per set
20	Inspect assembly. Check fit and mismatch
30	EBW one ring
40	EBW opposite ring
50	Stress relieve at 325° ± 10° for 5.0 hours
60	Inspect visually
70	Grind end face to remove weld bead per operation drawing
80	Grind opposite end face to remove weld bead per operation drawing
90	Magnaflux weld joints on large end faces
95	Shot peen area indicated .012"/.016"A
100	Reinspect large gears each end for distortion and record
110	Grind bearing diameter per operation drawing Note 8 micro finish
120	Grind bearing diameter per operation drawing Note 8 micro finish
130	Grind end of part per operation drawing
140	Grind end of part per operation drawing

RG351-11182-061 First-Row Pinion Assembly

Operation No.	Description
150	Grind roller diameter per operation drawing Note 8 micro finish
160	Grind roller diameter per operation drawing Note 8 micro finish
170	Grind .050"/.055" rad on roller diameter one end
180	Grind .050"/.055" rad on roller diameter opposite end
190	Grind .020" rad on roller diameter one end
200	Grind .020" rad on roller diameter opposite end
210	Nital etch
220	Stress relieve
230	Burr
240	Clean
250	Magnaflux
260	Inspect gears and record
270	Inspect. Match seven RG351-11182-062 gear assemblies as noted per B/P note #21. Furnish as a matched set assembly
280	Identify. Keep as matched sets. Note: Each set to carry same serial no.
290	Mask for parco per operation drawing
300	Parco
310	Clean up
320	Bake
330	Magnaflux
340	Visually inspect and check identification. Keep in matched sets
360	Ultrasonically inspect weld joints.



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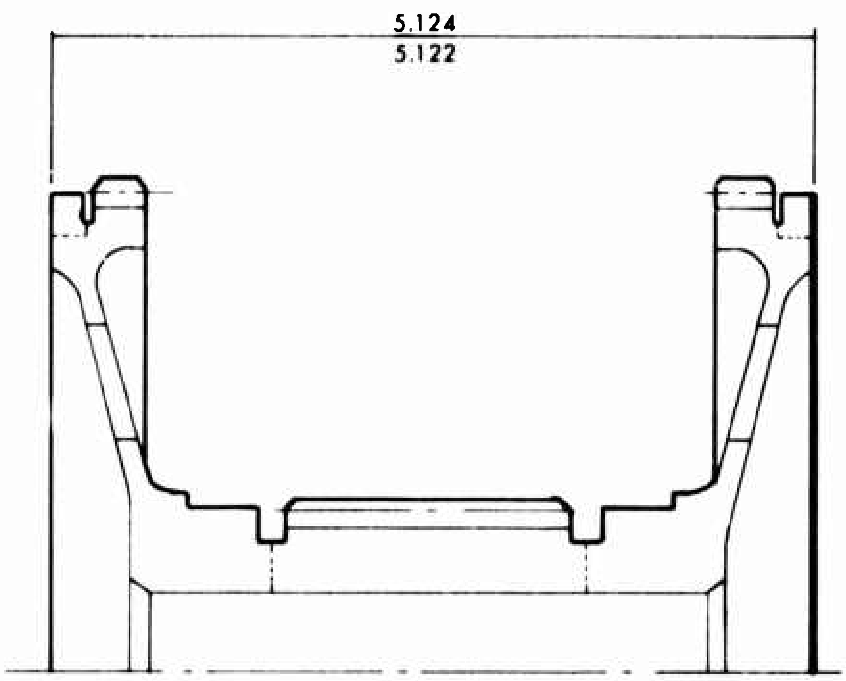

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Figure E-6. RG351-11182-061, Machine Operation Drawing. (Sheet 1 of 3).

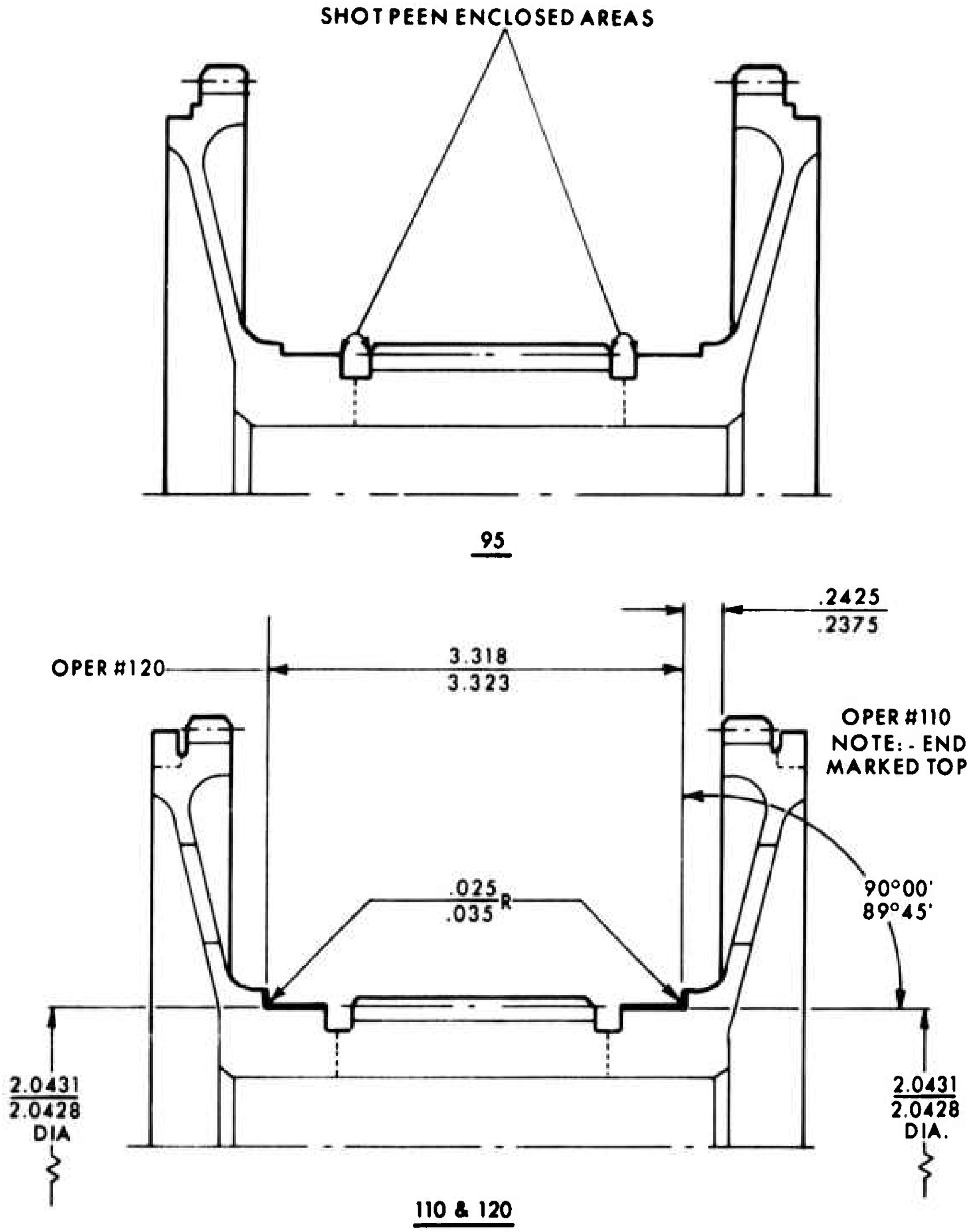


Figure E-6. RG351-11182-061, Machine Operation Drawing. (Sheet 2 of 3).

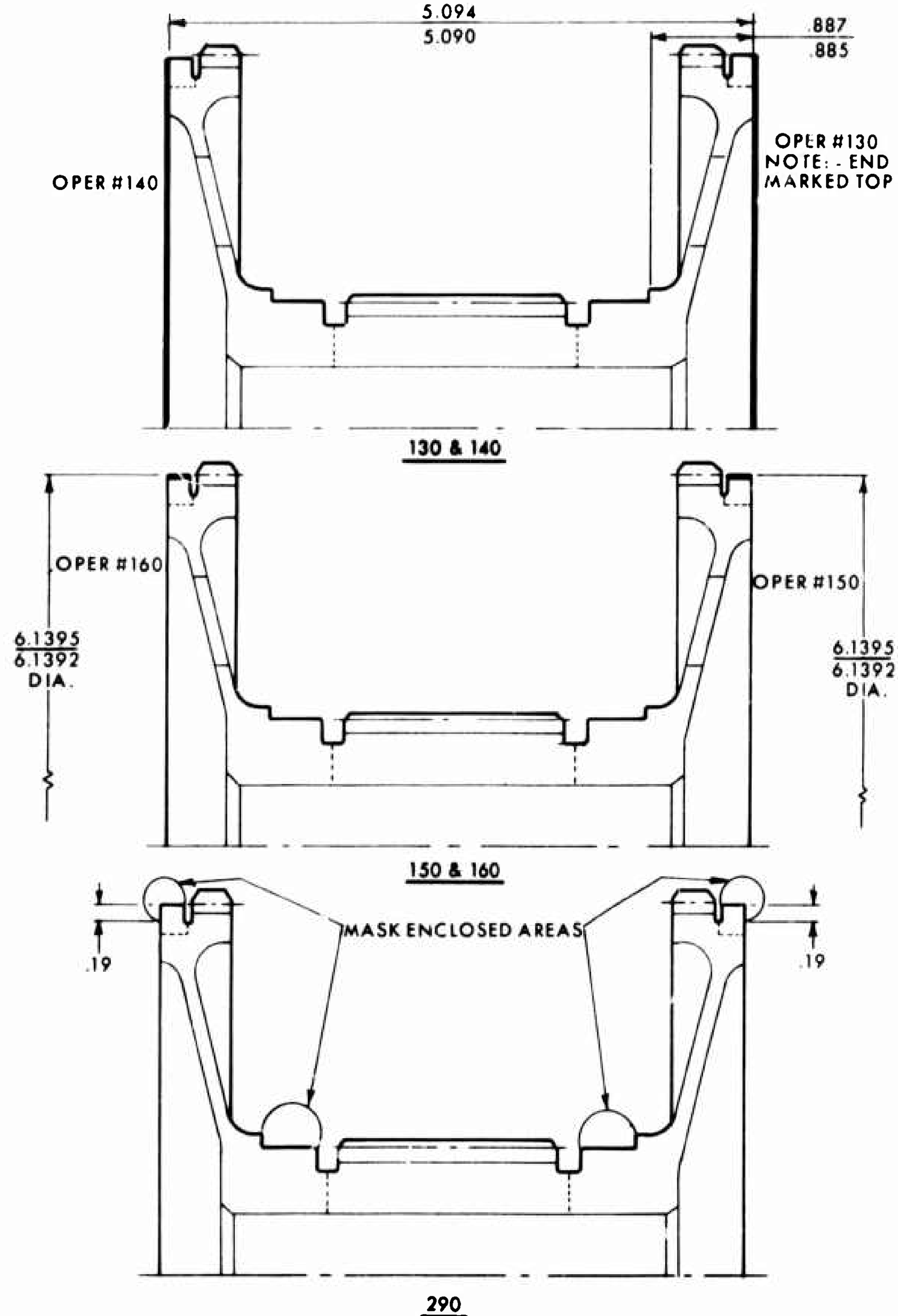


Figure E-6. RG351-11182-061, Machine Operation Drawing. (Sheet 3 of 3).

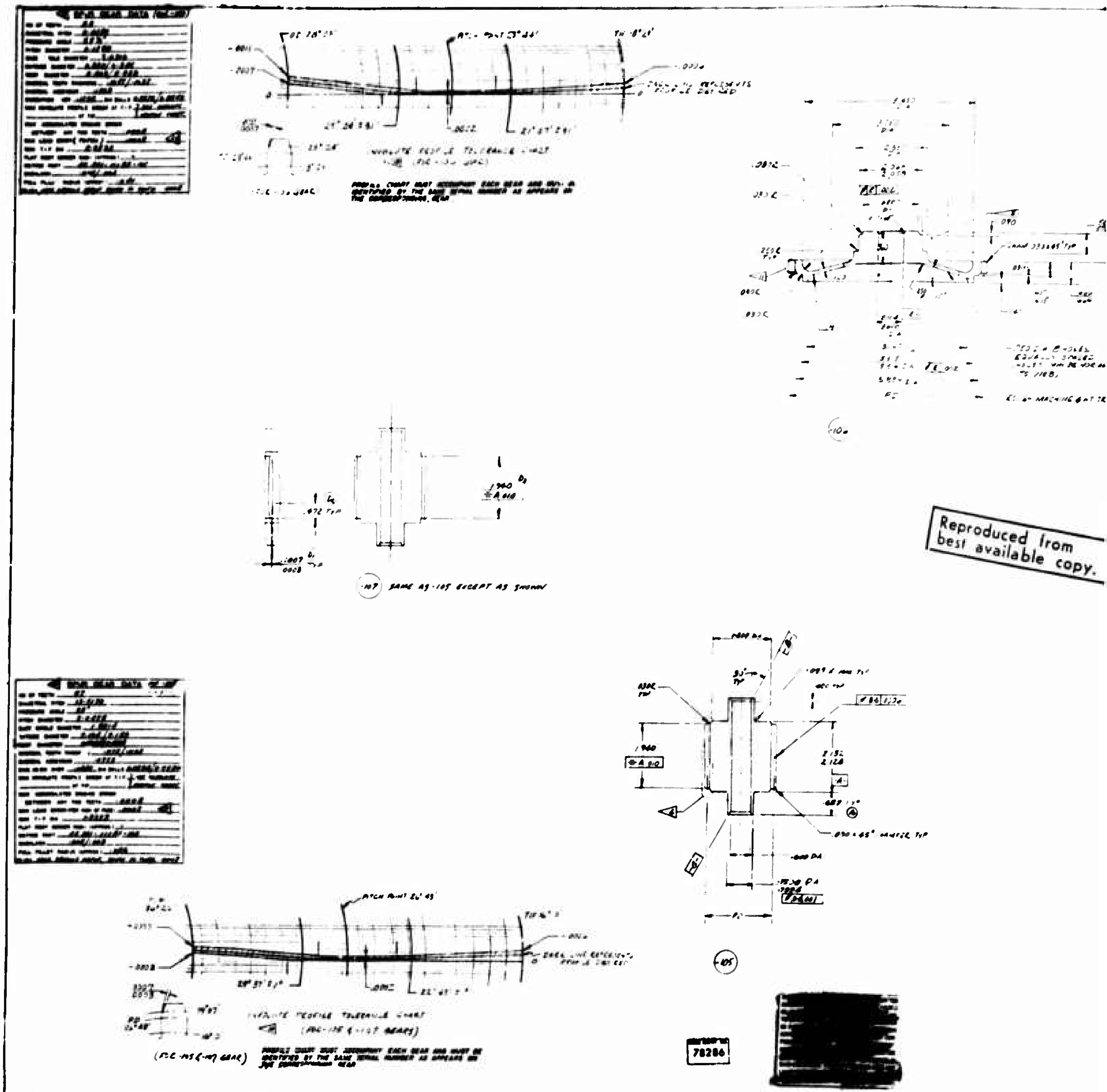
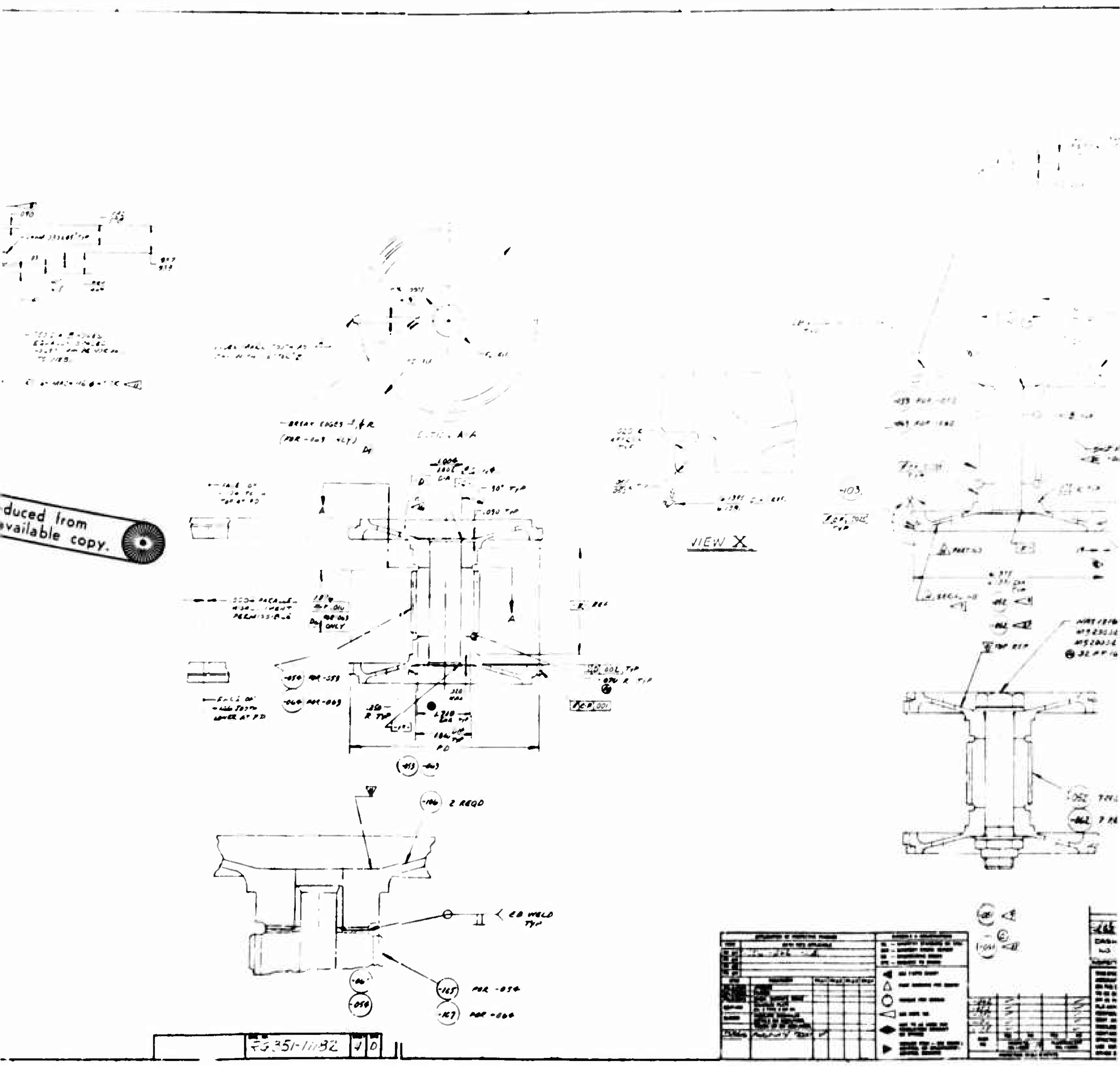
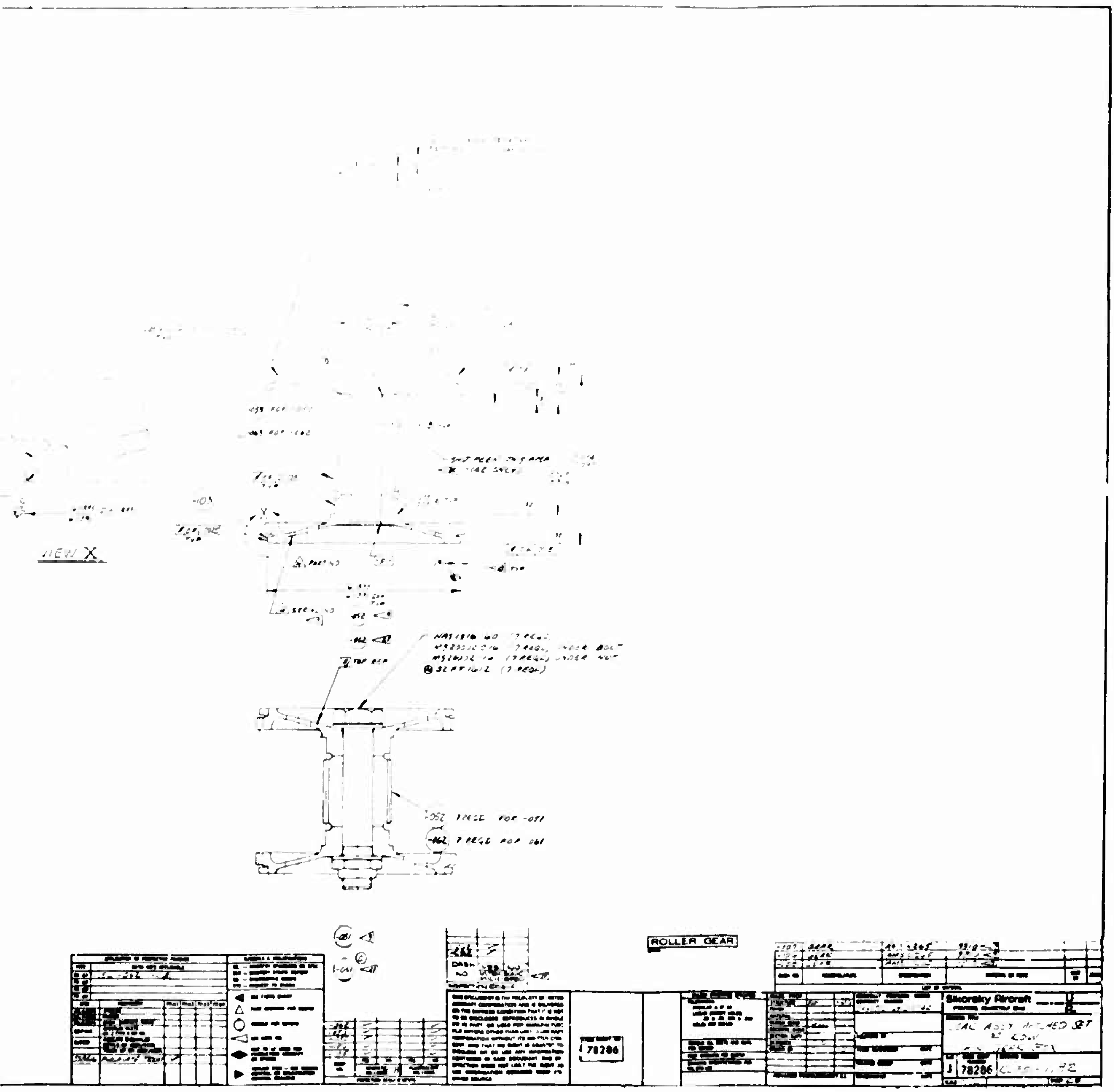


Figure E-7. RG351-11182 First-Row Pinion Drawing.


BREAK EDGES
VIEW X
-103
2 REQD
EB WELD TYP
FOR -054
FOR -064
PD
FG351-11182



VIEW X
ROLLER GEAR
Sikorsky Aircraft
78286
J

APPENDIX F

MANUFACTURING PROCEDURE, SUN GEAR RG351-11183

This appendix presents the manufacturing process sheets used in the fabrication of the sun gear. The sun gear assembly consists of two rollers, RG351-11183-102, which are electron-beam-welded to a gear shaft, RG351-11183-101.

Figure F-1 shows an exploded view of the sun gear. A detail drawing is presented in Figure F-4.

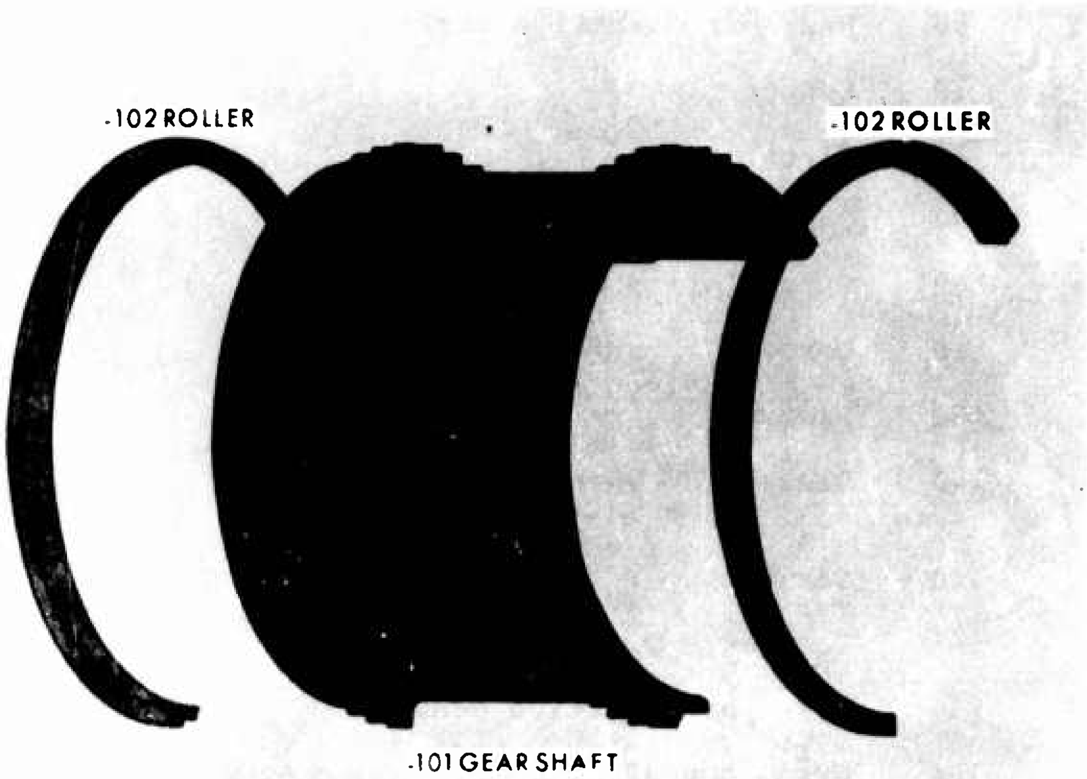


Figure F-1. Exploded View, Sun Gear RG351-11183.

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RG351-11183-102 Rollers

Two rollers per sun gear assembly are machined from a rolled ring forging, AMS 6265-9310 steel.

Operation No.	Description
10	Heat treat for machinability
20	Draw to Rc 25-30
30	Face one end to clean-up: Scribe 8-1/2" diameter bolt circle.
40	Drill and tap four 3/8-16" thread x 1/2" deep equally spaced on 8-1/2" bolt circle
50	Blank and cut off per operation drawing
60	Mask per operation drawing
70	Copper plate
80	Clean up
90	Carburize to produce .045"/.060" finish depth
100	Copper plate all over
110	Harden
120	Freeze
130	Draw to Rc 58-64 case Rc 30-45 core
140	Strip copper
145	Inspect H.T. operations
150	Bore per operation drawing
160	Grind cut off end (large diameter) of part .581"/.579" OAL
170	Grind opposite end to .573"/.570" OAL
180	On magnetic chuck, finish grind I.D. to 8.391"/8.390"
190	On magnetic chuck, finish grind 8.925"/8.915" diameter concentric with bore within .001" TIR x .2325"/.2275" dim with .030R

RG351-11183-102 Rollers

Operation No.	Description
200	Deburr .005"/.0015" edge break except edges of bore to be .005" max.
210	Polish
220	Clean
230	Magnaflux
240	Inspect. Note: 9.160" diameter to be finished after E.B. weld
250	Visually inspect and identify

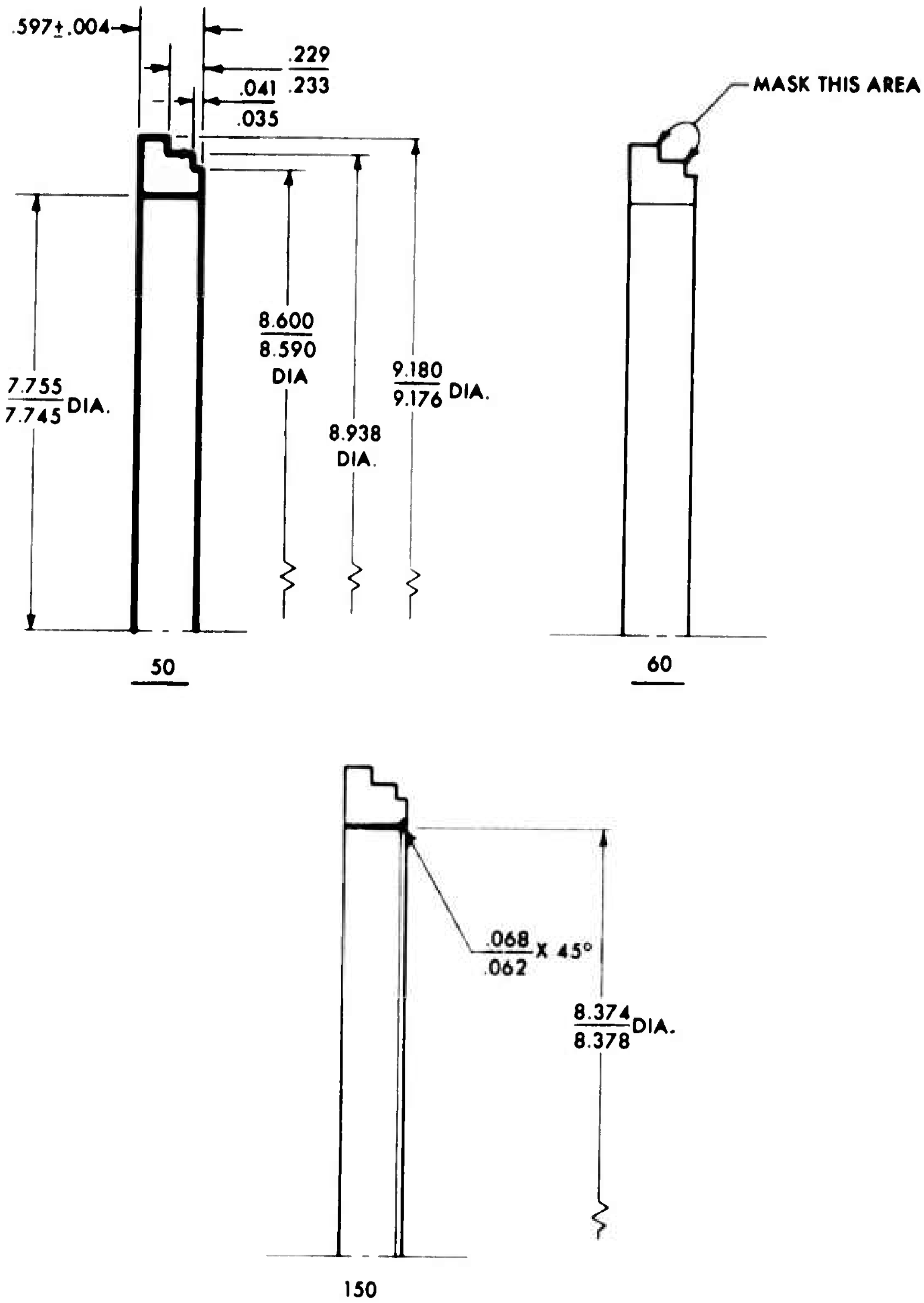


Figure F-2. RG351-11183-102, Machine Operation Drawing.

RG351-11183-041 Gear Assembly

The sun gear is fabricated from an AMS 6265-9310 steel forging. The gears are finished machined prior to electron-beam-welding of the rollers

Operation No.	Description
10	Blank per operation drawing
20	Blank per operation drawing
30	Heat treat for machinability
40	Draw to Rc 25-30
50	Blank per operation drawing
55	Blank per operation drawing
60	Blank per operation drawing
65	Blank per operation drawing
70	Magnaflux
80	Lap one end of part flat
90	Surface grind other end to 5.767" + .007" OAL - .981"/.971" dim to check .986" ± .005"
100	Surface grind opposite end to 5.762" + .001" OAL - .981"/.971" dim to check .986" ± .005"
110	On magnetic chuck grind gear O.D.'s two places to 9.112"/9.113" diameter
120	Grind per operation drawing
130	Grind per operation drawing
140	On magnetic chuck, surface grind 7.900" I.D. in one end to 7.887"/7.888" concentric with gear O.D. within .001" TIR - Blend into .030R and 30° Angle
150	Surface grind 7.900" I.D. on opposite end to 7.887"/7.888" diameter - Indicate opposite end bore within .001" TIR - Blend into .030R and 30° angle
160	Surface grind spline I.D. to 7.677"/7.678" concentric with ground bores within .001" TIR

RG351-11183-041 Gear Assembly

Operation No.	Description
170	Shape internal spline
180	Hob gears
190	Burr gears and spline
200	Mask gears only - mask to root diameter
210	Copper plate
220	Clean up. Note first of two carbs. Double carb cycle
230	Carburize to produce .015"/.030" finish case. Note: Internal spline will get .010"/.020" depth
240	Strip copper
250	Mask external gears and internal spline
260	Copper plate
370	Strip masks and clean up
280	Carburize (.015"/.230" on gears - .010"/.020" on spline)
290	Strip copper
300	Oxide blast
310	Copper plate all over
320	Harden
330	Freeze
340	Draw to Rc 58-64 case, Rc 30-45 core
350	Strip copper
360	Inspect heat treat operations
370	Turn per operation drawing
380	Turn per operation drawing
390	Grind one end of part to 5.757" + .002" OAL - .981"/.971" dim to check .981" ± .003"

RG351-11183-041 Gear Assembly

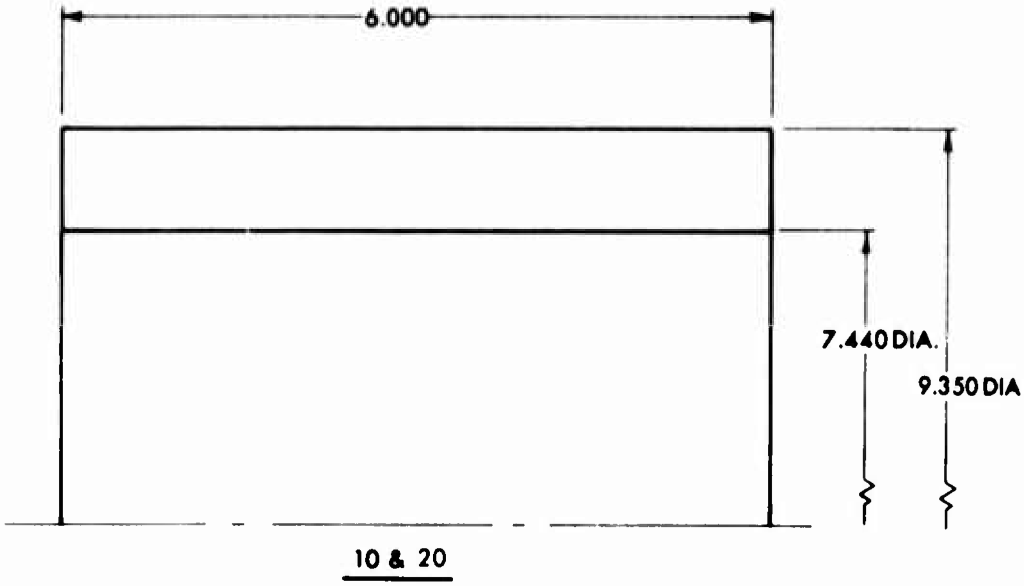
Operation No.	Description
400	Grind opposite end to 5.752" ± .003" OAL - .981"/.971" dim to check .981" ± .003".
410	On magnetic chuck, face inside faces of both gears to 3.8025"/3.7975" dim - Blend with .250 rad. Split stock to bring in dims - .005" stock on each face - check .375" gear width typ - check grind stock for .4085"/.4035" dim - check .976" ± .005" dim typ
420	Indicate gear P.D. within .002" TIR. Finish grind 8.392"/8.391" diameter x.4085"/.4035" dim with .030R one end
430	Grind gear O.D. to 9.101"/9.100" concentric with 8.397 diameter within .001" TIR both ends
440	Finish grind 8.392"/8.391" diameter on opposite end x.4085"/.4035" dim with .030R. Hold .0005" TIR concentric with 8.392"/8.391" diameter on opposite end
450	Indicate the 8.392"/8.391" O.D. .001" TIR. Finish grind spline I.D. to 7.691"/7.690" diameter
460	Grind 7.900" I.D. in one end to 7.900"/7.901" concentric with 8.392"/8.391" O.D. within .005" TIR. Blend into .030R at 30° angle
470	Grind 7.900" in other end to 7.900"/7.901" concentric with 8.392"/8.391" O.D. within .0005" TIR. Blend into .030R and 30° angle
480	Finish grind gears. Note: Spline to be ground after EB weld
490	Nital etch
500	Stress relieve
510	Deburr. Except corner of 8.392" diameter to be .005" max
520	Polish
530	Buff

RG351-11183-041 Gear Assembly

Operation No.	Description
540	Clean
550	Magnaflux
560	Inspect. Note: Internal spline and centers to be ground after E.B. weld
570	Identify
590	Withdraw the following parts from finish stores Clean with MER and assemble one RG-351-11183-101 Gear two RG-351-11183-102 Rollers
600	Inspect assembly
610	EB weld one end
620	EB weld other end
625	Stress relieve at 325° ± 10° for 5.0 hours
630	Inspect visually
635	Ultrasonic inspect weld joints
640	
650	
655	Reinspect gears after EBW and record
660	Chuck on O.D. and indicate gear P.D. on opposite end with .005" TIR. Face end to clean up weld square with P.D. within .0005" TIR Note: OAL to check 5.742" ± .004"
670	Grind other end to 5.732" ± .003" OAL parallel with opposite face within .0005" TIR
680	On magnetic chuck, grind 8.8917"/8.8914" diameters x 5.109"/5.113" dim with .025"/.035R concentric with gear P.D. within .0005" TIR Note: .300" min dim on both ends Split stock on each end

RG351-11183-041 Gear Assembly

Operation No.	Description
690	On magnetic chuck, grind the 9.160" diameters two places on -102 roller to 9.1600"/9.1605" concentric with 8.8912"/8.8913" diameters within .0005" TIR for spline grinding fixture
700	Grind center in one end concentric with 8.8917"/8.8913" diameter within .00025" TIR 30° x .120" dim deep
710	Grind center in opposite end concentric with 8.917"/8.8913" diameter within .00025" TIR 30° x .120" dim deep
720	Finish grind internal spline. Note .001" TIR core with gear P.D.'s.
725	Inspect internal spline
730	Nital etch spline and 8.8917"/8.8913" diameters
740	Stress relieve
750	Deburr
760	Polish
770	Clean
780	Magnaflux
790	Inspect
800	Dulite
810	Magnaflux
820	Visually inspect and identify



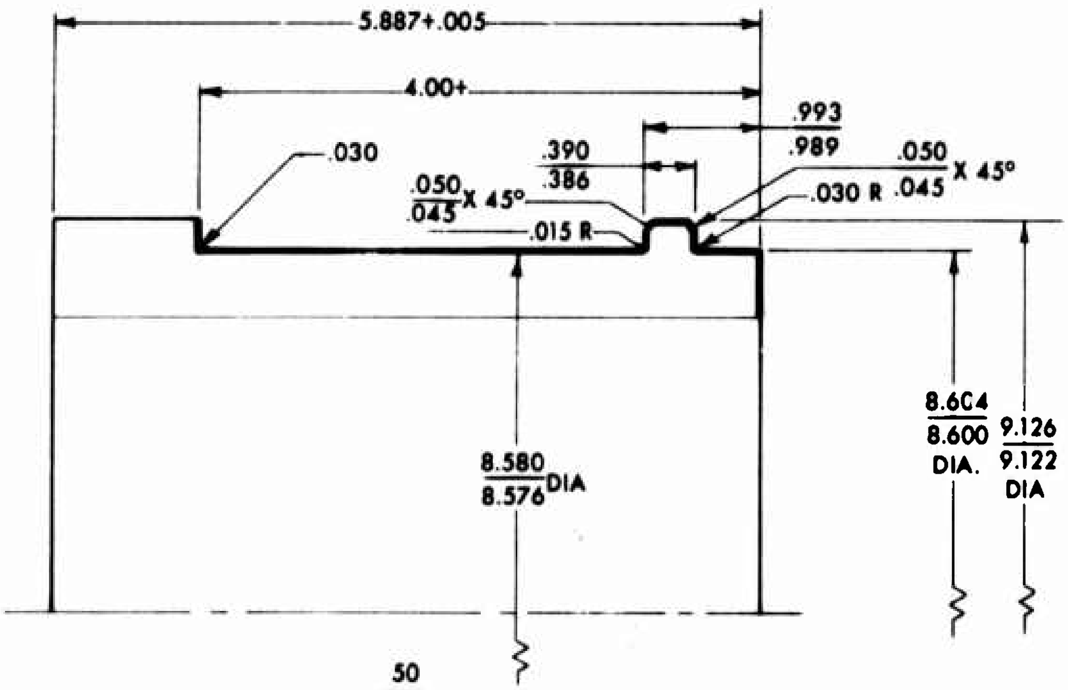


Figure F-3. RG351-11183-041, Machine Operation Drawing. (Sheet 1 of 4).

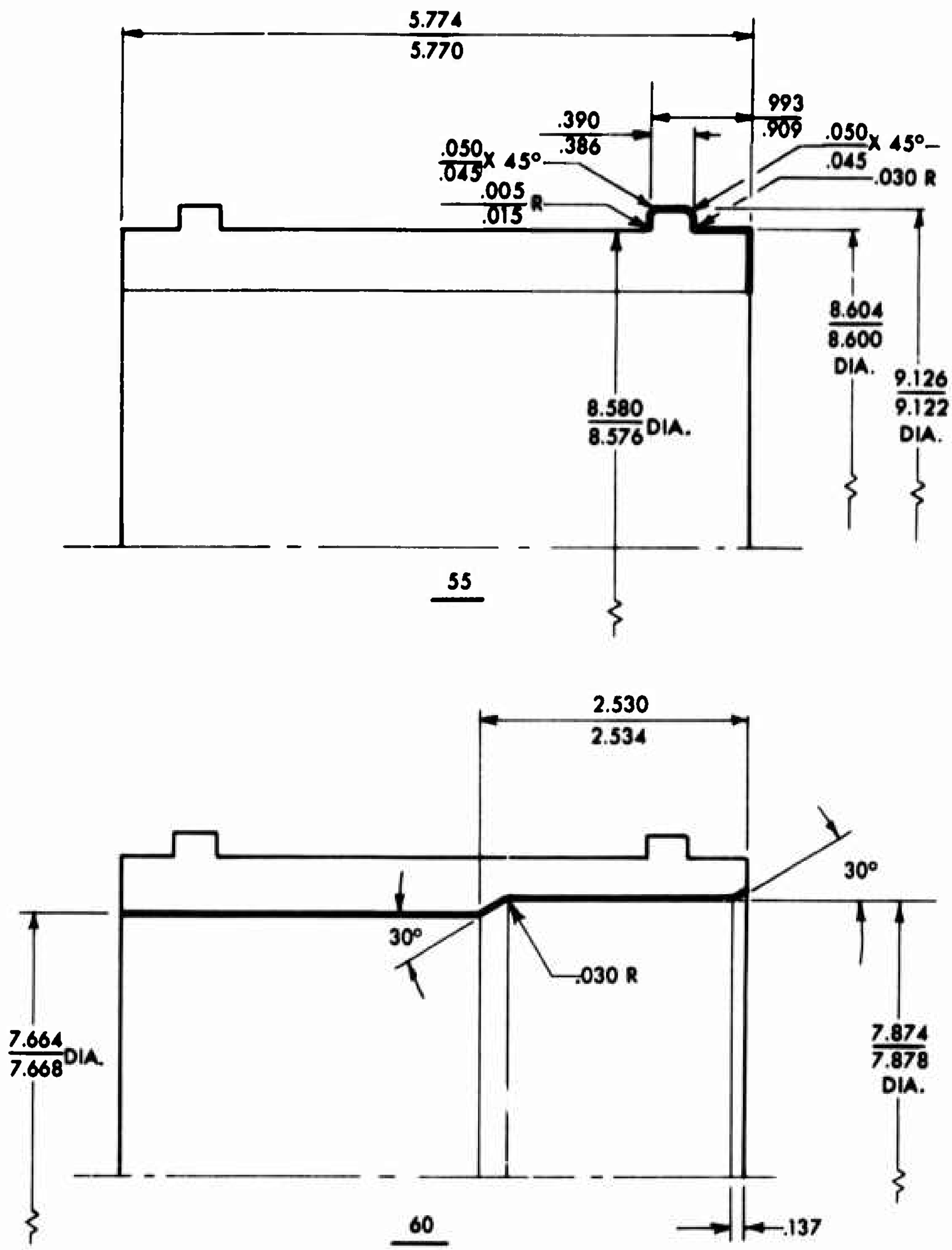


Figure F-3. RG351-11183-041, Machine Operation Drawing. (Sheet 2 of 4).

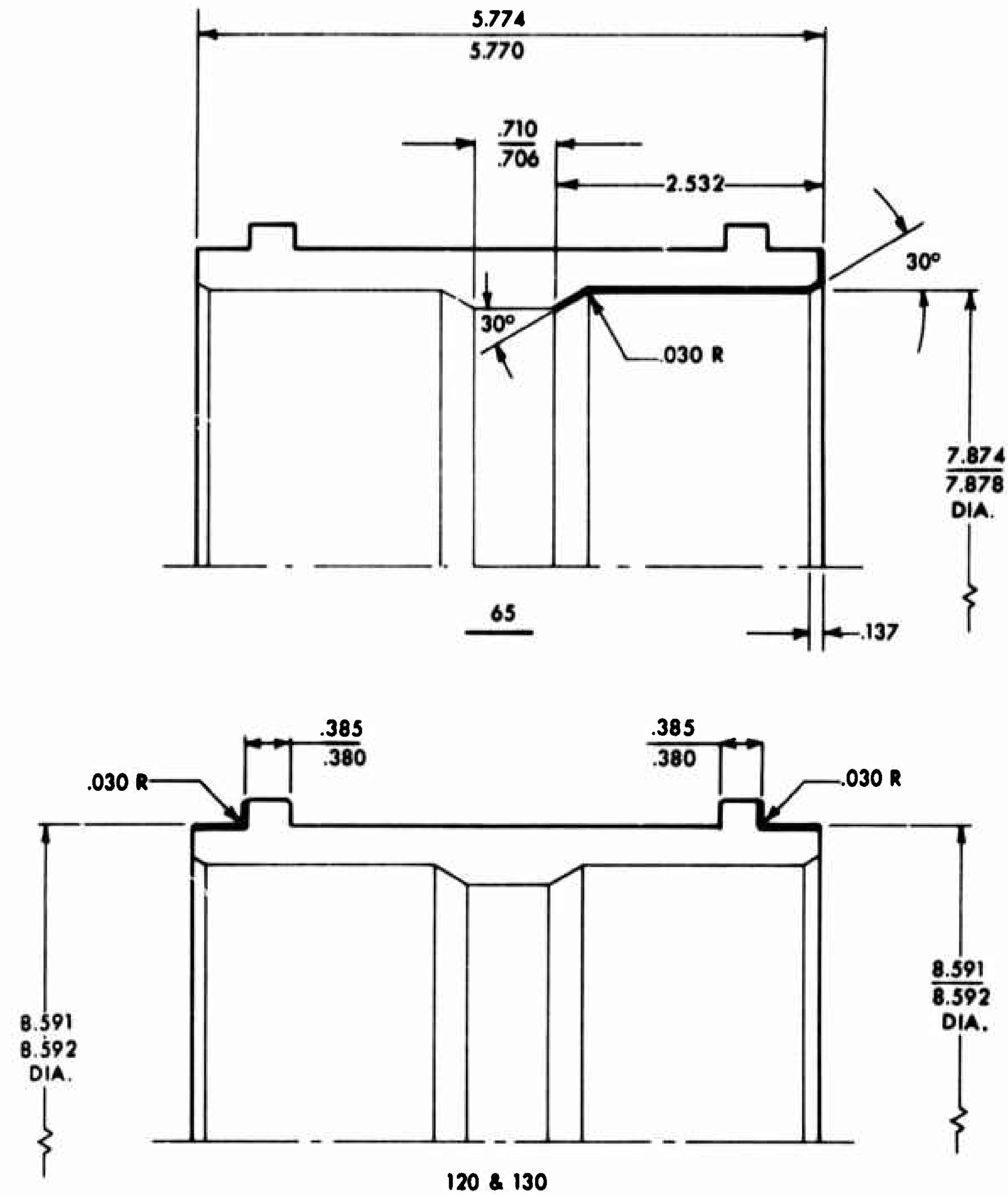
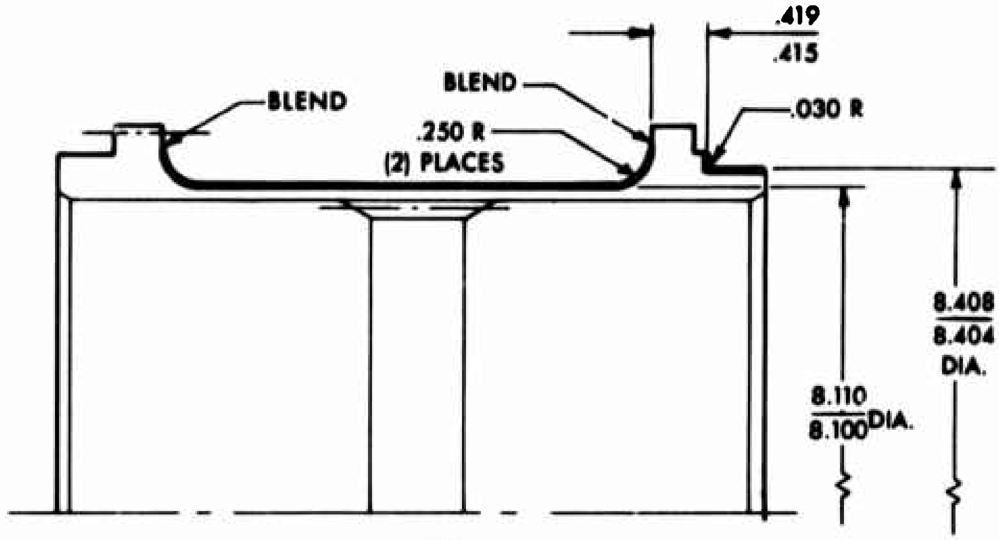


Figure F-3. RG351-11183-041, Machine Operation Drawing. (Sheet 3 of 4).



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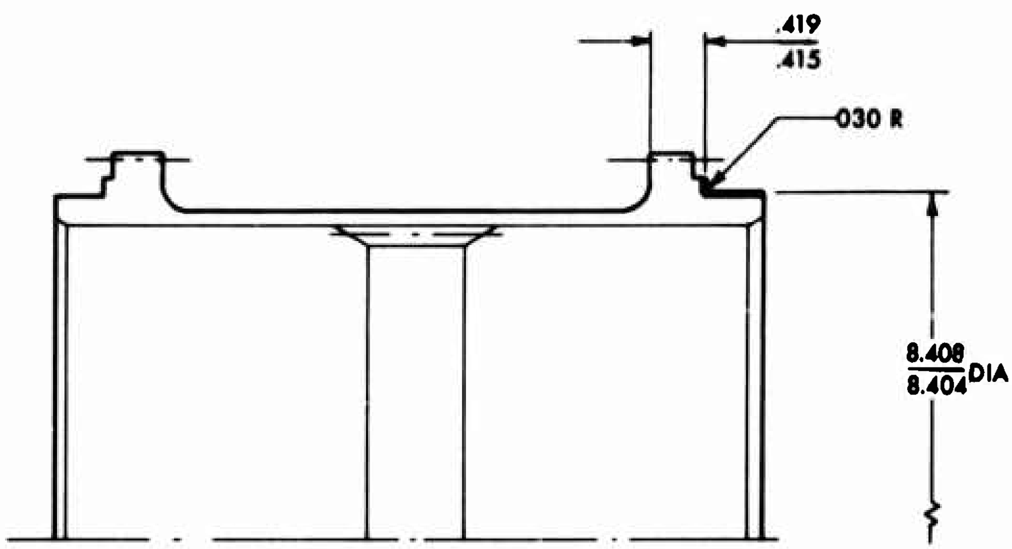

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Figure F-3. RG351-11183-041, Machine Operation Drawing. (Sheet 4 of 4).

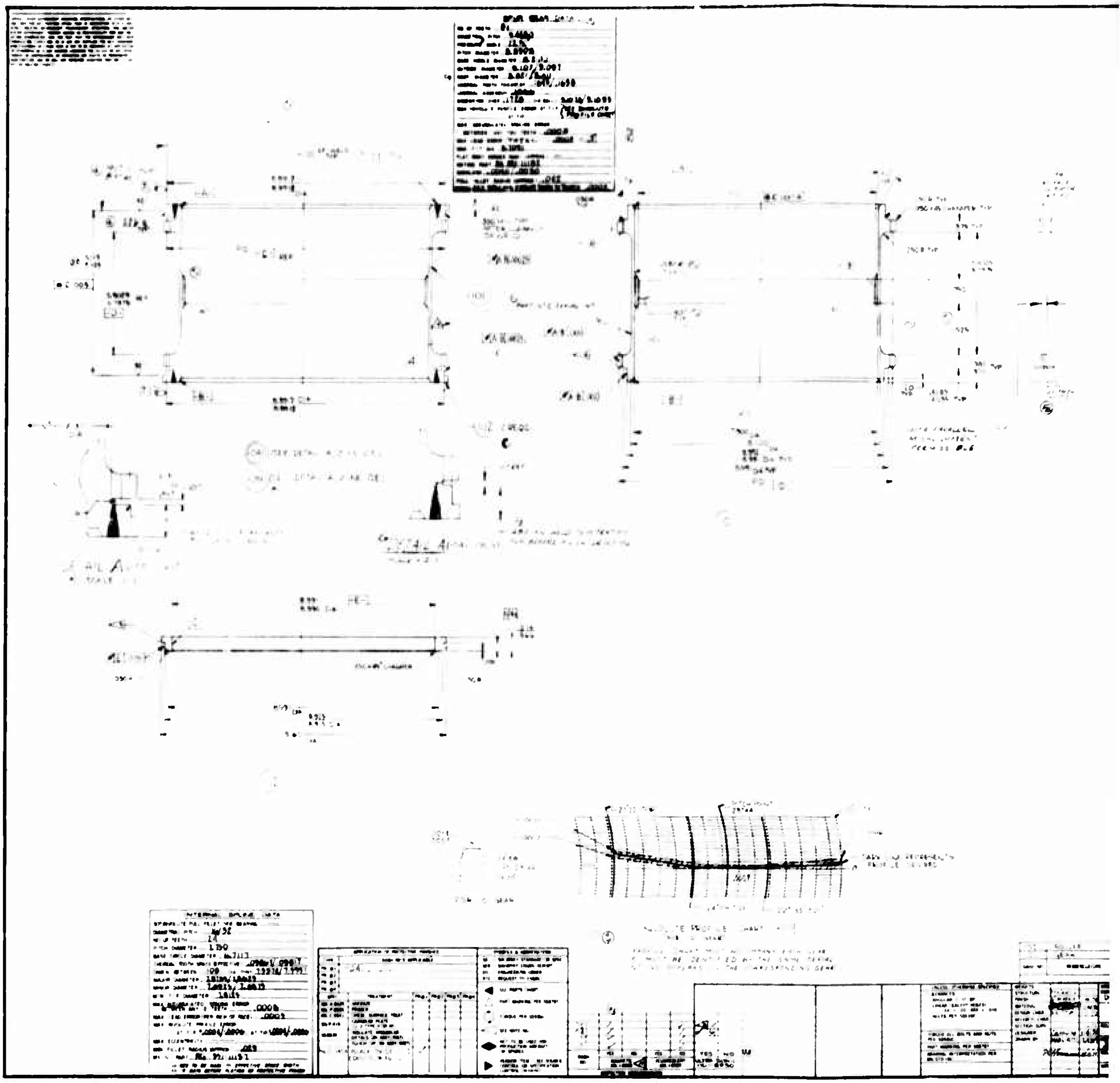

Figure F-4. RG351-11183, Sun Gear.

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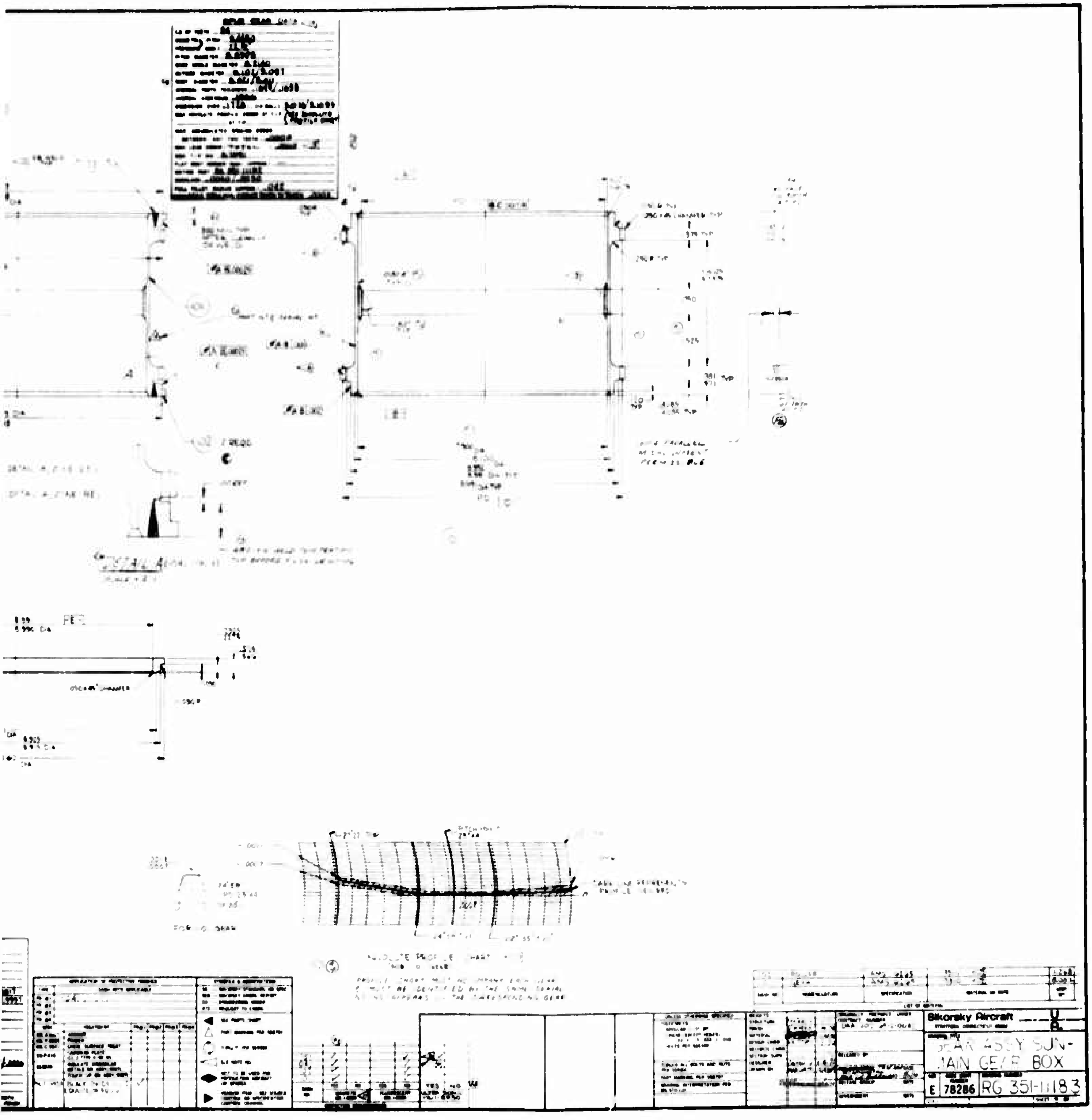

4. RG351-11183, Sun Gear.

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