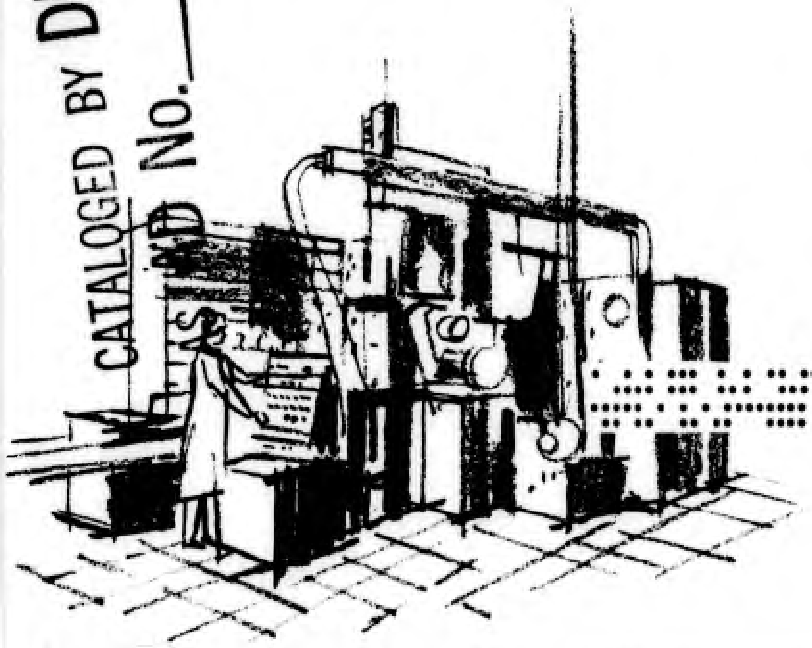
N-63-4-3

CINCINNATI HYDROTEL

NUMERICAL CONTROL RETROFIT PROGRAM



1 OCTOBER 1961

PREPARED UNDER NAVY | BUREAU OF WEAPONS

contract NOas 59-4184-f

FINAL REPORT

NORTH AMERICAN AVIATION INC. COLUMBUS DIVISION

CINCINNATI HYDROTEL NUMERICAL CONTROL RETROFIT PROGRAM

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PREPARED UNDER NAVY BUREAU OF WEAPONS

contract NOas 59-4184-f

final report

PREPARED BY D. H. Ross — D.H.Ross, PROJECT ENGINEER

R W Banks — R.W.Banks, PROJECT ENGINEER

APPROVED R G Sherman — R.G.Sherman, CHIEF INDUSTRIAL ENGINEER

F. D. Moorhead — F.D. Moorhead, PLANT ENGINEER

NORTH AMERICAN AVIATION INC. COLUMBUS DIVISION

abstract

This report covers the rehabilitation, numerical control retrofitting and production evaluation of a 36" x 72" Cincinnati horizontal hydrotel milling machine. The purpose of this project was to determine the technical and economical feasibility of such a modernization approach as compared to the procurement of new equipment.

The performance tests and production part evaluation indicate that for specific, well qualified machines retrofitting is justified both technically and economically. The machine retrofitted in this project shows a savings of 33% as compared to an equivalent new machine. Future retrofit of an identical machine will result in a savings of 11% due to an increased vendor bid.

The retrofit approach to modernization and increased capabilities must be used with caution. Only well qualified machines will demonstrate a significant economic advantage as compared to the purchase of new equipment.

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1.0 history

GENERAL REVIEW

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HISTORY

1.1 GENERAL REVIEW

This report covers the rehabilitation, numerical control retrofitting and production evaluation of a 36" x 72" Cincinnati Horizontal Hydrotel Milling Machine. The Columbus Division of North American Aviation entered into this program with the receipt of a contract in June 1959, from the Bureau of Weapons, to establish the economic and technical feasibility of retro-actively fitting machine tools with numerical control systems. This program is an outgrowth of an investigation conducted for the Bureau by Stanford Research Institute, Pasedena, California. Their summary report recommends such undertakings as the best means of determining the required information. Associated with North American were three other Navy Contractors: The Grumman Aircraft Engineering Corporation, McDonnell Aircraft Corporation, and Chance-Vought Aircraft, Inc.

1.2 PERTINENT DATES

The following is a chronological order of events as they occurred, starting with the pre-negotiations prior to the awarding of a contract, through the rebuild phases and concluding with the machining of a production part.

26 September 1958

Mr. G. W. Guise, Plant Engineer, North American Aviation, was advised during visit to Bureau of Aeronautics, that plans were being finalized for subject project. Arrangements were made to send Plant Engineering representative to Bureau to discuss details.

1 October 1958

Mr. D. H. Ross, Plant Engineering, visited Bureau and discussed program with H. Mohler and M. Procter.

1 December 1958

M. Procter, BuAer, in telephone conversation with G. Mead, Plant Engineering, asked for transmittal of formal proposal to BuAer for retrofitting Cincinnati Horizontal Hydrotel with a Bendix Aviation Numerical Cont.ol System. BuAer requested urgent processing so that contract could be issued during January 1959.

10 December 1958

Mr. D. Ross visited Bendix Aviation, Industrial Controls Division, in Detroit, Michigan, to expedite preparation of Bendix quotation. This quotation was completed and transmitted to North American Aviation on 12 December 1958. Total cost of this initial Bendix proposal was $139,150, plus the contingency that North American would perform approximately $15,000 labor for machine rehabilitation and control system installation.

12 December 1958

Cincinnati Milling Machine Company was requested to prepare alternate quotation for performing hydrotel retrofit. This proposal was received at North American Aviation on 15 December 1958. Total cost for machine rehabilitation and retrofit was $109,955.

17 December 1958

Preliminury proposals reviewed with BuAer representatives E. Gleason, R. Watson, M. Procter and H. Mohler. North American representatives were F. Krintz, BAR, G. Guise and G. Mead. N.A.A. was requested to negotiate engineering charges quoted by Bendix.

19 December 1958

Bendix reduced quoted "Non-recurring Engineering Cost" of their 12 December proposal from $31,150 to $3,115.

19 December 1958

In phone conversation between E. Gleason and R. Watson of BuAer and G. Guise and D. Ross of N.A.A., decision was made that alternate quotation of Cincinnati would be submitted along with original Bendix quotation. Although Bendix had reduced their price to $111,116, the Cincinnati proposal was less and was considered of greater value to the Contractor due to the additional machine rehabilitation work included.

30 December 1958

N.A.A. proposal transmitted to Chief, Bureau of Aeronautics, with a recommendation that alternate Cincinnati quotation be accepted at cost of $109,955.

39 January 1959

At this time, North American received verbal knowledge that necessary endorsements for this study contract had been obtained and we could expect Contractor review of the advanced proposal by 16 February 1959.

4 May 1959

In a phone conversation between F. Krintz, BAR, Columbus, G. Mead and M. Procter, BuAer, information relative to the breakdown of N.A.A. quotation and the method of handling study contract was received. BuAer was advised of forth - coming cost increase of 10% by Cincinnati Milling Machine Company.

27 May 1959

Official confirmation was received by Contractor of 10% cost increase on quotation submitted by Cincinnati Milling Machine Company.

29 May 1959

N.A.A. was advised by phone that no additional money was available to cover cost increase in equipment.

1 June 1959

Advance copy of Fixed Price Contract NOas 59-4184-f received by N.A.A. for retrofit at a price of $109,955. No provisions were included for cost increases.

2 June 1959

In a meeting with N.A.A. officials, Mr. C. Stugart, Vice President of Cincinnati Milling Machine Company, Special Machinery Division, reconfirmed initial Cincinnati quotation to accomplish complete job for $109,955.

29 June 1959

Bu Aer Contract NOas 59-4184-f formally approved by Corporate officials for rehabilitation and retrofit of hydrotel milling machine.

23 July 1959

N.A.A. Specification H-59-121 formally approved and transmitted to Purchasing Department for request of formal quotation.

20 August 1959

N.A.A. Job Order H-59-9346-64 processed authorizing placement of purchase order with Cincinnati Milling Machine Company for retrofit per Specification H-59-121.

25 August 1959

Cincinnati formal proposal #44146 rejected by project engineer D. Ross due to non-conformity with Specification H-59-121. Cincinnati was instructed to revise and re-submit.

1 October 1959

Revised Cincinnati proposal #44146, dated 29 September 1959, was received by Contractor. This quotation conformed to the requirements of N.A.A. Specification H-59-121.

14 October 1959

Purchase Order H-022-FP-050062 issued by Purchasing Department for accomplishment of work in accordance with specification.

28 December 1959

Letter received from Cincinnati Milling Machine Company requesting shipment of hydrotel milling machine to their plant approximately 30 January 1960.

18 January 1960

N.A.A. Job Order H-60-6226-77 processed authorizing shipment of hydrotel to Cincinnati Milling Machine Company.

1 February 1960

N.A.A. 25R #177238 authorization processed for payment of freight charges for hydrotel to Cincinnati, Ohio.

5 February 1960

Hydrotel milling machine shipped via Johnson Trucking Company, Columbus, Ohio to Cincinnati Milling Machine Company. Arrival date, 6 February 1960.

10 February 1960

In telephone conversation, Mr. Gordon Hammergren of Cincinnati estimated completion date of machine retrofit as 27 August 1960.

1 March 1960

Placement of orders for all purchased components completed by Cincinnati Milling Machine Company.

14 March 1960

N.A.A. requests extension of Contract NOas 59-4184-f based upon revised estimate of machine completion by Cincinnati Milling.

1 April 1960

Cincinnati Milling Machine Company reports mechanical engineering completed.

1 July 1960

Cincinnati Milling Machine Company reports further delay in delivery of machine due to behind schedule of control system fabrication.

14 October 1960

Progress of machine reviewed at Cincinnati Milling Machine Company by Fred Krintz, Columbus BuWeps Facilities Director; Peter Tilton, Stanford Research Institute; and Dave Ross, N.A.A. project engineer.

28 December 1960

Machine foundation installation completed at North American's Columbus plant.

5 February 1961

Machine run-off begins at Cincinnati Milling Machine Company.

20 February 1961

Final checkout of completed machine began at Cincinnati Milling under direction of D. H. Ross, N.A.A. project engineer, and Peter D. Tilton, Stanford Research Institute.

23 February 1961

Machine authorized for shipment pending minor modifications (see check-out report) to be completed at Cincinnati Milling Machine Company plant.

6 March 1961

Machine shipped from Cincinnati Milling Machine Company. Electronic controls transported by motor freight; machine components by rail.

8 March 1961

Machine controls received at North American's Columbus plant.

13 March 1961

Machine structural components received at North American.

15 March 1961

Mechanical installation began at Contractor's plant.

27 March 1961

Mechanical installation completed.

29 March 1961

Electrical installation started at Contractor's plant.

5 April 1961

Electrical installation completed.

10 April 1961

In-Plant A.I.A. checkout started.

19 April 1961

Spindle gear train failed during full horsepower test.

20 April 1961

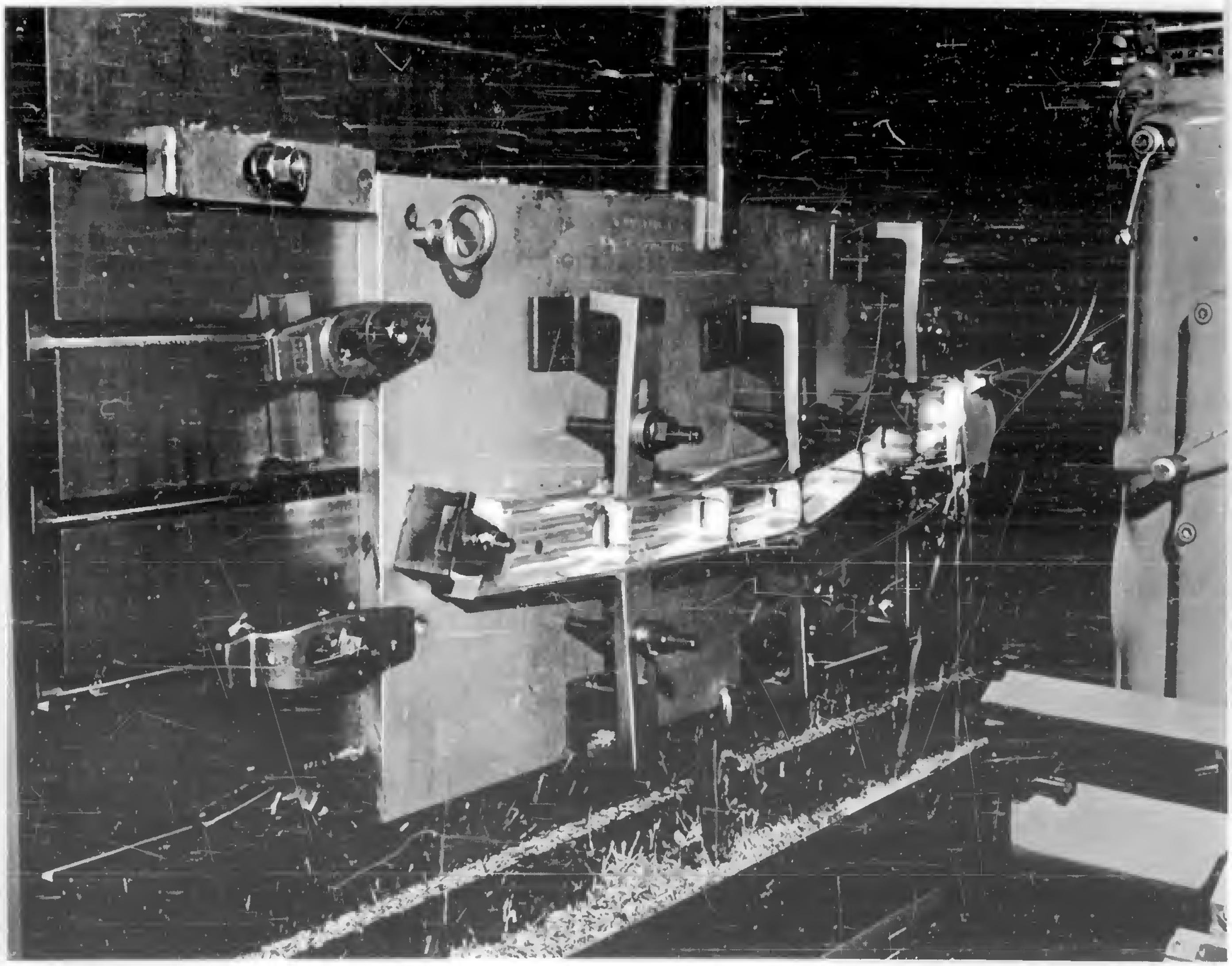
Operator familiarization and program proofing of first production part began under direction of Cincinnati service personnel.

28 April 1961

Spindle gear train repair completed and final A.I.A. acceptance test passed.

3 May 1961

First production part completed (Part No. 247-32348-6, Photo #1).



1 FIRST PRODUCTION PART

2.0 system description

GENERAL DESCRIPTION OF MACHINE AND CONTROLS

SPECIFICATIONS

MACHINE REWORK

PHOTOS DURING RETROFIT

SYSTEM DESCRIPTION

2.1 GENERAL DESCRIPTION OF MACHINE AND CONTROLS

The machine selected for the North American project was a 1942 model 36" x 72" Cincinnati Horizontal Hydrotel (see Photo #1). It was manually controlled, equipped with overarm and style "B" arbor supports, and a #60 milling machine tapered spindle nose. Longitudinal travel (X axis) was 72", utilizing a moving table and a reinforced cast iron bed. Transverse motion (Z axis) was 18", provided by a spindle carrier and saddle slide. Vertical (Y axis) travel of 36" was accomplished by vertical movement of the saddle. This machine was used for slabbing and hogging type cuts employing a horizontal cutter and overarm set-up. This type of operation is not widely used in the fabrication of present aircraft parts. The basic machine configuration was changed during retrofitting by the addition of a massive angle plate to the table (see photo #2). This angle plate permits mounting the workpiece in a vertical, instead of a horizontal, plane and allows two and three-dimensional profiling and contouring operations with end and face mills.

2.2 SPECIFICATIONS

The retrofit of North American's Cincinnati Horizontal Hydrotel Milling Machine with a numerical control system was accomplished in accordance with Specification H-59-121 (Attachment #1).

2.3 MACHINE REWORK

The North American contract with Cincinnati Milling called for a complete rehabilitation of the basic machine tool prior to retrofitting with a 3-dimensional numerical control system. This rehabilitation included the following:

a. Complete disassembly and inspection of machine.

b. Disposal of all machine components not required on retrofitted machine.

c. Replacement of horizontal and vertical ways, table, and saddle.

d. Replacement of spindle nose and carrier bearings.

e. Replace #60 M.M. taper spindle with #50 M.M. taper.

f. Replacement of all spindle gears which show evidence of evidence of excessive wear.

g. Complete rework of spindle drive motor and replacement of drive sprockets and chain.

h. Install flywheel to spindle power transmission train.

i. Replace all hydraulic and coolant units and their associated piping and valving.

j. Replace lubricating system with automatic Farvel system.

k. Scrape and paint entire machine with prime coat and one coat machinery gray.

To facilitate response to numerical commands, all drive motions were fitted with precision recirculating ball-nut screws and hydraulic fluid motors. All other moving components were replaced if evidence of wear was noted.

The numerical system selected for installation on the retrofitted machine was a 3-dimensional, continuous contouring Cincinnati "Acramatic" control. Data input for the three (3) axes of motion is obtained from Remington-Rand punched cards. These cards specify linear or curvilinear motion, including feed rate and auxiliary commands. The system is described as being an "absolute analogue" control. This means that numerical data representing slide motions or dimensions give specific distances from a zero reference line and do not represent an increment of slide motion. This technique simplifies the problem of maintaining synchronization between the input data and the machine. Digital input data for each axis is read into memory units, converted to analogue form, interpolated and compared to a feedback signal, which indicates the exact position of the machine slide. A resultant signal from this comparison is continuously fed to the slide servo drive in order that the spindle may be oriented exactly as intended by the input commands. The "Acramatic" system uses "parabolic interpolation" for curvilinear motion. This permits curve approximations to be made much more accurately than is possible with straight line segments and reduces the number of data points required.

2.3.1 Minimum Requirements for Retrofit

The machine selected for this project was a 1942 model 36" x 72" Cincinnati Horizontal Hydrotel. Due to design considerations and the machine age, a complete machine rebuild was performed in order that the machine tolerance capabilities would be in keeping with numerical control tolerances. Under these conditions, minimum requirements for retrofit considerations are as follows:

a. The basic machine castings must be sound and free from defects or mechanical damage.

b. The basic machine design must be compatible with the dimensions and capabilities of the intended retrofit performance.

2.3.2 Special Problems Encountered

During the rebuild and retrofit phases of this project, several problems were encountered which had not been anticipated prior to the inception of this project. The corrective action necessary to eliminate these problems account, to a large degree, for the delayed delivery date of this machine. The following is a brief description of these problems:

a. During the rebuild phase, Cincinnati Milling determined that the saddle casting would require replacement due to a design limitation. This condition had been overlooked during preliminary inspection and did not constitute an unexpected or special condition. The casting was replaced with no increase in rebuild cost to North American.

b. During performance test #13 at the Cincinnati Milling plant, chatter was noted during the full horsepower cut. This condition was corrected by the addition of a flywheel to the spindle inside the carrier casting.

c. The "Acramatic" numerical control system was designed to operate from punched tape. In order that the retrofit numerical control system be compatible with existing equipment at North American, Remington-Rand card input was specified. Zero shift and mirror image were also added to the "Acramati" design to permit the machining of right and left-hand parts from the same data input. These changes required minor design modifications and extensive checkout procedures. This is not unusal with a new system but did result in delaying the completion schedule.

d. The addition of numerical controls to a machine tool increases the machining ability resulting in a chip removal problem. Since the machine retrofitted in this project was changed from horizontal to vertical work holding, adequate chip removal was not present in the basic design. A logical solution to this problem would be the installation of a chip trough in the floor during the foundation installation.

e. After installation at North American, performance test #13 was re-run at the request of the project engineer and under the supervision of Cincinnati Milling Machine Company personnel. During the performance of a full horsepower test cut, in the vertical (Y) axis, a failure occurred in the spindle gear train. Further investigation disclosed that the work piece shifted, causing an excessive chip load and cutter failure; this resulted in the spindle gear train failure. Repairs were accomplished by Cincinnati Milling after which the tests were re-run with very satisfactory results.

2.4 PHOTOGRAPHS DURING RETROFIT

Photographs were taken during the retrofit machine installation and assembly at North American. These photographs illustrate the major features of typical numerical control construction.

a. Photographs 3, 4, and 5 show the rigid construction of the bed and column. These views also show the new bed and column hardened and ground ways.

b. Photographs 6 and 7 show the underside of the table. Note the ball screw assembly and the roller bearing assemblies in the table ways.

c. Photographs 8 and 9 show the back side saddle with ball screw assembly for vertical (Y) axis.

d. Photograph 10 shows the front side of the saddle with the ball screw assembly for depth (Z axis). On the upper part of the saddle is shown a portion of the automatic lubrication system.

e. Photographs 11 and 12 show the roller bearing ways on the saddle.

f. Photograph 13 shows the saddle assembled with the column.

g. Photographs 14 and 15 show the spindle carrier front and side view.

h. Photographs 16 and 17 show the director cabinet with doors exposing a portion of the internal electronic components.

i. Photograph 18 shows the control console and general arrangement of operator controls.

j. Photograph 19 shows a general view of the machine. Note the angle plate providing a vertical work surface and the control console.

k. Photograph 20 shows the general arrangement of machine components. At the extreme right is the director cabinet and the card reader.

SPECIFICATION

FOR

RETROFIT OF CINCINNATI HORIZONTAL HYDROTEL

MILLING MACHINE WITH NUMERICAL CONTROL SYSTEM

NAVAL INDUSTRIAL RESERVE AIRCRAFT PLANT
(NORTH AMERICAN AVIATION, INC.)
4300 E. Fifth Ave. Columbus 16, Ohio

INDUSTRIAL ENGINEERING DEPARTMENT
Manufacturing Development Group
W. R. Lowe, Group Leader

Prepared By: D. H. Ross

APPROVED BY: H. W. Todd
Chief Industrial Engineer

SPECIFICATION NO. H-59-121

DATE: July 23, 1959

J.I.R. H-59-9346-64

REVISED: September 30, 1959

ATTACHMENT #1

REVISIONS TO SPECIFICATION H-59-121

September 30, 1959

The following revisions and/or detailed explanations are hereby incorporated in Specification No. H-59-121:

Section I - General

1.1 Scope - Page 1 of 15

Delete paragraphs II and III. Machine will not necessarily comply with NAS standards.

Section II - Detail Requirements

2.2 Working Surface - Page 1 of 15

Work clearance distance (adjustable)	11 1/8" - 21"

2.3 Movements - Page 1 of 15

Vertical (y axis)	48"
Longitudinal (x axis)	72"

2.4 Movements - Manually Controlled - Page 2 of 15

Vertical (y axis)	48"
Longitudinal (x axis)	72"

2.5 Movements - Power Feed - Page 2 of 15

Vertical (y axis)	48"
Longitudinal (x axis)	72"

2.6 Feed Rates, Inches Per Minute (Infinitely Variable) - Page 2 of 15

Vertical (y axis)	1/4" - 25"
Longitudinal (x axis)	1/4" - 25"
Depth (z axis)	1/4" - 25"

Section III - General Requirements

3.7 Coolant - Page 4 of 15

Delete requirement for spray coolant.

3.10 Electrical Equipment - Page 4 of 15

Please make the following additions to the paragraph:

"Other equipment not covered by J.I.C. Hydraulic Standards will conform to good commerical standards".

REVISIONS TO SPECIFICATION H-59-121

September 30, 1959

Section IV - Tolerance Requirements and Cutting Test

4.2 Tolerance Requirements - Page 6 of 15

2. Runout, spindle nose to working surface, transversely

.002 inches/ft.
Max. .005" T.I.R.
Over Full Length

4.3.6.5 Overshoot and Undercut - Page 8 of 15

Overshoot .006 Undercut .008

4.3.6.6 Accuracy

(a) At quadrant change; not to exceed ± .003"
(b) Angles; not to exceed ± .005" per 12" measured normal to machine work surface.
(c) Circles; not to exceed ± .005" T.I.R. on diameter including quadrants change.

SECTION I - GENERAL

1.1 - Scope

This specification outlines the general requirements for the rehabilitation and retrofitting of a Cincinnati 36" by 72" Horizontal Hydrotel Milling Machine with a Cincinnati 3 - axis Numerical Control System.

The resulting machine is to be in general accordance with a type II, 360° profiling plus depth milling machine of National Aircraft Standards Specifications NAS 913, Sheets 1 through 10 inclusive, all as dated 6-15-55, which by this reference is made a part hereof.

Under Section II of this specification, entitled "Detail Requirements", specific requirements for this machine are listed. In instances where the requirements of this specification do not conform with those of specification NAS 913, this specification shall govern.

It is intended that the machine modified in accordance with this specification shall be of the horizontal spindle, vertical work surface type equipped with the Cincinnati Numerical Control System with Remington Rand Data Card input.

SECTION II - DETAIL REQUIREMENTS

2.1 - Exceptions

Below are listed specific detail requirements. Cincinnati Milling and Grinding Machines, Inc. must either meet or exceed these detail requirements or a statement enumerating all exceptions must be included in quotation. Any exceptions will be reviewed to determine whether or not they are acceptable. No exceptions will be accepted unless specifically approved.

2.2 - Working Surface

Vertical Height	48"
Length	72"
Work Clearance Distance (adjustable)	18"
T-Slots - Longitudinal	13/16" x 5" C.C.

2.3 - Movements

Vertical (y axis)	52"
Longitudinal (x axis)	76"
Depth Axial (z axis)	18"

SECTION II - DETAIL REQUIREMENTS (Cont'd.)

2.4 - Movements - Manually Controlled

Vertical (y axis)	52"
Longitudinal (x axis)	76"
Depth Axial (z axis)	18"
"Zero" Shift (all axes)	10"

2.5 - Movements - Power Feed

Vertical (y axis)	52"
Longitudinal (x axis)	76"
Depth Axial (z axis)	18"

2.6 - Feed Rates, Inches per Minute (Infinitely Variable)

Vertical (y axis)	0-25"
Longitudinal (x axis)	0-25"
Depth (z axis)	0-25"

NOTE: Above rates to apply under numerical and power feed modes of operation.

2.7 - Feed Rates - Rapid Traverse, Inches per Minute

Vertical (y axis)	100
Longitudinal (x axis)	100
Depth Axial (z axis)	30

NOTE: Above rates to apply under numerical and power feed modes of operation.

2.8 - Spindle Data

Horsepower	20
R.P.M. Range	15 to 900
No. of Steps	24
Spindle Taper	#50

SECTION III - GENERAL REQUIREMENTS

3.1 - Objective:

It is the objective of North American Aviation, Inc. by means of specified retrofit to fulfill their obligations to the Bureau of Aeronautics under contract NOas 59-4184-F. This contract provides for the complete retrofitting of the Cincinnati Hydrotel as specified herein to determine the feasibility, both technically and economically, of such a program.

After completion and return of the retrofitted machine tool, North American will conduct, at their expense, extensive studies to prove the merit of the program.

SECTION III - GENERAL REQUIREMENTS (Cont'd.)

3.2 - Shipment of Milling Machine

North American Aviation, Inc. will crate and ship to Cincinnati Milling and Grinding Machines, Inc., at North American Aviation's expense, one (1) 36" x 72" Cincinnati Horizontal Hydrotel Milling Machine, serial 42 M-360576-11. Cincinnati Milling and Grinding Machines, Inc. will notify North American Aviation at least three (3) weeks in advance of the date machine is required at their plant.

3.3 - Machine Rebuild

Cincinnati Milling will completely rebuild machine. This will include complete dismantling down to the last detail. Each component will be cleaned and carefully inspected. Those showing signs of wear will be replaced or reworked. All bearing slides will be resurfaced, all electrical equipment reconditioned and the machine, in general, placed in first class condition. It is understood that such rebuild is not to include replacement of major castings for the front bed, headstock, saddle, or spindle carrier.

All replacement parts are to be new and are to conform to regular new machine standards. All work is to be accomplished by regular mechanics under regular machine shop supervision. The rebuilt machine is to carry standard factory new machine performance guarantee.

Necessary machine work to the existing castings, such as that required for mounting of ball screw assemblies, will be performed. Hardened and ground way strips will be added and a new hydraulic unit supplied.

3.4 - All parts found to be excess to rebuild requirements will be crated and returned with the completed machine to North American Aviation, Inc. These will include the machine table, all apron feed controls, servo valves, table cylinder and hydraulic unit.

3.5 - Design Modifications

The design of all machine modifications shall be compatible with the dimensions and capacities stipulated in Section II. Resulting machine shall be of the horizontal spindle, vertical work surface configuration. Emphasis shall be placed on extreme rigidity to permit the successful machining of high strength steels. Hardened steel way strips and adequate way covers and wipers are to be provided.

Suitable anti-backlash features and feed-back controls as required for the maintenance of tolerances and for the successful performance of cutting tests specified in Section IV shall be included in the design modifications.

SECTION III - GENERAL REQUIREMENTS (Cont'd.)

3.6 - Numerical Control System

The rebuilt machine shall be retrofitted with a Cincinnati Numerical Control System complete with Remington Rand Card Reader. The system shall provide simultaneous control of three (3) axes of motion. Format of data card input shall be that presently utilized by North American Aviation; details of which are attached.

The control system shall be of the latest design and shall incorporate the standard Cincinnati system features of parabolic interpolation, tool radius compensation, tool radius compensation brake, decimal data card input, zero shift, interpolator speed attenuator, manual feed rate controls and error signal lights.

3.7 - Coolant

Spray and flood type coolant shall be provided by reconditioning and/or modification of existing equipment.

3.8 - Lubrication

All moving parts shall be automatically and adequately lubricated as necessitated by good machine design.

3.9 - Operator Controls

All operating controls shall be located convenient to the operator's normal operating position whenever practical. A spindle horsepower meter is required.

3.10 - Hydraulic Equipment

All hydraulic equipment and its installation shall conform to the latest revision of the JIC Hydraulics Standards.

3.11 - Electrical Equipment

All electrical equipment and its installation shall conform to the latest revision of the N. M. T. B. A. Machine Tool Electrical Standards. All electrical equipment shall operate from an original power source of 440 volts, 3 phase, 60 cycle supply.

3.12 - Safety Devices

3.12.1 Machine shall be furnished with suitable safety devices of the latest type. Parts which are hazardous to the operator shall be suitably guarded where practical.

3.12.2 Ample protection against electric shock shall be provided.

3.12.3 Safety stops limiting excessive travel of moving components shall be installed.

SECTION III - GENERAL REQUIREMENTS (Cont'd.)

3.12 - Safety Devices (Cont'd.)

3.12.4 Overload relays shall be supplied with all motors.

3.12.5 The machine shall be brought to a stop when spindle motor is overheated.

3.13 - Interchangeability

All replaceable parts shall be constructed to definite standards, tolerances, clearances, and performance in order that any such part may be replaced or adjusted without requiring modification. All such parts, where practical, shall be permanently and legibly marked with the manufacture's part number.

3.14 - Paint

After completion of all rebuild, modification and installation work, the machine shall be painted with one (1) coat of suitable metal primer, plus one (1) coat of standard machinery gray.

3.15 - Field Service Engineer

Cincinnati Milling and Grindings Machines, Inc. shall furnish a competent field service engineer at no extra cost to North American Aviation, Inc. to supervise reinstallation and initial production stages of the machine.

3.16 - Loading

Cincinnati Milling and Grindings Machines, Inc. shall bear full responsibility and cost for loading of machine for return shipment in accordance with railroad or transporting vehicle requirements. It shall be properly covered, waterproofed, and crated for transportation to North American Aviation, Inc., Columbus, Ohio.

Cost of freight, both ways, shall be borne by North American Aviation, Inc.

SECTION IV - TOLERANCE REQUIREMENTS AND CUTTING TESTS

4.1 - General

Machine shall be completely inspected and approved for shipment, in writing, by an authorized North American Aviation representative. Final acceptance is dependent upon machine performance at North American Aviation Plant. It shall be the responsibility of the manufacturer to program and prepare control data and to conduct the operational performance and tolerance tests listed below. Copies of manuscript data and control cards are to be supplied to North American Aviation at time of delivery.

SECTION IV - TOLERANCE REQUIREMENTS AND CUTTING TESTS (Cont'd.)

4.1 - General (Cont'd.)

Cincinnati Milling and Grinding Machines, Inc. shall be responsible for performing the following cutting and tolerance tests in such a manner as to satisfy the reasonable desires of the inspecting representative. It is not intended that he repeat the performance tests after installation at North American Aviation Plant.

4.2 - Tolerance Requirements

The following maximum tolerances, as specified by National Aircraft Standards, will be met:

Test No.	Test	Tolerances
1	Runout, spindle nose to working surface, longitudinally.	.002 inches/foot T.I.R. Max. .005 " T.I.R. over full length
2	Runout, spindle nose to working surface, transversely	.001 inches/ft. Max. .005" T.I.R. over full length
3	Depth slide movement of head, runout	Max. .0006"/ft. Check at 90°
4	Depth slide parallel with spindle	Max. .0006"/ft. Check at 90°
5	Displacement of any slide during locking	Max. .001 at 12" from spindle nose.
6	Spindle face axial runout	Max. .0004"
7	Spindle face radial runout	Max. .0004"
8	Spindle Runout - 1 1/4" from face	Max. .0005"
	12" from face	Max. .001"

4.3 - Performance Tests

The following performance tests for NAS Specification 913 are to be conducted by the manufacturer.

These tests, per descriptive drawings, are (1) for testing the functional accuracy of the machine under actual cutting conditions, and (2) to prove the performance of the card transport, the machine control unit, the machine drive and feed-back units.

These tests shall follow the performance and acceptability of the Requirements of Section III and the performance of Tolerance Tests of Section 4.2.

4.3.1 Test Material

4130 or 4140 steel alloy bar or plate stock, Brinell Hardness 250-300.

SECTION IV - TOLERANCE REQUIREMENTS AND CUTTING TESTS (Cont'd.)

4.3 - Performance Tests (Cont'd.)

4.3.2 Tooling

Tests shall be processed to give the machine common usage of holding devices and cutting tools throughout the various tests. Expensive and/or elaborate fixtures shall be avoided. Justifiable variations in cutters specified under each of these tests will be permissable.

4.3.3 Feed Rates

Feed rates shall be maintained as specified.

4.3.4 Spindle Speeds

Justifiable variations in spindle speeds under each of these tests will be permitted.

4.3.5 Control Cards

Control card decks are to be provided by the manufacturer. A copy of the test program and manuscript shall be furnished at the time of the tests.

4.3.6 Evaluation of Machine Accuracy

The test cuts shall be evaluated on the following items when noted in the test.

4.3.6.1 Surface Finish

The surface finish value of all test cuts will be evaluated and shall not exceed the following:

Roughing Cut	Finish Cut
150 micro inches RMS, Max.	60 micro inches RMS, Max.

4.3.6.2 Parallelism

Parallelism is not to exceed .003 inches per foot or .010" inches for 75% of the full working length.

4.3.6.3 Squareness

Squareness is not to exceed .003 inches per foot or .010 inches for 75% of the full working length.

4.3.6.4 Flatness

Flatness not to exceed .002 inches per foot or .006 inches for 75% of the full working length.

SECTION IV - TOLERANCE REQUIREMENTS AND CUTTING TESTS (Cont'd.)

4.3 - Performance Tests (Cont'd.)

4.3.2 Tooling

Tests shall be processed to give the machine common usage of holding devices and cutting tools throughout the various tests. Expensive and/or elaborate fixtures shall be avoided. Justifiable variations in cutters specified under each of these tests will be permissable.

4.3.3 Feed Rates

Feed rates shall be maintained as specified.

4.3.4 Spindle Speeds

Justifiable variations in spindle speeds under each of these tests will be permitted.

4.3.5 Control Cards

Control card decks are to be provided by the manufacturer. A copy of the test program and manuscript shall be furnished at the time of the tests.

4.3.6 Evaluation of Machine Accuracy

The test cuts shall be evaluated on the following items when noted in the test.

4.3.6.1 Surface Finish

The surface finish value of all test cuts will be evaluated and shall not exceed the following:

Roughing Cut	Finish Cut
150 micro inches RMS, Max.	60 micro inches RMS, Max.

4.3.6.2 Parallelism

Parallelism is not to exceed .003 inches per foot or .010" inches for 75% of the full working length.

4.3.6.3 Squareness

Squareness is not to exceed .003 inches per foot or .010 inches for 75% of the full working length.

4.3.6.4 Flatness

Flatness not to exceed .002 inches per foot or .006 inches for 75% of the full working length.

SECTION IV - TOLERANCE REQUIREMENTS AND CUTTING TESTS (Cont'd.)

4.3.6 - Evaluation of Machine Accuracy (Cont'd.)

4.3.6.5 Overshoot and Undercut

Feed Rate - 25 IPM   Overshoot - .003" Max.   Undercut - .004"

4.3.6.6 Accuracy

(a) At quadrant change; not to exceed ± .002 inches.
(b) Angles; not to exceed ± .004 inches per 12" measured normal to machine work surface.
(c) Circles; not to exceed ± .004" T.I.R. on diameter including quadrant change.
(d) Depth; see flatness.

4.3.6.7 Horsepower

4.3.6.8 Feed Rate

4.3.6.9 Rigidity and Spindle Performances

Machine shall be free from chatter, and feed motion shall be smooth and even.

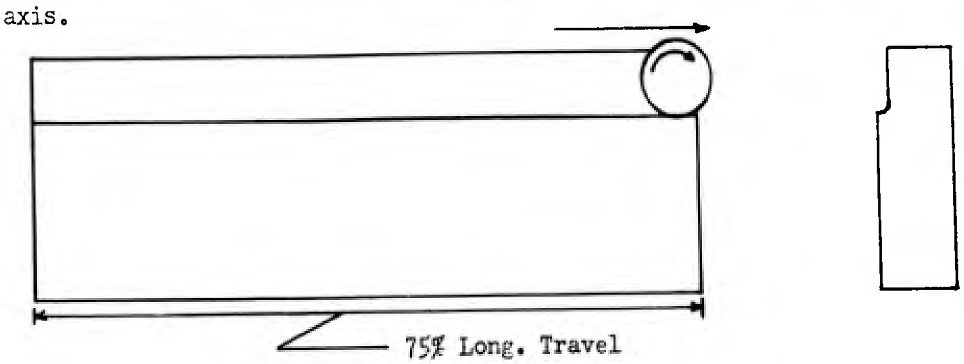
4.3.7 - Test Cuts

4.3.7.1 Maximum Rated Horsepower

A straight cut 75% the length of the table shall be made at full rated horsepower. (Roughing Cut)

Cutter	8" T. C. Face Mill
Spindle Speed	150 RPM
Feed Rate	5 IPM
Depth	As Required
Width	Optional

Work Location - Work pieces to be adjoined and located on bed of machine to demonstrate 75% of the total working length of machine surface. Test to be performed in longitudinal axis and transverse axis.



Evaluate: Feed Rate Horsepower Finish (Rough Cut) Flatness

SECTION IV - TOLERANCE REQUIREMENTS AND CUTTING TESTS (Cont'd.)

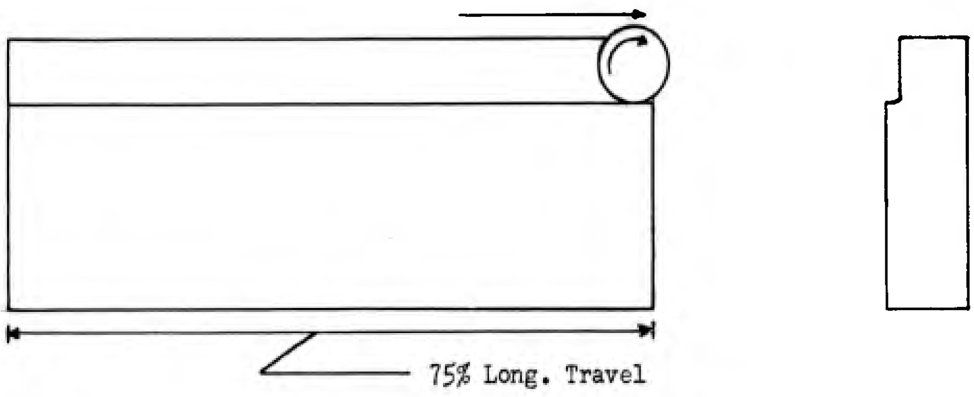
4.3.7 - Test Cuts (Cont'd.)

4.3.7.2 Maximum Feed Rate

A straight cut 75% of the length of the table shall be made at selected cross sectional area at maximum feed rate utilizing 50% of the full rated horsepower.

Cutter	8" T. C. Face Mill
Spindle Speed	200 RPM
Feed Rate	25 IPM
Depth	Optional
Width	Optional

Work Location - Work pieces to be located on bed of machine to demonstrate 75% of the total working length of the machine surface. Tests to be performed in the longitudinal axis and **transverse axis.**



Evaluate: Feed Rate

Finish (Finish Cut)

Flatness

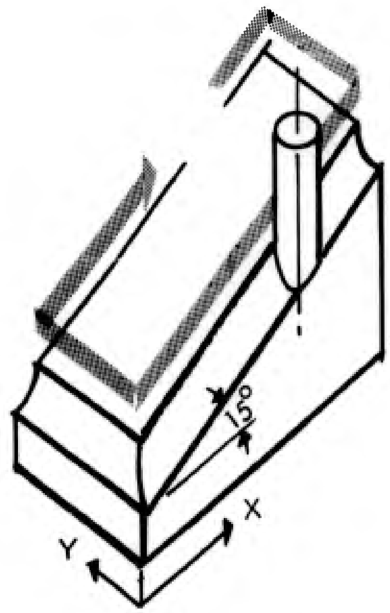
4.3.7.3 Profiling - Rectangular Pattern with Depth

Profile mill the periphery of an 20" long x 6" wide block with constant depth on ends and with a 15^{o} angle plunge on one side and a 15^{o} rise on the other. All cuts to be parallel to axis of machine.

SECTION IV - TOLERANCE REQUIREMENTS AND CUTTING TESTS (Cont'd.)

4.3.7.3 (Cont'd.)

Work Location - Work piece to be located centrally on machine bed.



Cutter	1 1/4" dia. Ball Nose End Mill H.H.S.
Spindle Speed	320 RPM
Feed Rate	10 IPM
Depth	.050" x .020"

Evaluate: Finish

Squareness

Parallelism

Angle

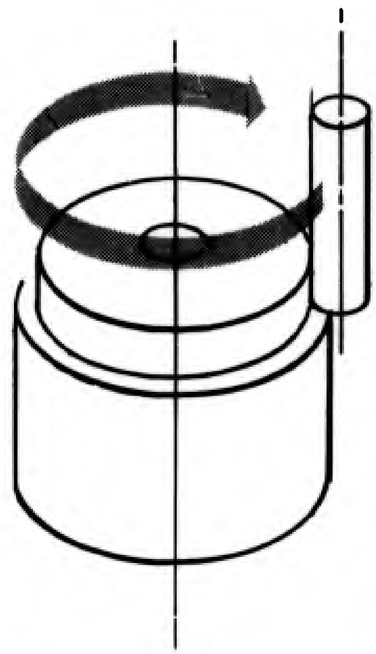
SECTION IV - TOLERANCE REQUIREMENTS AND CUTTING TESTS (Cont'd.)

4.3.7 (Cont'd.)

4.3.7.4 Profiling - Rectangular Pattern with Depth

Repeat test 3, with axis of work piece rotated 90°.

4.3.7.5 360° Profiling - Circle



Cutter	2" Dia. T. C. End Mill
Spindle Speed	800 RPM
Feed Rate	10"
Depth	.020"
Width	

Work Location - Work piece to be located centrally on machine bed.

Evaluate: Finish

Accuracy (a) At quadrant change
(b) Circle Diameter

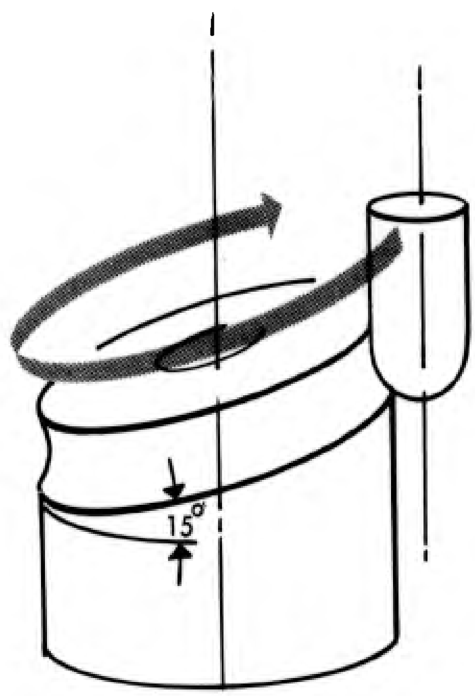
SECTION IV - TOLERANCE REQUIREMENTS AND CUTTING TESTS (Cont'd.)

4.3 - Performance Tests (Cont'd.)

4.3.7 Test Cuts (Cont'd.)

4.3.7.6 360° Profiling plus Depth (Circle)

Profile mill the periphery of a 10" dia. circle with simultaneous variation in depth of 15°.



Cutter	1 1/4" Dia. H.S.S. Ball Nose End Mill
Spindle Speed	185 RPM
Feed Rate	8" per minute
Depth of Cut	.015" x .020" radial

Work Location - Work piece to be located centrally on machine bed.

Evaluate: Finish

Accuracy of Periphery

Accuracy of Depth

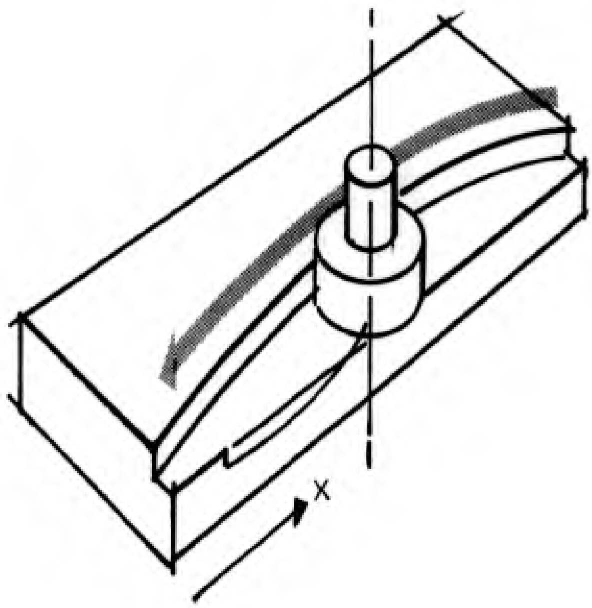
SECTION IV - TOLERANCE REQUIREMENTS AND CUTTING TESTS (Cont'd.)

4.3 - Performance Tests (Cont'd.)

4.3.7 Test Cuts (Cont'd.)

4.3.7.7 360° Profiling (Circular Segment)

Profile mill circular segment with 24" chord length and .480" chord height (approximately radius of 150").



Cutter	2" Dia., 4 flute, T. C. End Mill
Spindle Speed	900 RPM
Feed Rate	10"/min.
Depth of Cut	1/4"
Width of Cut	5/16"

Work Location - Centrally on working surface.

Evaluate: Finish

Accuracy

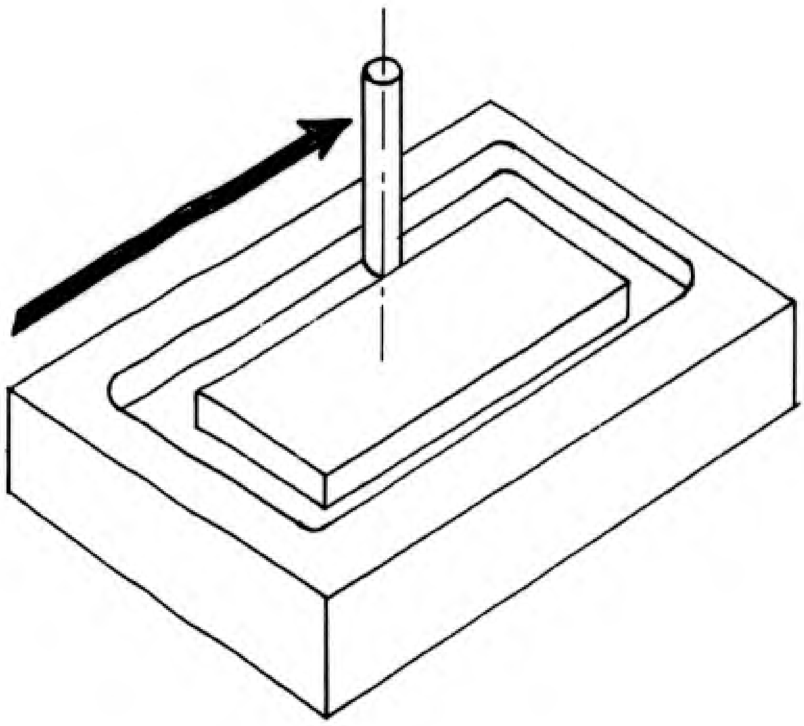
SECTION IV - TOLERANCE REQUIREMENTS AND CUTTING TESTS (Cont'd.)

4.3 - Performance Tests (Cont'd.)

4.3.7 Test Cuts (Cont'd.)

4.3.7.8 360° Profiling for Overshoot and Undercut

Profile mill rectangular channel cuts as indicated without programmed slowdown or parabolic deceleration in control data.



Cutter	1 1/4" H.S.S. End Mill
Spindle Speed	525 RPM
Feed Rate	25"/min.
Depth of Cut	.020"

Work Location - Work piece centrally located on work surface with longest dimension parallel to column travel.

Evaluate: Overshoot and Undercut

Finish

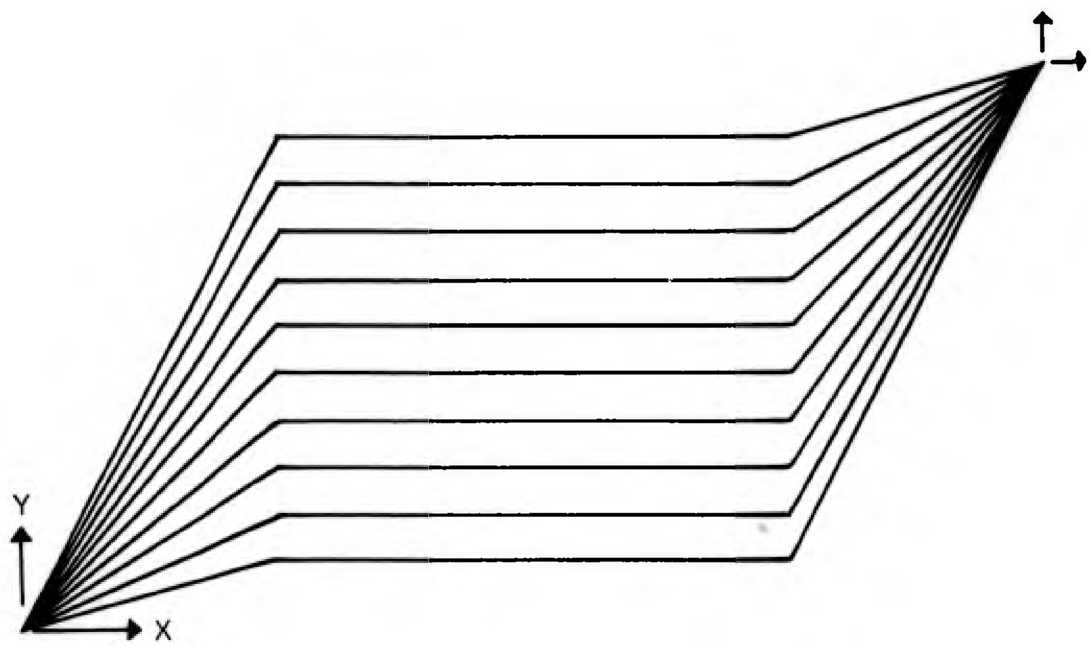
SECTION IV - TOLERANCE REQUIREMENTS AND CUTTING TESTS (Cont'd.)

4.3 - Performance Tests (Cont'd.)

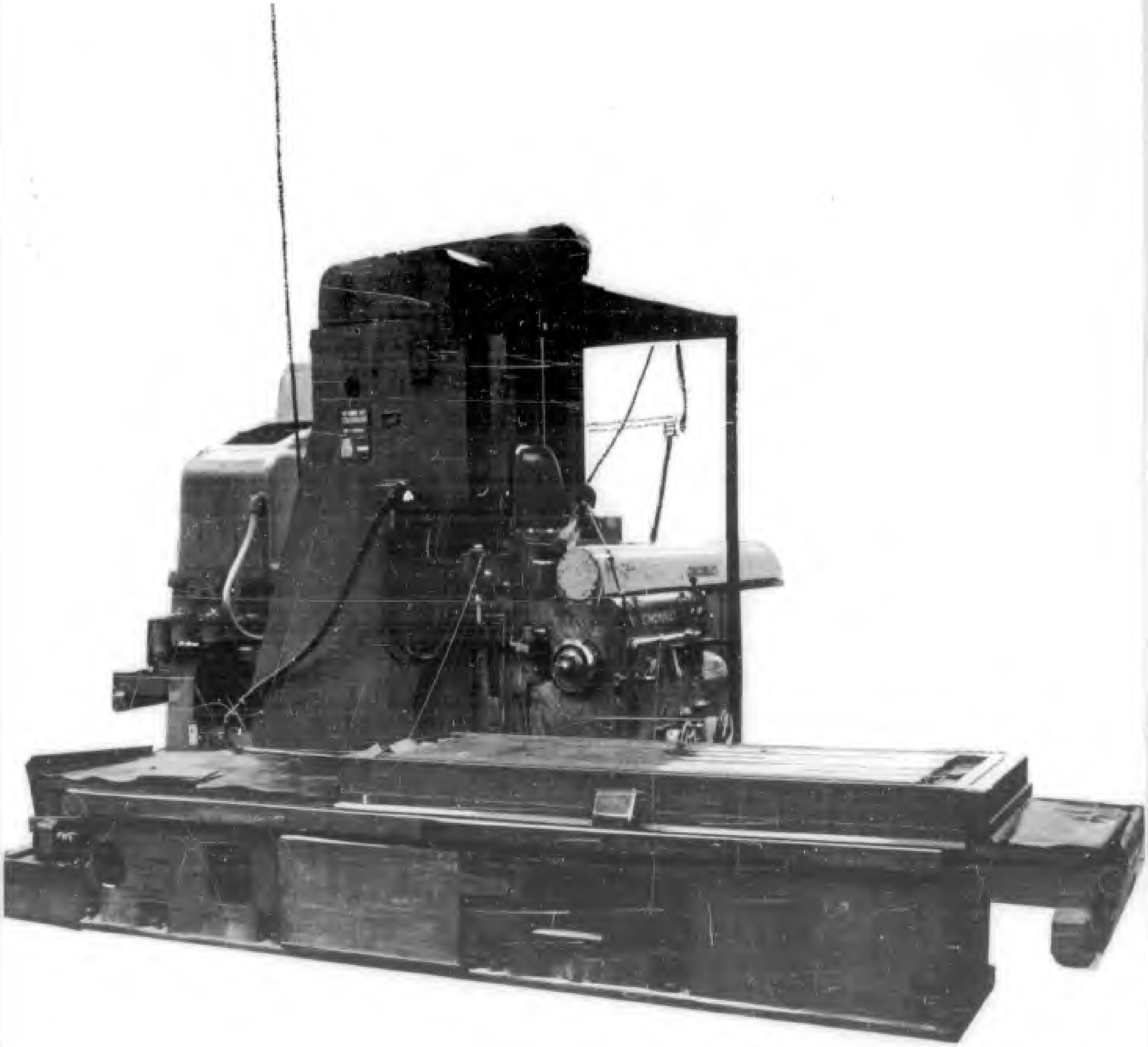
4.3.7 Test Cuts (Cont'd.)

4.3.7.8 Repetitive Positioning Accuracy

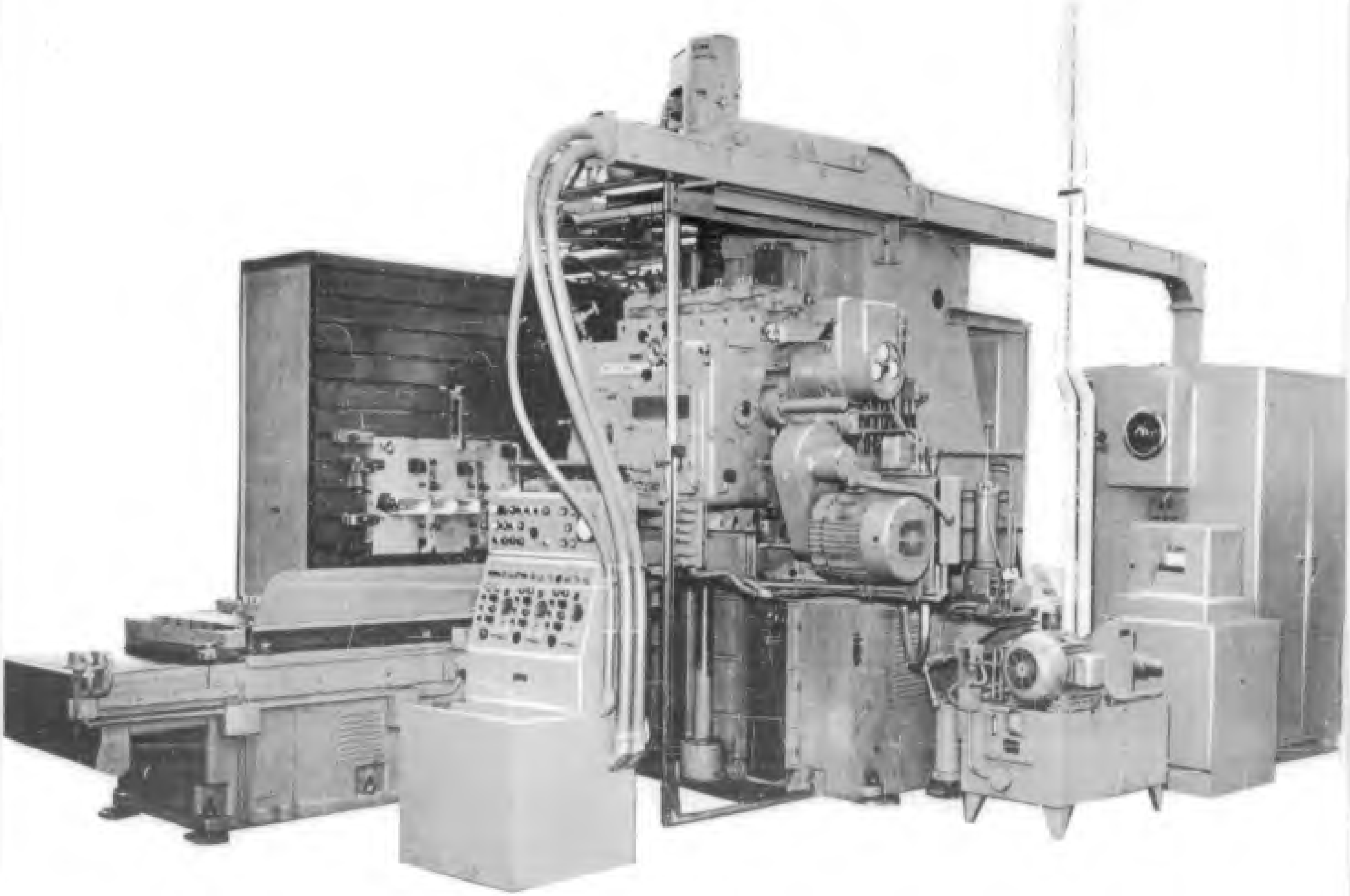
Check repetitive positioning accuracy of machine by making a total of ten (10) separately interpolated paths, criss-crossing and diagonally across work surface, between targets points located one in lower left and one in upper right conrner



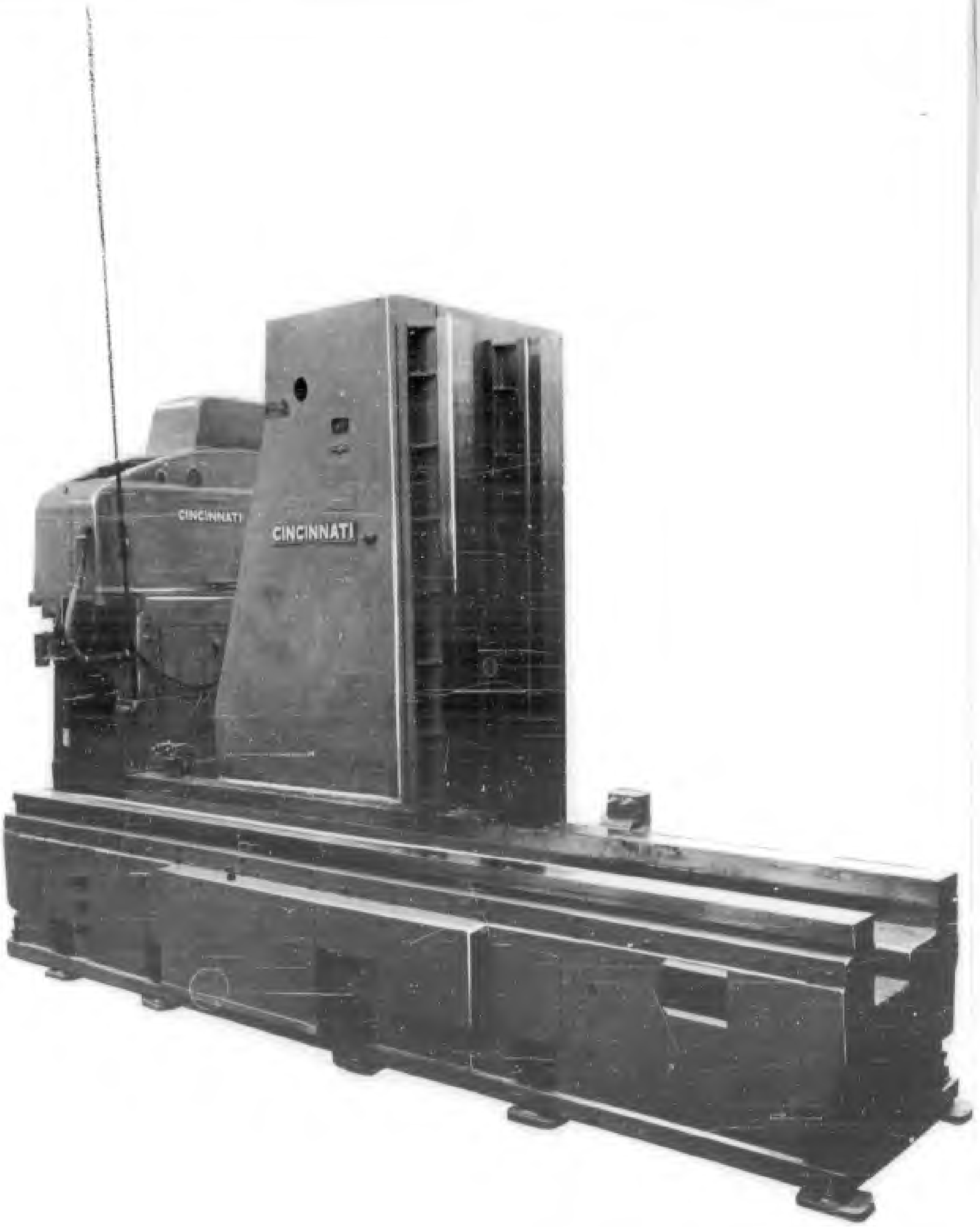
Evaluate: Positioning Accuracy - (Max. T.I.R. = .005")



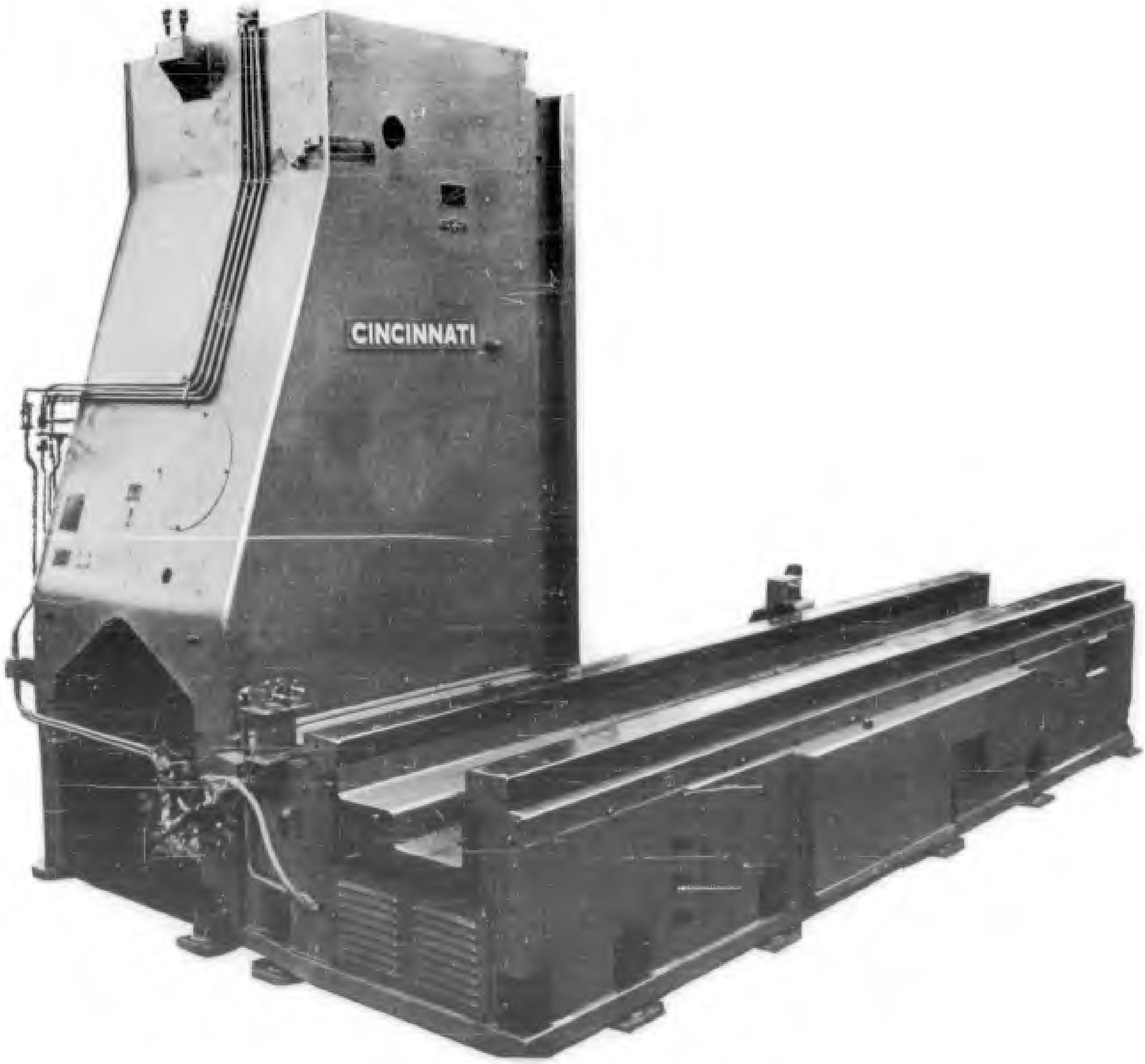
1 model 1942 CINCINNATI HORIZONTAL HYDROTEL



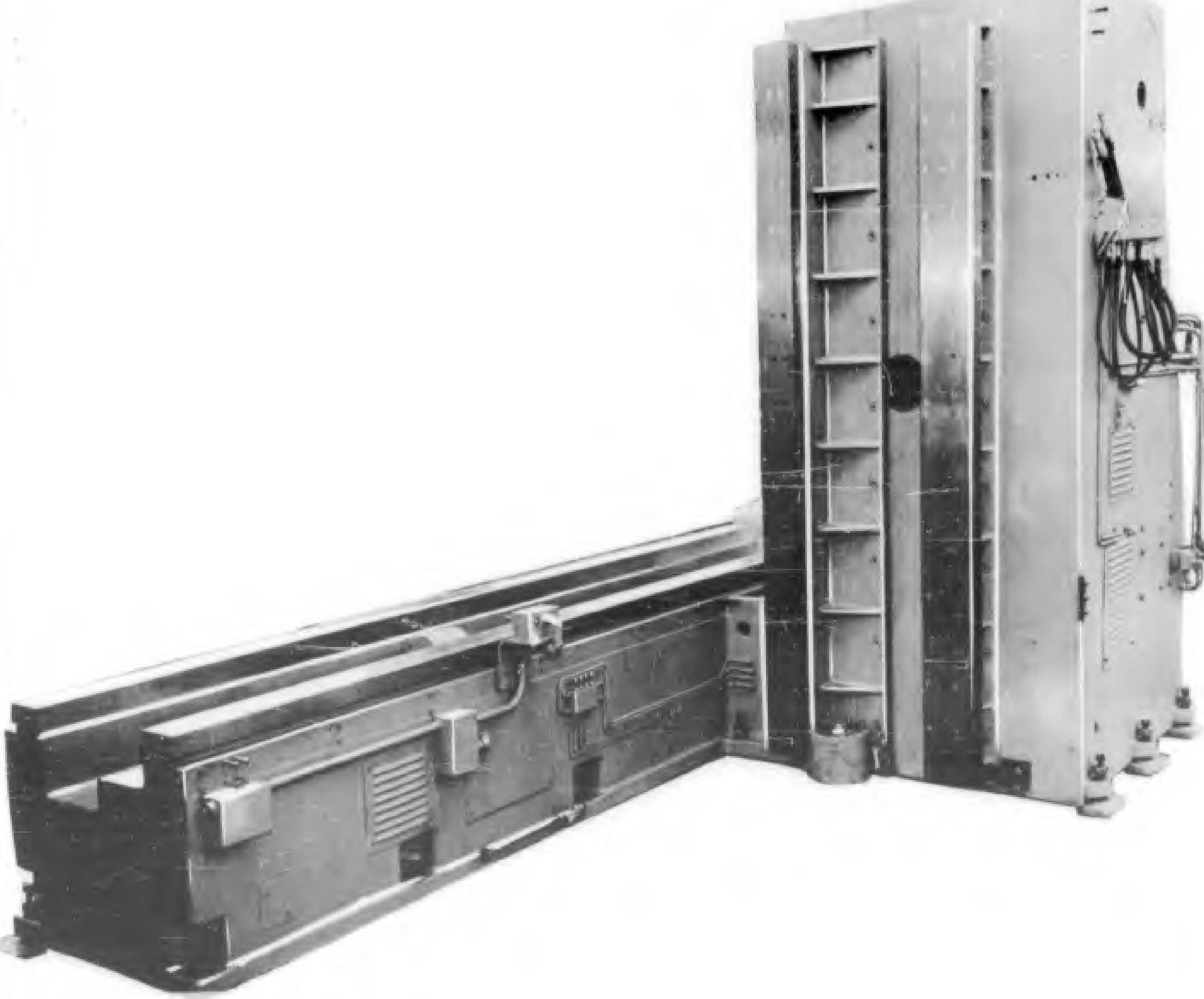
2 ADDITION OF ANGLE PLATE TO TABLE



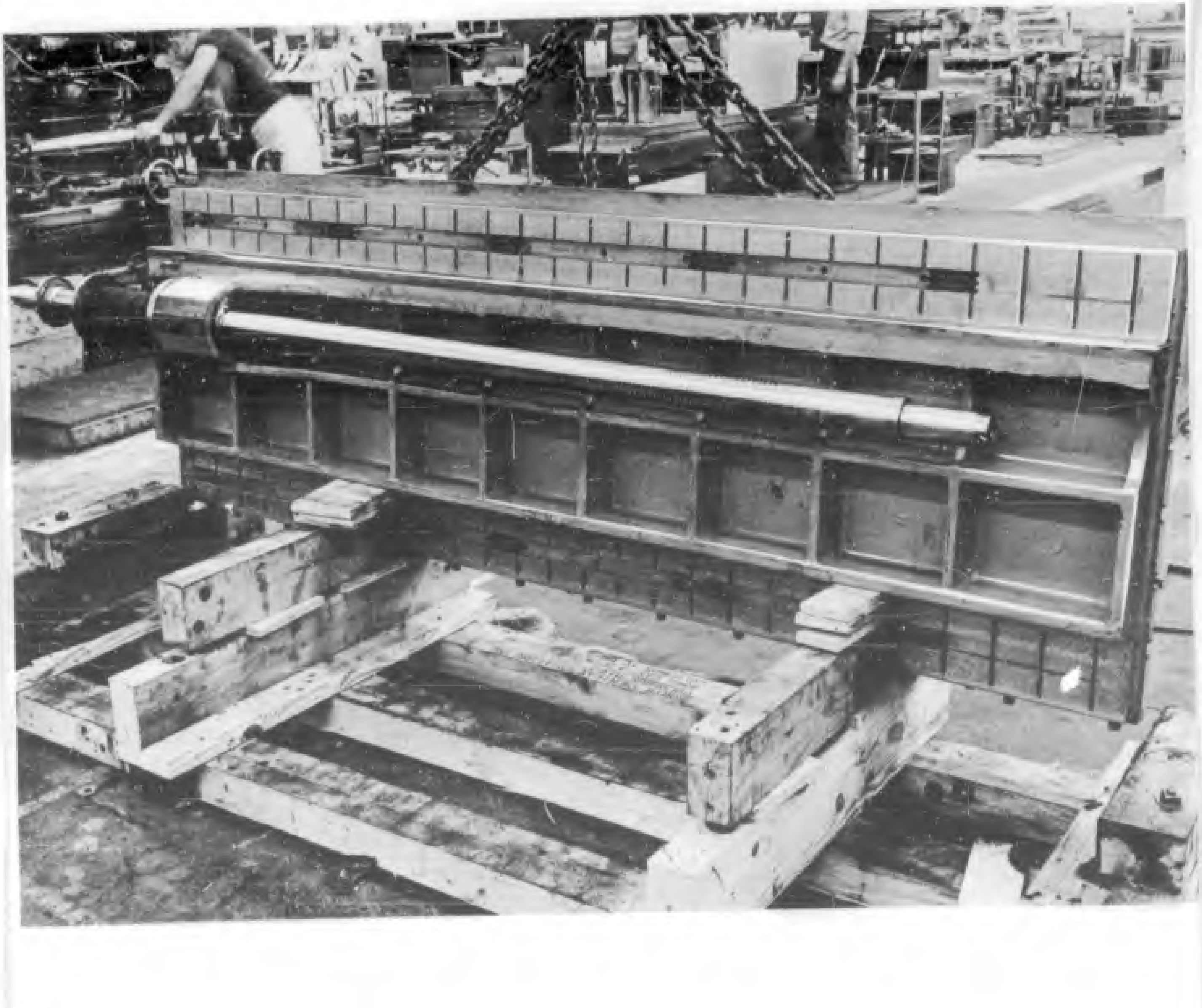
3 BED AND COLUMN



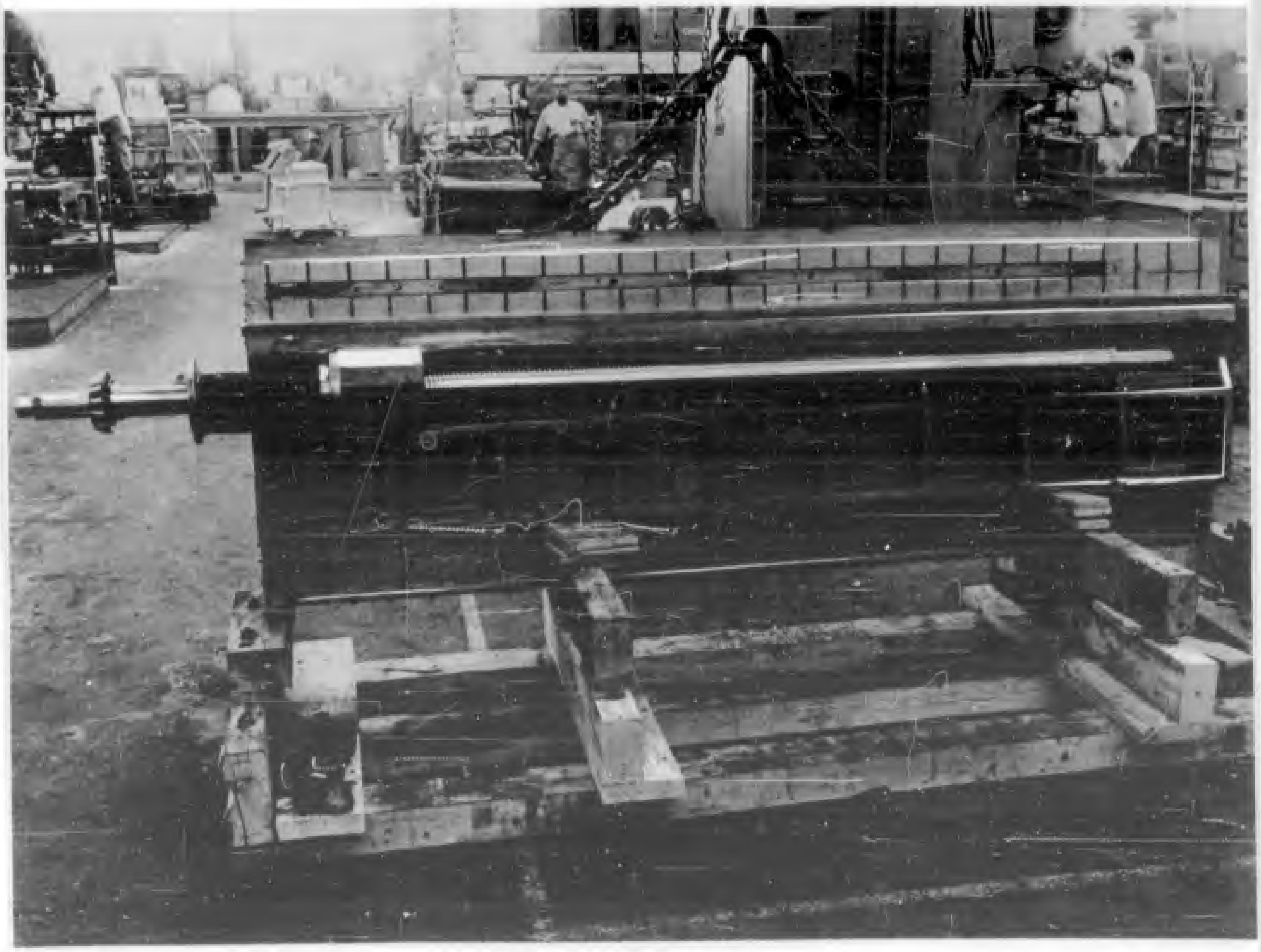
4 BED AND COLUMN



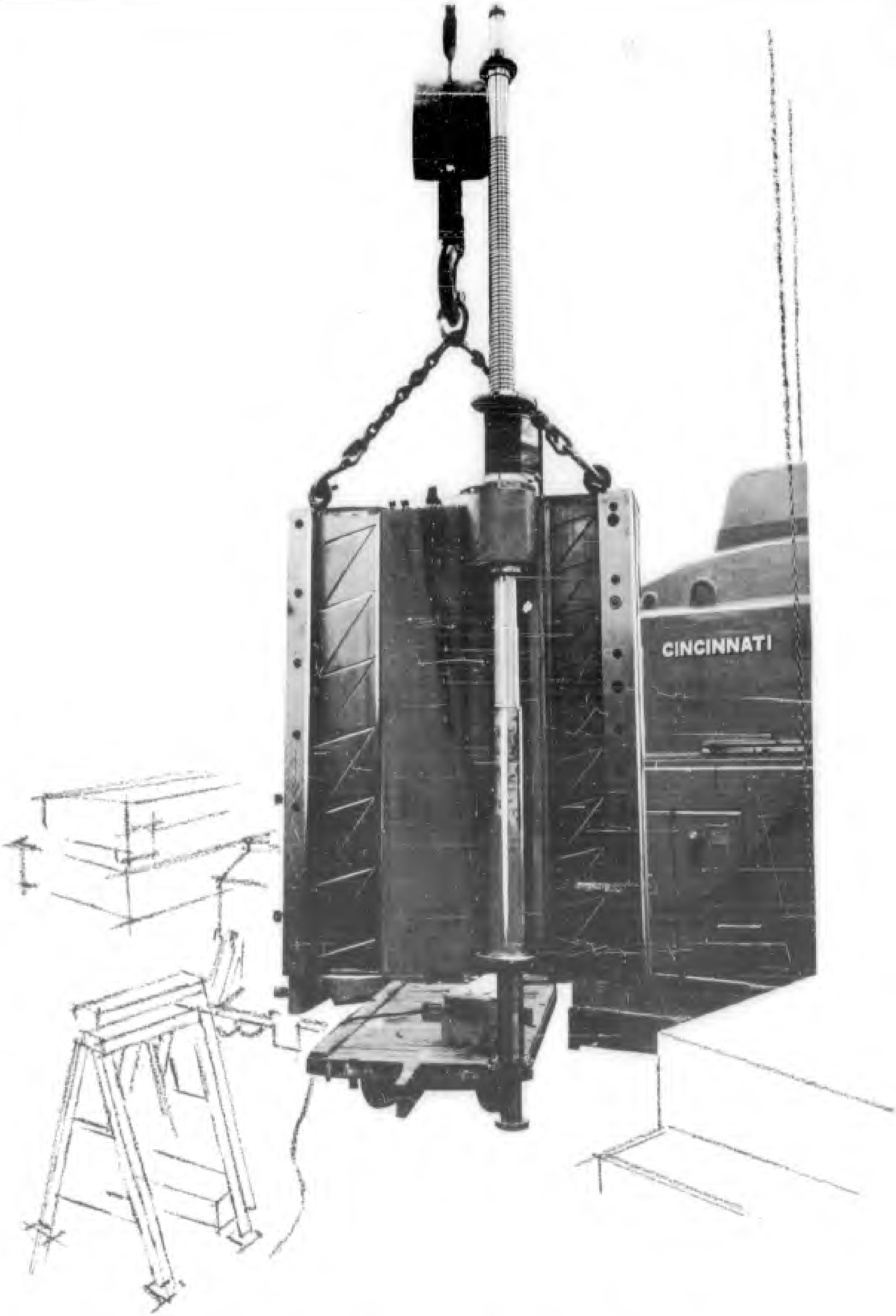
5 BED AND COLUMN



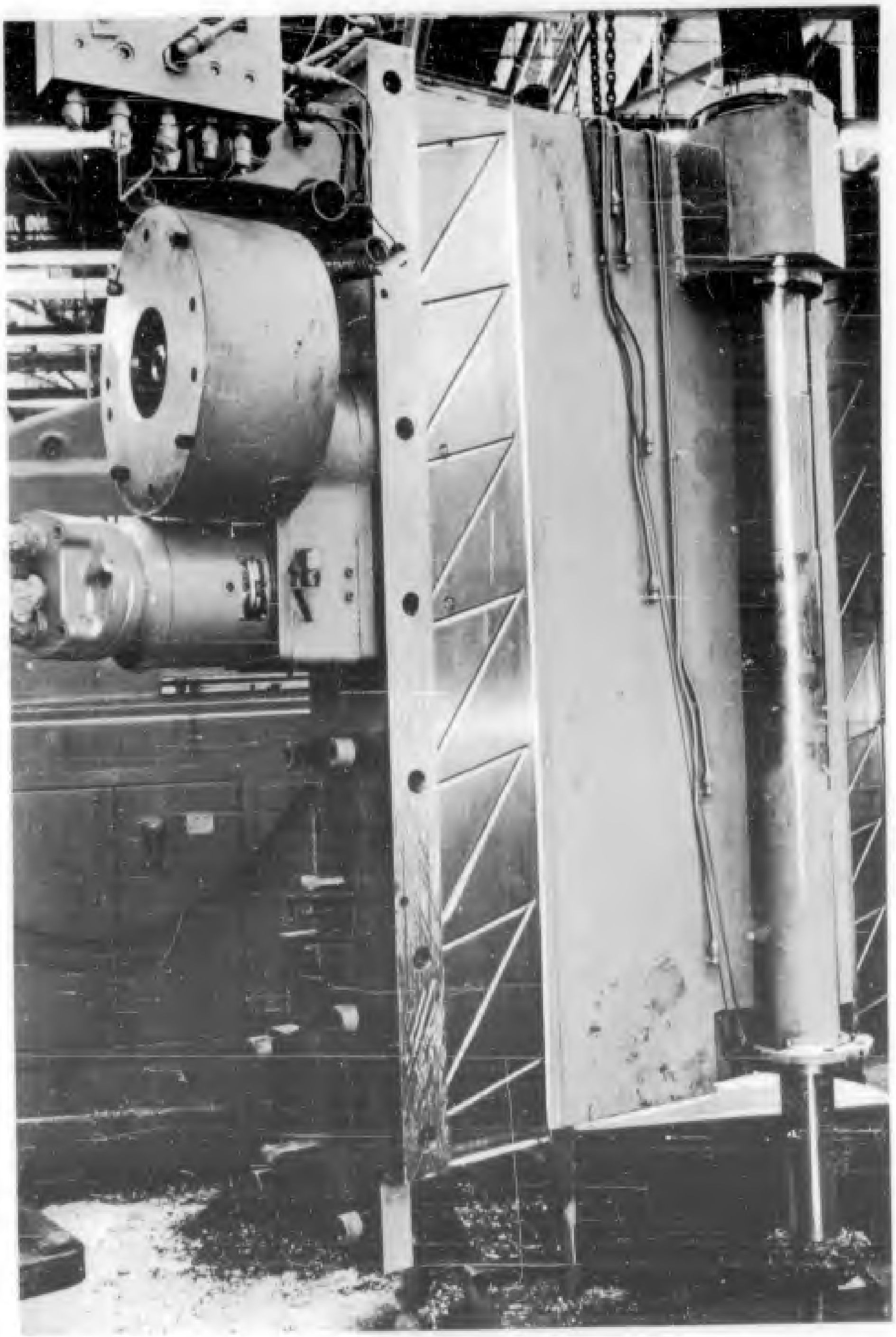
6 UNDERSIDE OF TABLE



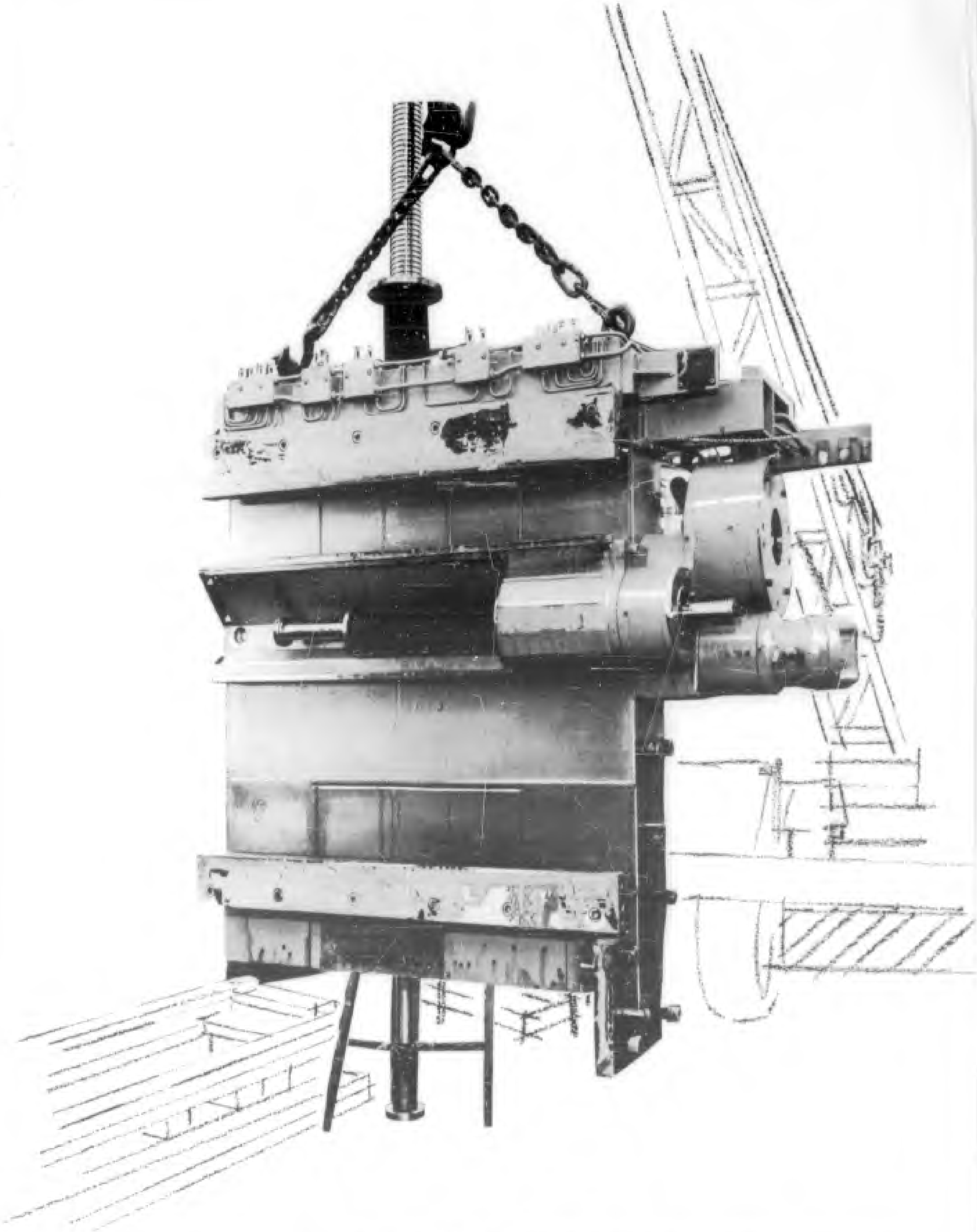
7 UNDERSIDE OF TABLE



8 BACK OF SADDLE WITH BALL SCREW ASSEMBLY

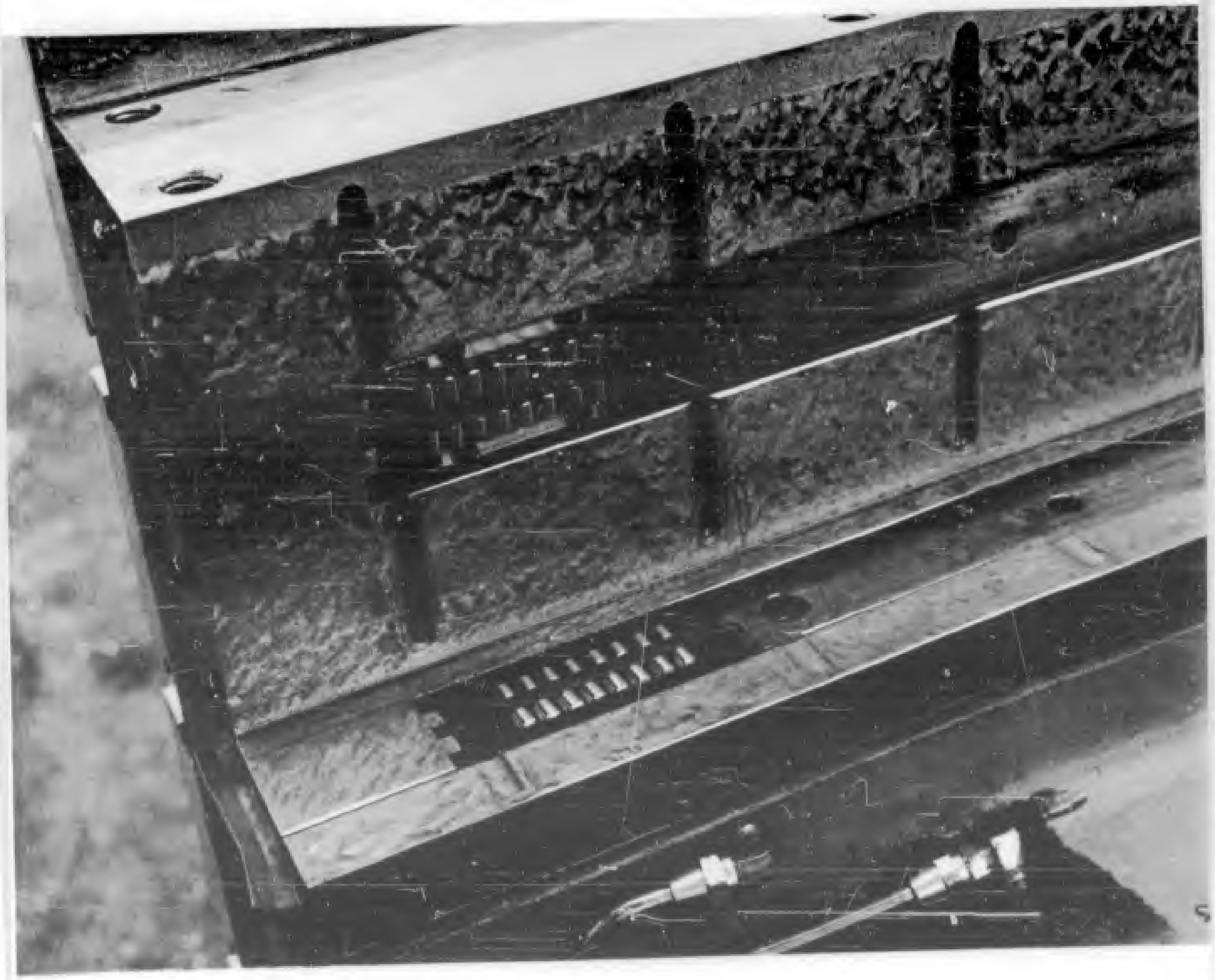


9 BACK OF SADDLE WITH BALL SCREW ASSEMBLY / detail

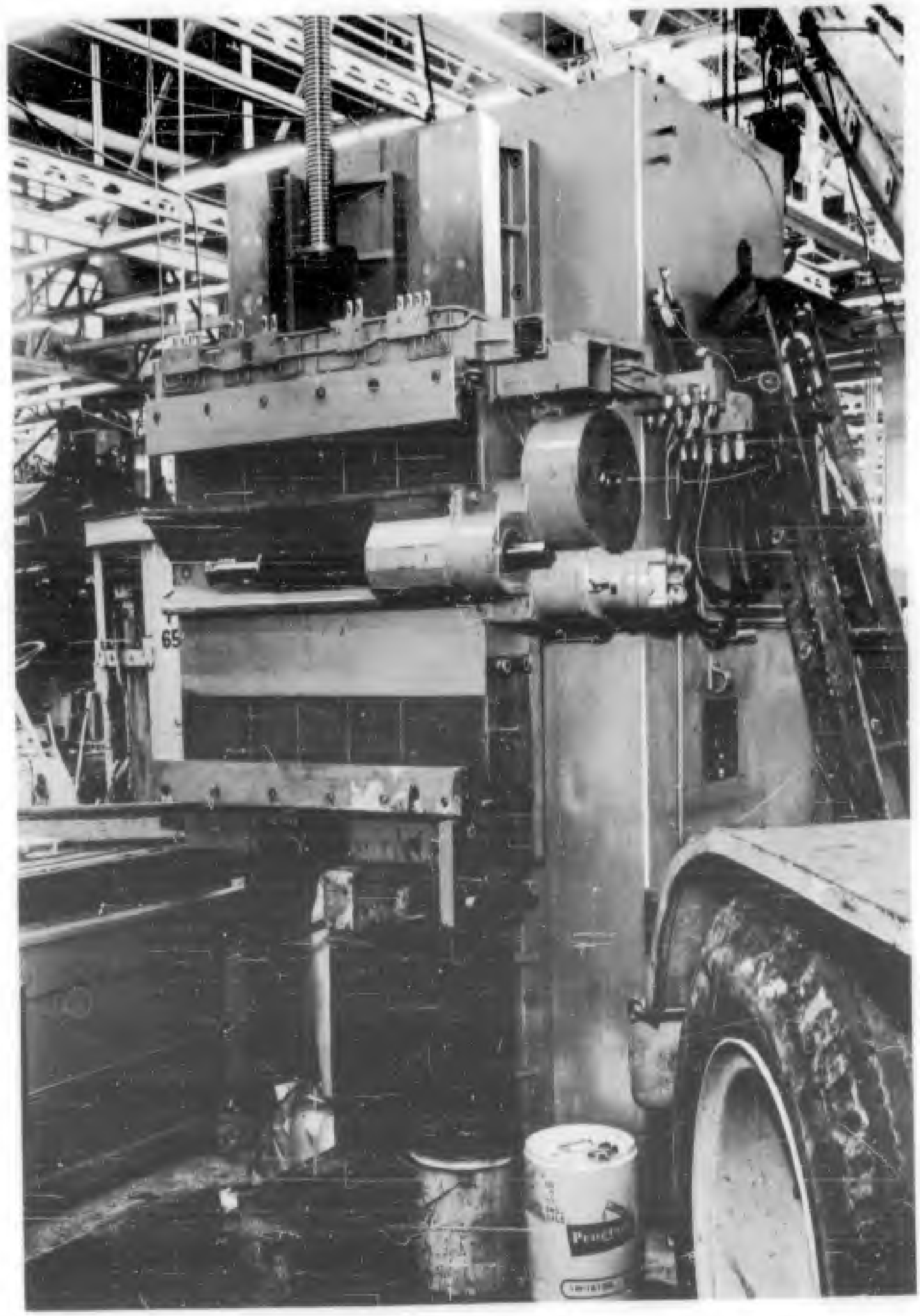


10 FRONT OF SADDLE WITH BALL SCREW ASSEMBLY

11 ROLLER BEARING WAYS

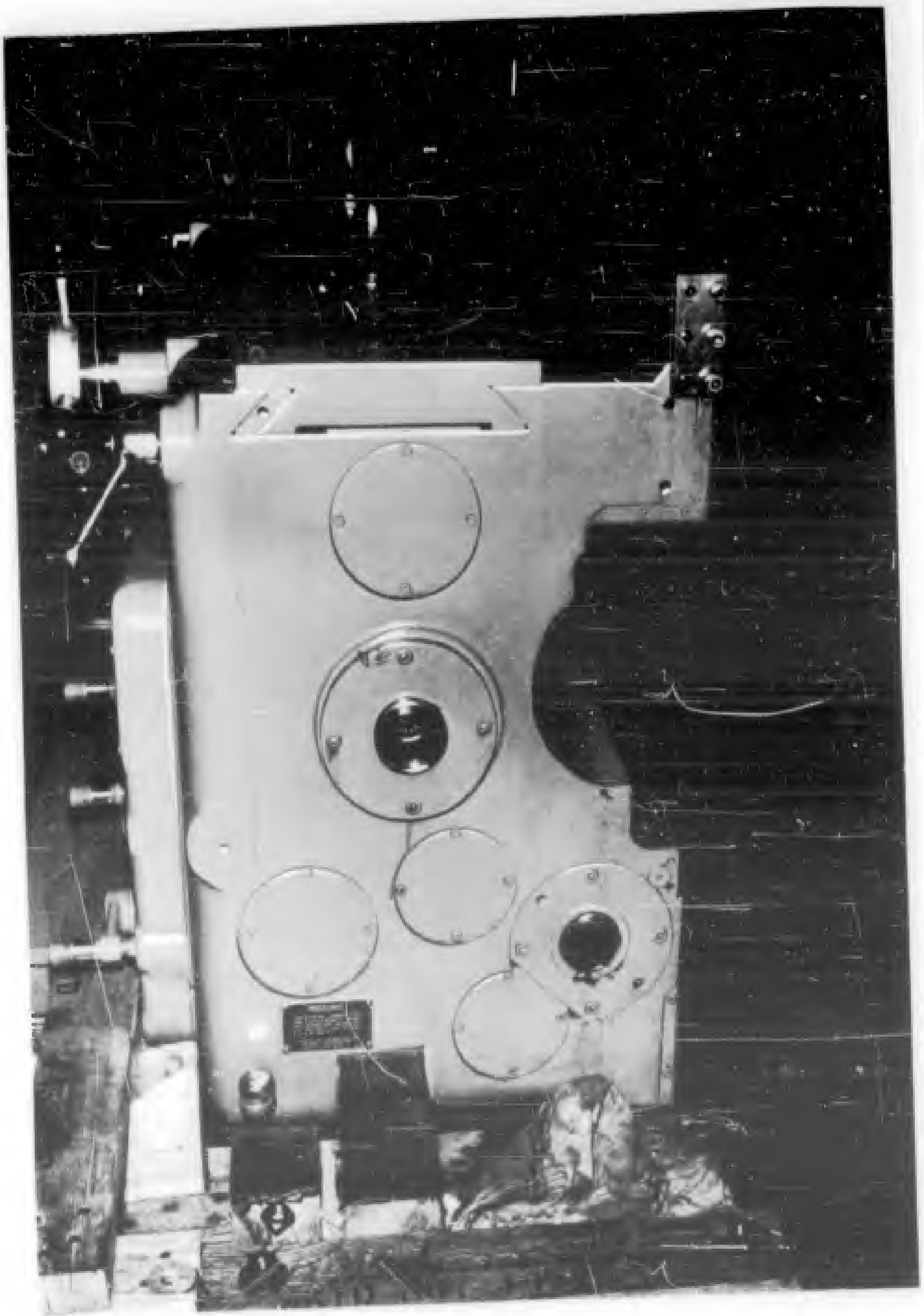


12 ROLLER BEARING WAYS / detail

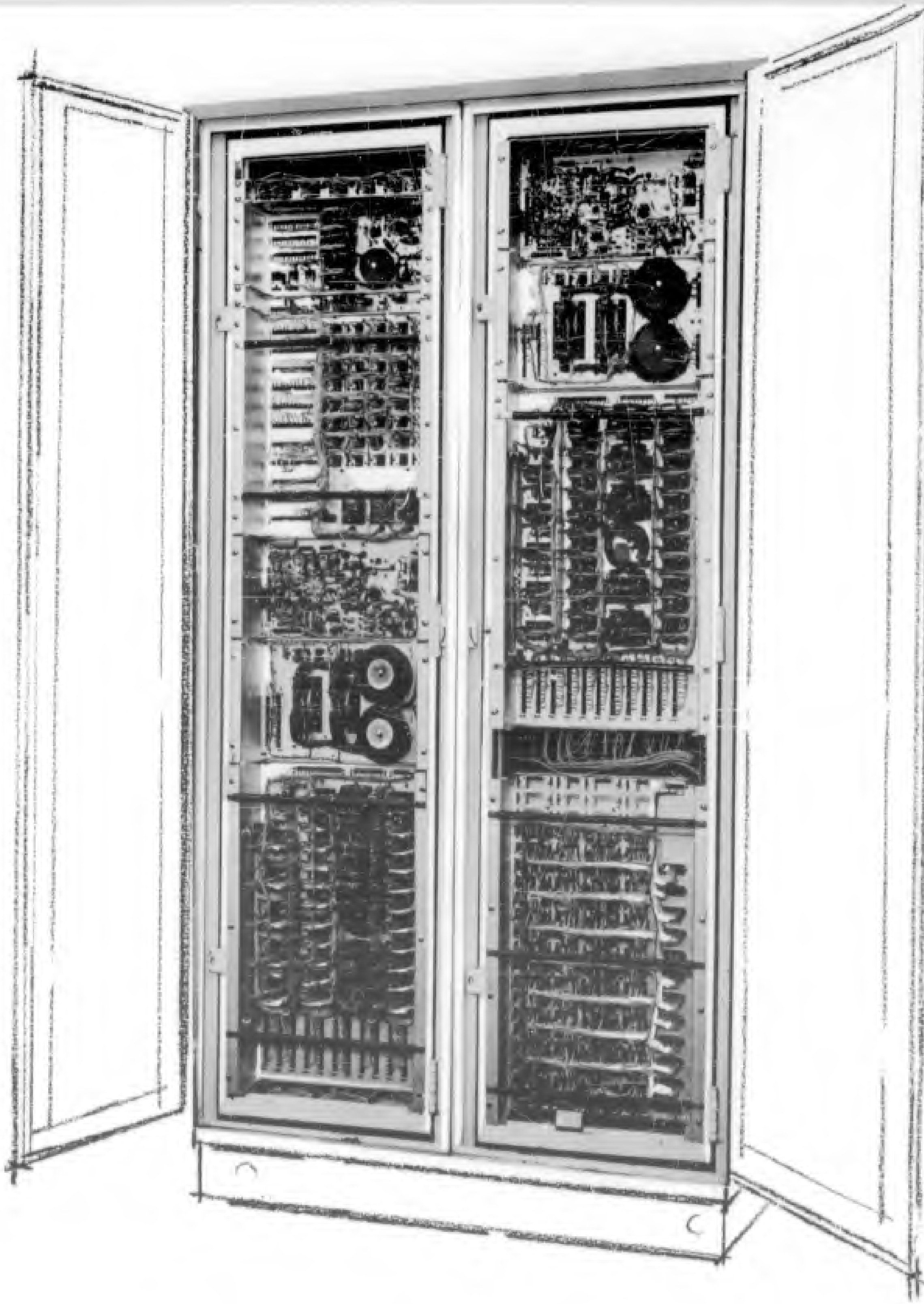


13 SADDLE ASSEMBLY WITH COLUMN

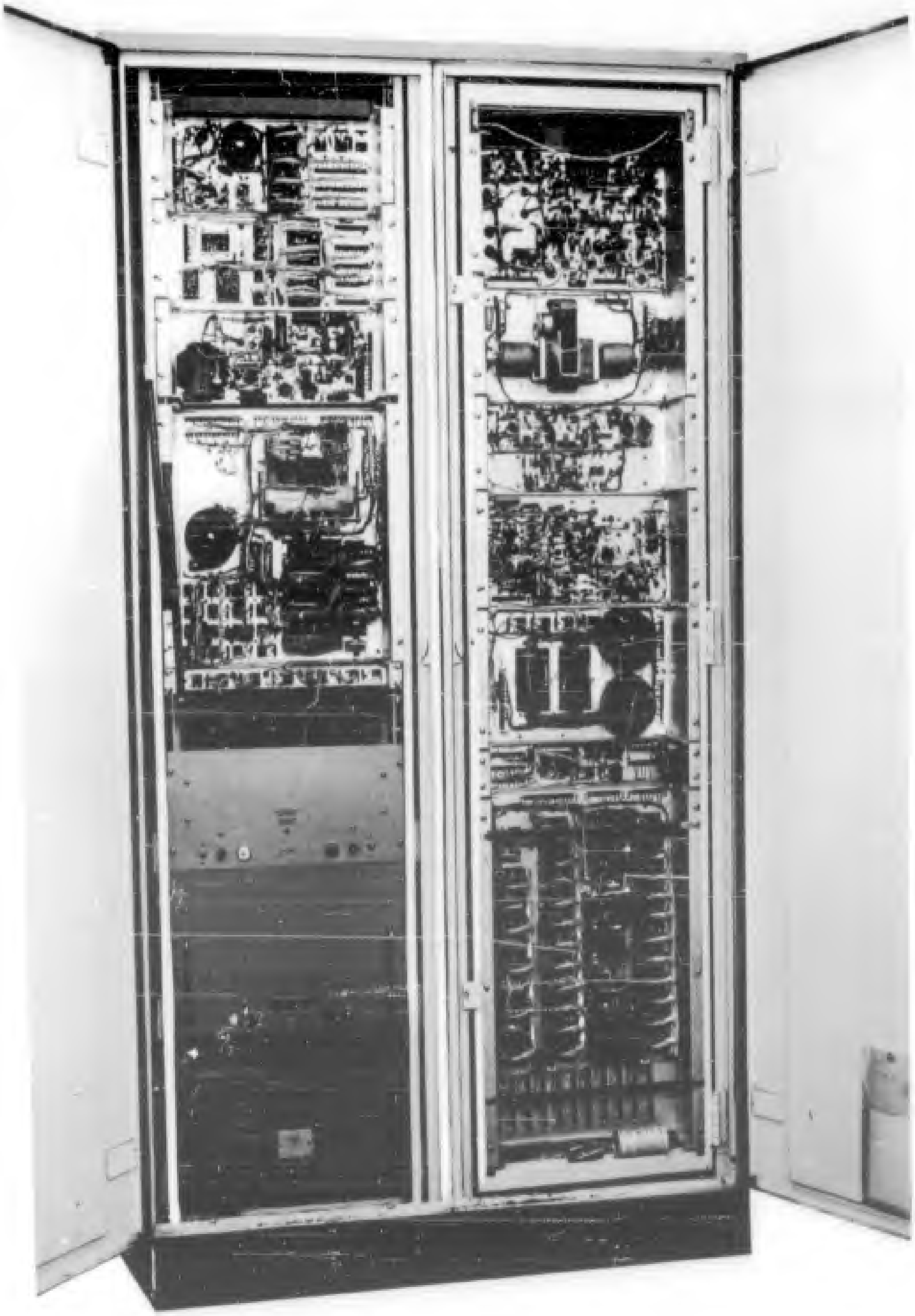
14 SPINDLE CARRIER / front view



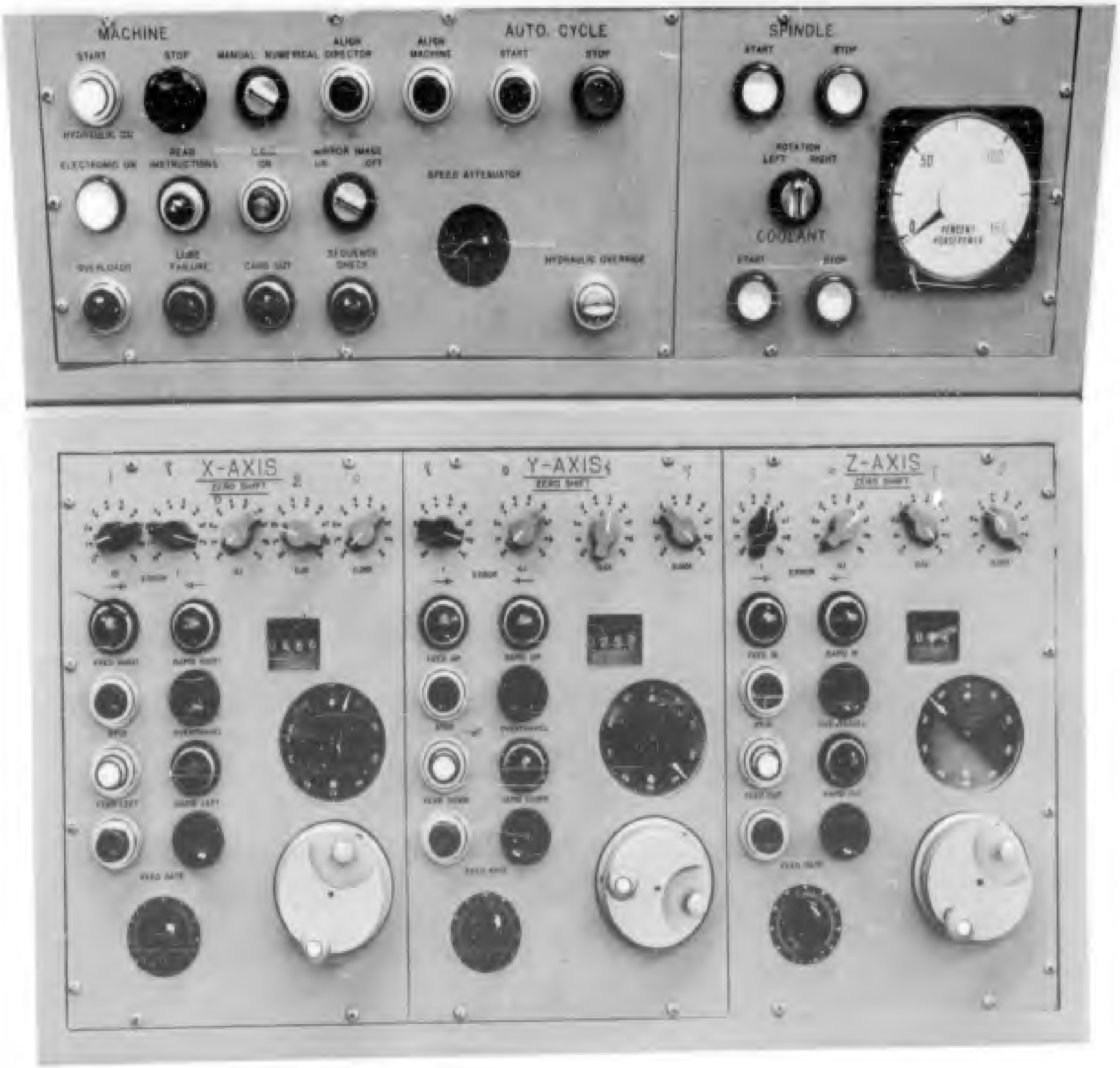
15 SPINDLE CARRIER / side view



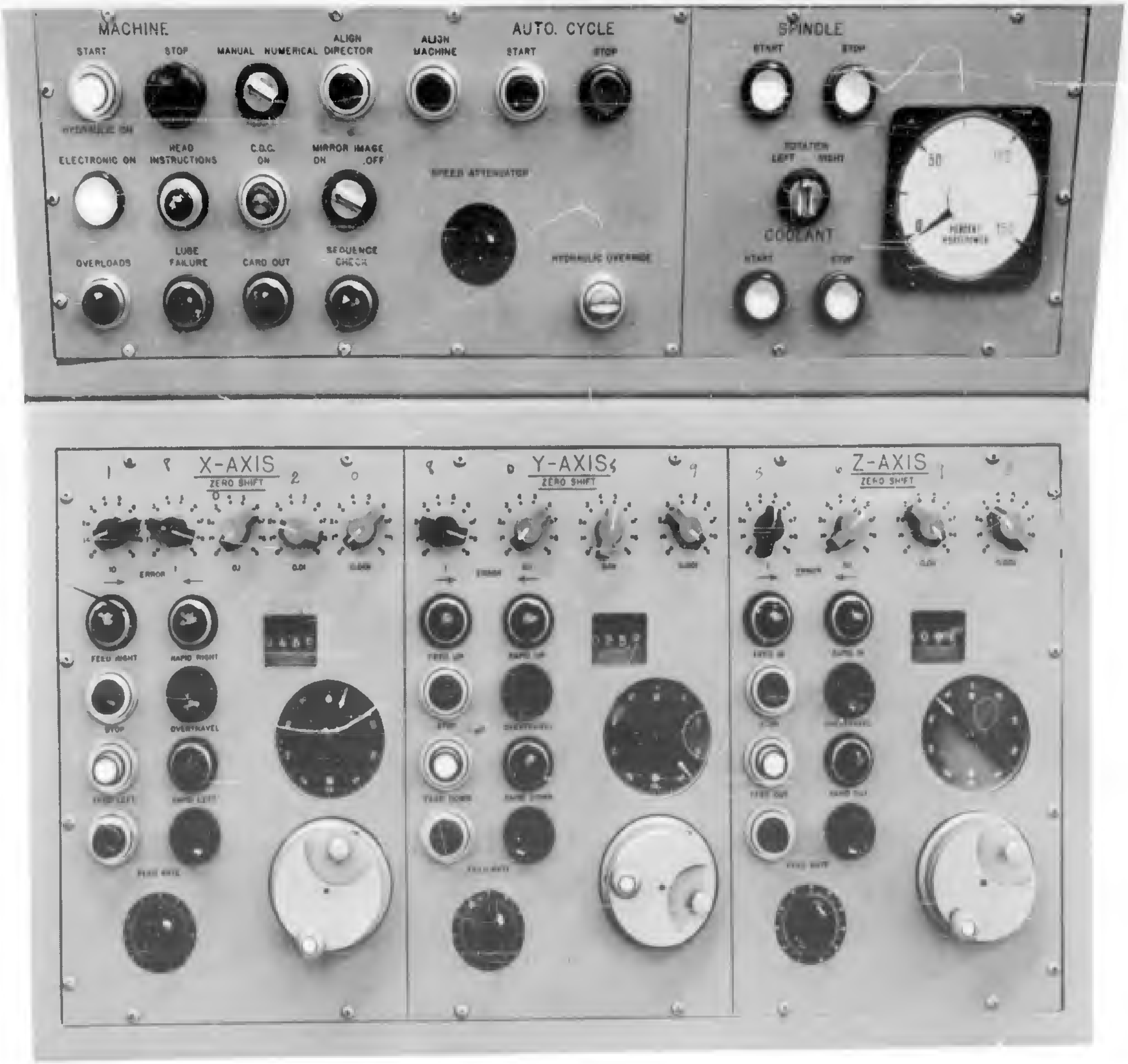
16 DIRECTOR CABINET SHOWING ELECTRONICS COMPONENTS



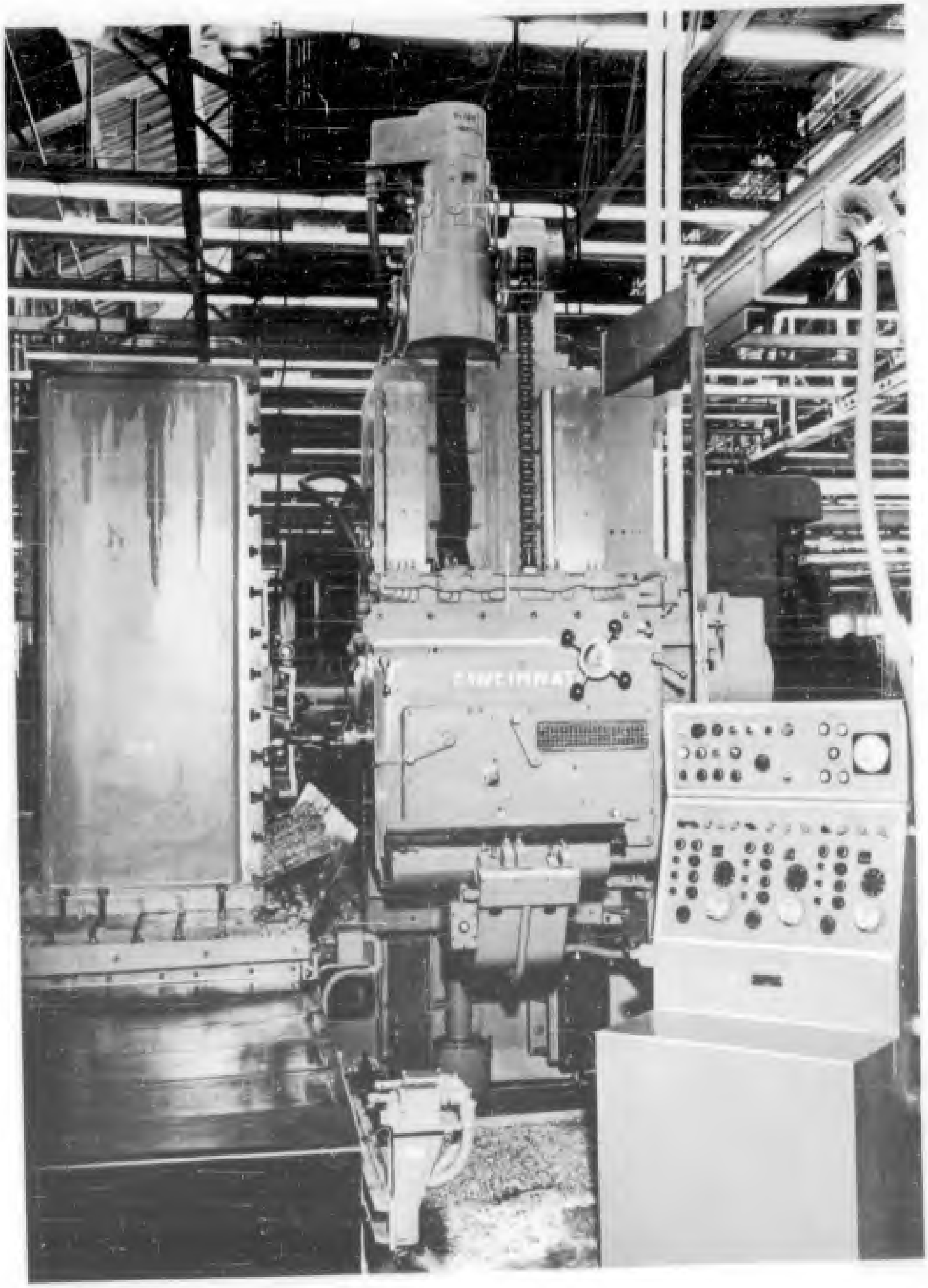
17 DIRECTOR CABINET



18 CONSOLE AND OPERATOR CONTROLS



18 CONSOLE AND OPERATOR CONTROLS



19 general view showing ANGLE PLATE AND CONSOLE

20 general view of MACHINE COMPONENTS with DIRECTOR CABINET AND CARD READER

3.0 trial performance results

APPLICABLE SPECIFICATIONS
PERFORMANCE RESULTS
SUPPLEMENTARY OBSERVATIONS

TRIAL PERFORMANCE RESULTS

3.1 APPLICABLE SPECIFICATIONS

Performance specifications applicable to this retrofit project are contained in North American Specification No. H-59-11, as revised, and as listed under Section 2.2 Specifications, of this report.

3.2 PERFORMANCE RESULTS

Results of the alignment and cutting tests conducted at Cincinnati Milling follow:

3.2.1 Deviations from A.I.A. Specifications

There were no deviations to North American Specification H-59-121. This specification was patterned from applicable A.I.A. specifications; however, in some cases the North American specification was more stringent and demanded greater accuracy from the machine and control system.

3.2.2 Tolerances

Alignment and tolerance tests were conducted to determine the relationship between the spindle and the work surface. All tests were performed successfully; in many cases the machine tolerance bettered the specifications by 100%. The following is a brief description of the alignment and tolerance tests and their results:

a. Test No. 1 - Run-out, Spindle Nose to Working Surface, Longitudinally (Horizontal)

This test was performed with a dial indicator attached to a tooling bar in the spindle. The table was traversed longitudinally (X axis) and readings taken on the vertical angle plate. Specified tolerances were plus or minus .001" per foot maximum and plus or minus .0025" over the full length. The retrofit machine indicated a tolerance of .00025" per foot and .0005" over the full length. This performance is better than the specification requirement.

b. Test No. 2 - Runout, Spindle Nose to Working Surface, Transversely (Vertical)

This test was performed in the same manner as Test No. 1 except the spindle was moved transversely (Y axis). Specified tolerances were plus or minus .001" per foot maximum and plus or minus .0025" over the full width. The results of this test were .001" over the full width and

.00025" per foot. This performance meets the specification requirement. Supplemental information on Test Nos. 1 and 2 is contained in 3.2, attachment no. 1. This attachment indicates more clearly the close tolerance that was maintained between the column and table ways.

c. Test No. 3 - Depth Slide Movement of Head - Runout, Depth

This test was performed with a dial indicator attached to a tooling bar in the spindle. A square was placed with one leg forming a 90° angle with the vertical angle plate and in a horizontal plane. The spindle carrier was then moved in the depth dimension (Z axis) and readings taken on the perpendicular leg of the triangle. The specified tolerance was .0006" per foot; the result of this test was .0003" per foot.

d. Test No. 4 - Depth Slide Movement of Head - Runout, Check at 90°

This test was performed in the same manner as Test No. 3, except the square leg perpendicular to the vertical angle plate was in a vertical position. The specified tolerance was .0006" per foot; the result of this test was .0006" per foot. Test Nos. 3 and 4 indicate the squareness of the spindle carrier ways with the work surface.

e. Test No. 5 - Depth Slide Parallel with Spindle, Horizontally

This test was performed with a right angle tooling bar in the spindle with a dial indicator attached to the tooling bar in such a manner that the work surface area can be trammed. The measurements are made with the bar in a horizontal position, one measurement being 180° from the other. The specified tolerance was .0006" per foot. In this test a 12" tooling bar was used resulting in a 21" tram diameter. The result of this test was .0003" per foot.

f. Test No. 6 - Depth Slide Parallel with Spindle, Vertically

This test was performed in the same manner as Test No. 5 except the measurements are made vertically. The specified tolerance was .0006" per foot; the result of this test was .00023" per foot. Test No. 5 and 6 indicate the parallelism of the spindle with the spindle carrier ways.

g. Test No. 7 - Spindle Face Axial Runout

This test was performed by mounting a dial indicator on the vertical angle plate. The spindle was rotated with axial runout being read on the indicator in contact with the spindle. The specified tolerance for this test was .0004" maximum. The tolerance recorded was .0002".

h. Test No. 8 - Spindle Face Radial Runout

This test was performed in the same manner as Test No. 7 except that the indicator was placed in contact with the side of the spindle face.

The specified tolerance was .0004"; the result of this test was .0001". The results of Test Nos. 7 and 8 were better than the specification requirement.

i. Test No. 9 - Spindle Runout

This test was performed by placing a tooling bar in the spindle. A dial indicator was mounted perpendicular to the vertical angle plate. Readings were taken 1 1/4" and 12" from the spindle face while the spindle was rotated. The specified tolerances for this test were .0005" maximum, 1 1/4" from the spindle face, and .001" maximum, 12" from the spindle face. The results of this test were .0004" - 1 1/4" from the spindle face, and .001" - 12" from the spindle face. This test indicates the parallelism of the spindle taper with the spindle carrier.

j. Test No. 10 - Displacement of Any Slide During Locking

With a numerically controlled machine, the displacement of a slide is a function of the numerical control system. No movement occurred when the numerical controls were locked.

k. Test No. 11 - Repetitive Positioning Accuracy

This test checks the repetitive positioning accuracy by making a total of 10 separately interpolated paths, diagonally across the work surface, between target points located in the lower left-hand corner and the upper right-hand corner of the work surface. Specification tolerance for this test was .005" T.I.R. maximum. The results show a maximum deviation of .0007". The majority of readings were .0001" or less. This performance is considerably better than the specification requirements.

l. Test No. 12 - Cutter Compensation

This test was performed by placing a tooling bar in the spindle, and mounting a dial indicator on the vertical angle plate in contact with the tooling bar. Cutter compensation was dialed in as listed on the test chart. Since the reading was taken on a radius, a dial setting of .002" should result in a change of .001" on the indicator. No test requirements were established in the North American specifications for cutter compensation. Test results were quite satisfactory for the entire range of dial settings. Exceptional accuracy was obtained for dial settings up to .020", the maximum deviation being .00015".

3.2.3 Cutting Tests

The cutting tests were performed to test the functional accuracy of the machine under actual cutting conditions and to prove the performance of the card transport, the machine control unit, the machine drive, and the feedback units. All.cutting tests were performed on 4130 or 4140 steel alloy bar or plate stock heat treated to 250 - 300 Brinell. Notarized copies of the chemical analysis and heat treatment for the steel billets used in the cutting tests is contained in attachment no. 2. The following is a brief description of the cutting tests and their results:

a. Test No. 13 - Maximum Rated Horsepower Cut in Both X and Y Axes

This test was performed on a piece of 4130 steel, heat treated to 250-300 Brinell, securely attached to the vertical angle plate. Cuts were taken with an 8 T.C. 10-tooth cutter in both the X and Y axes of sufficient depth, width and feed rate to require maximum rated horsepower. The specified tolerances for this test were 150 RMS surface finish and a flatness error not to exceed .002" per foot, .006" full length. During the performance of this test, chatter was noted on the vertical (Y axis) cut. This condition was corrected by the addition of a flywheel on the spindle, inside the spindle carrier. The test was successfully re-run resulting in a surface finish of 80-130 RMS for the X axis cut and 40-60 RMS for the Y axis. Flatness error was less than half the specified tolerance at .001" per foot, .003" full length. The horsepower readings during the cuts exceeded the full rated horsepower. In view of the difficulty encountered during this test, an additional full rated horsepower test was scheduled to be run after the machine was installed at North American. The results of this test are contained under 4.0.

b. Test No. 14 - Maximum Feed Rate Cut, 50% of Full Rated Horsepower in Both X and Y axes

This test was performed under the same conditions as Test No. 13 except the depth and width of cut was reduced to permit a maximum feed rate of 25" per minute at 50% of full rated horsepower. The specified tolerances for this test were 60 RMS surface finish and a flatness error not to exceed .002" per foot, .006" full length. Test results were satisfactory, surface finish for the X axis cut 60-120 RMS, for the Y axis cut 50-60 RMS. Flatness error was less than half the specified tolerance at .001" per foot, .003" full length. The horsepower readings during the cuts exceeded the 50% specification requirement.

c. Test No. 15 - 360° Plus Depth Cut, X Axis (3 Dimensional)

This test was performed on a piece of 4130 steel, heat treated to 250-300 Brinell, securely attached to the vertical angle plate. The test piece was 6" x 20" rectangle with the 20" dimension placed parallel to the longitudinal, or X axis. The top surface of the test piece was pre-cut to form a 15° angle with the vertical angle plate. The test cut was made around the upper periphery with a 1 1/4" H.S.S. ball nose end mill at 9.5" per minute and .060" x .020" depth of cut. Specification requirements were 60 RMS surface finish, .003" per foot peripheral tolerance, ± .005" per foot depth tolerance and .003" per foot squareness tolerance. Test results were 20-40 RMS surface finish, .001" peripheral error, .0035" total depth error and .001" squareness error. The results of these tests are considerably better than the specification requirements.

d. Test No. 16 - 360° Plus Depth Cut, Y Axis (3 Dimensional)

This test was performed under the same conditions as Test No. 15, except the 20" dimension on the test piece was placed parallel to the transverse (vertical) or Y axis. Specification requirements and test results were indentical to Test No. 15.

e. Test No. 17 - 360° Circular Segment Cut

This test was performed on a piece of 4130 steel, 24" long, securely attached to the vertical angle plate. The test piece was placed with the 24" dimension parallel to the longitudinal or X axis. A circular cut (24" cord length, .480 cord height, 150" radius) was taken using a 2" diameter end mill at 10" per minute, .500" width x .250" depth. Specification requirements were: 150 RMS surface finish, ± .005" overall tolerance, ± .003" crossover point tolerance. Test results were 10-20 RMS surface finish, .003" error with template (curvature), .001" chord height error and no detectable error at the crossover point. The results of this test are better than the specification requirement.

f. Test No. 18 - 360° Full Circle Cut

This test was performed on a 10" diameter piece of 4140 steel heat treated to 250-300 Brinell. The test piece was securely attached to the vertical angle plate. A circular cut .500" in depth (Z axis) and .035" of metal removal (X and Y axes) was taken with a 1 1/4" diameter cutter at 10" per minute. Specification requirements were: 60 RMS surface finish, ± .006" peripheral tolerance. The circle diameter was programmed for a nominal diameter of 10.000" nominal.

g. Test No. 19 - 360° Full Circle Cut, Plus Depth (3 Dimensional)

This test was performed on a 10" diameter piece of 4130 steel. The test piece was securely attached to the vertical angle plate. The top of the test piece was pre-machined to form a 15° angle with the vertical angle plate. A circular cut around the test part periphery, .040" x .020" in depth, was taken with a 1 1/4" ball nose end mill at 10" per minute. Specification requirements were: 60 RMS surface finish, ± .005" peripheral tolerance and ± .005" depth tolerance. The results of this test were: 30-40 RMS surface finish, .0045" T.I.R. peripheral error and .003" T.I.R. depth error. The results of this test were better than the specification requirement. Quadrant change points were not detectable.

h. Test No. 20 - 360° Rectangular Cut

This test was performed on a rectangular piece of 4130 steel securely attached to the vertical angle plate. A test cut was taken around the part periphery, .020" deep, using a 1 1/4" end mill at a feed rate of 22" per minute. This cut was made without programmed slowdown or parabolic deceleration. Specification requirements were .006" maximum overshoot and 60 RMS surface finish. The results of this test were .000" overshoot and 60 RMS surface finish.

i. Test No. 21 - 360° Tracing Cut, Rectangular Channel Cuts

This test was performed on a rectangular piece of 4130 steel securely attached to the vertical angle plate. Channel cuts .500" deep x 2" wide were pre-cut in the form of a rectangle in the test part. A test cut .500" deep with a .040" total chip load was taken, using a 2" T.C. end mill, with a feed rate of 25" per minute, around the periphery of the pre-cut rectangles. This cut was made without programmed slowdown or parabolic deceleration. Specification requirements were 60 RMS surface finish and .008" maximum undercut. The results of this test were 50-60 RMS surface finish and .006" undercut error.

j. Test No. 22 - Cutter Compensation

This test was performed on a round piece of 4130 steel securely attached to the vertical angle plate. A cut was made around the periphery of the test part and the diameter measured and recorded. A cutter compensation of .010" was dialed in and the above cut repeated. Since cutter compensation is based on diameter, the second circle should be .010" smaller than the first. A comparison of the test results shows a maximum error of .0005". This test was not included in the North American specifications, but was performed exceptionally well.

3.3 SUPPLEMENTARY OBSERVATIONS

The tolerance and cutting tests were conducted at the Cincinnati Milling Machine Company plant. The workmanship-like manner in which these tests were conducted attests to the careful planning and thought which must have been expended in their preparation.

TEST NO. **1** - RUNOUT, SPINDLE NOSE TO WORKING SURFACE - LONGITUDINALLY

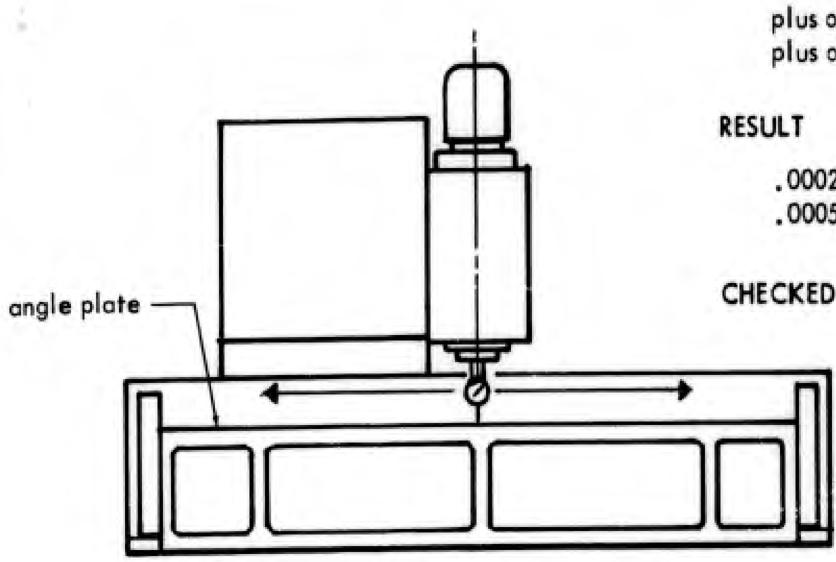
TOLERANCES

plus or minus 0.001" per foot max.
plus or minus 0.0025" over full length

RESULT

.00025/foot
.0005 over full length

CHECKED BY D. Ross & J. Caudill



TEST NO. **2**

RUNOUT, SPINDLE NOSE TO WORKING SURFACE, TRANSVERSELY (VERTICAL)

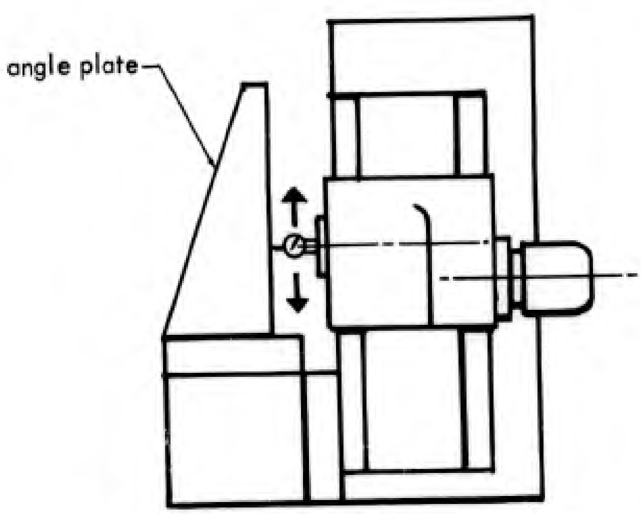
TOLERANCES

plus or minus 0.001" per foot max.
plus or minus 0.0025" over full length

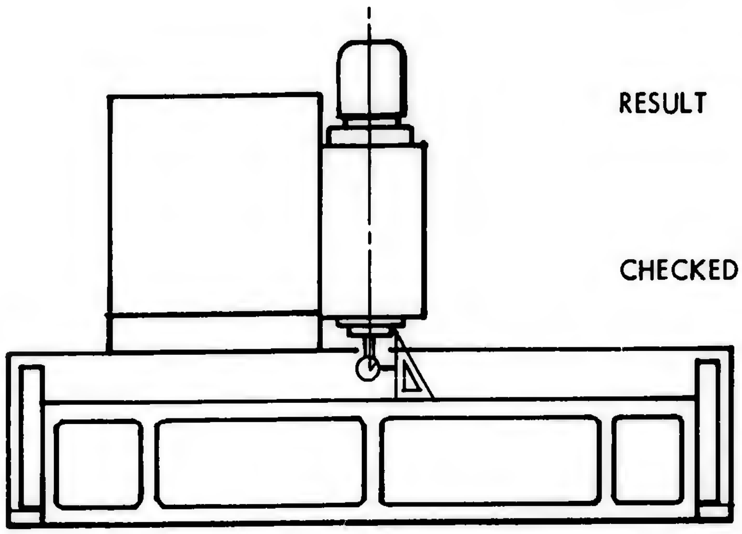
RESULT

.00025/foot
.001 over full length

CHECKED BY D. Ross & J. Caudill



TEST NO. 3 - DEPTH SLIDE MOVEMENT OF HEAD - RUNOUT, DEPTH



TOLERANCES max. 0.0006"/foot

RESULT .0003"/foot

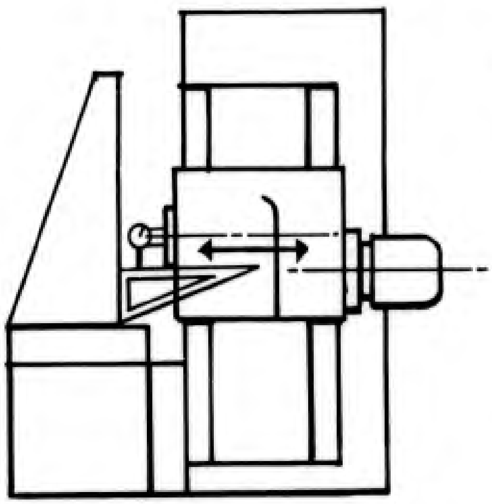
CHECKED BY D. Ross
J. Caudill

taken with square

TEST NO. 4

DEPTH SLIDE MOVEMENT OF HEAD - RUNOUT,

CHECK AT 90°

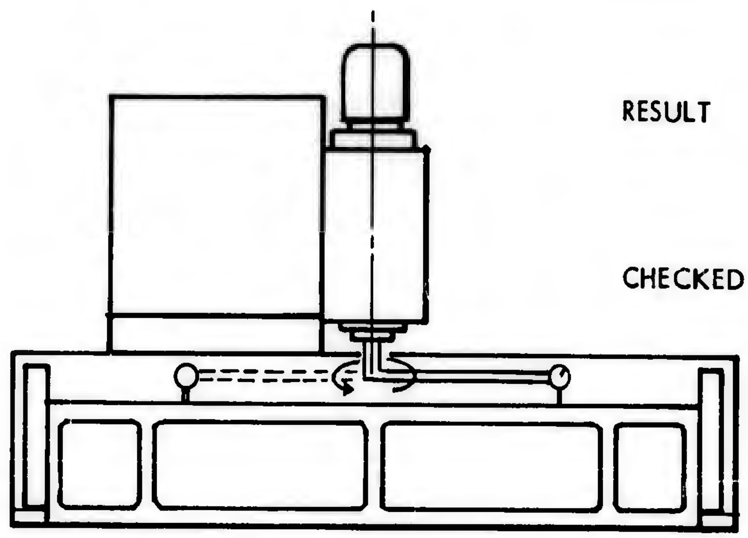


TOLERANCES max. 0.0006"/foot

RESULT .0006"/foot

CHECKED BY D. Ross
J. Caudill

TEST NO. 5 - DEPTH SLIDE PARALLEL WITH SPINDLE - HORIZONTALLY



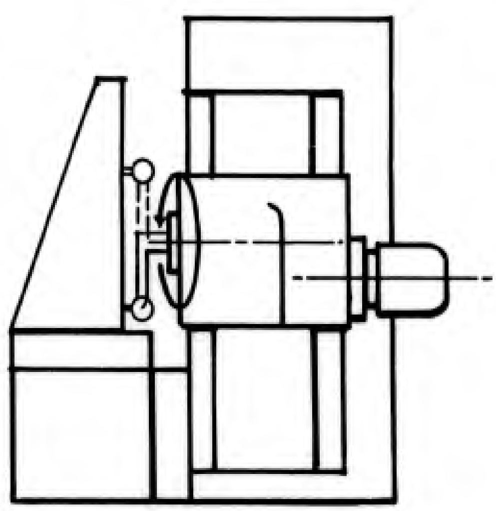
TOLERANCES max. 0.0006" per foot
check at 180°

RESULT .00035/foot

CHECKED BY D. Ross J. Caudill

TEST NO. 6

DEPTH SLIDE PARALLEL
WITH SPINDLE - VERTICALLY



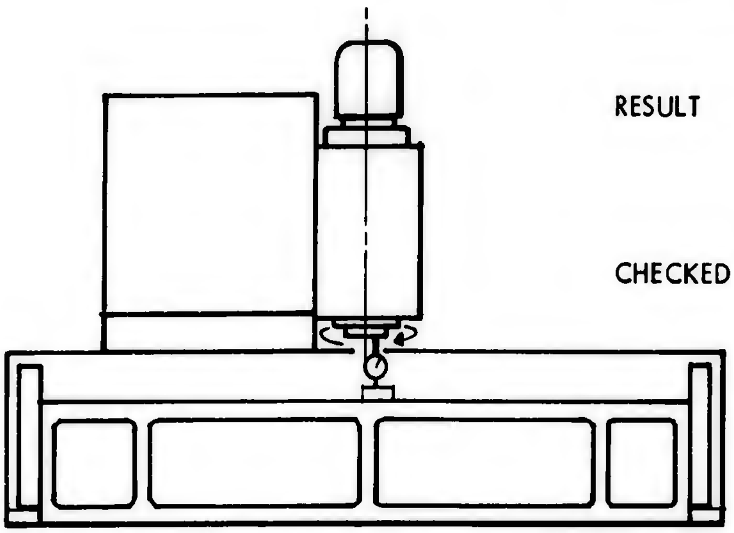
TOLERANCES max. 0.0006" per foot
check at 180°

RESULT .00023/foot

CHECKED BY D. Ross
J. Caudill

TEST NO. **7** SPINDLE FACE AXIAL RUNOUT

TOLERANCES max. 0.0004"



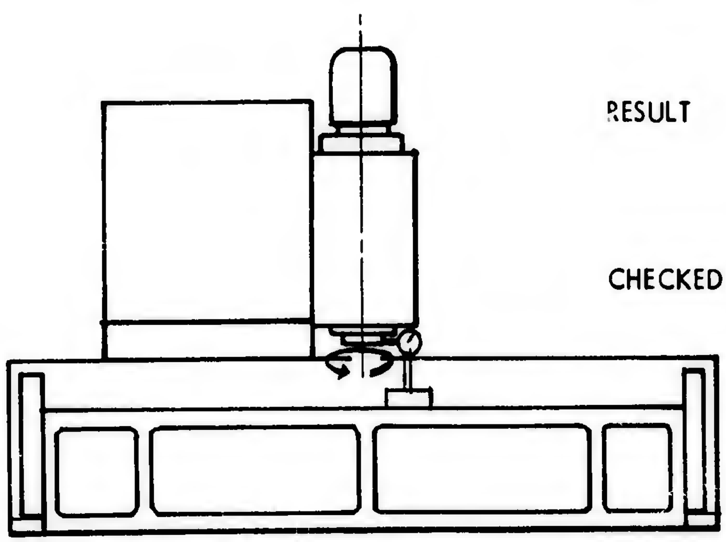
RESULT .0002

CHECKED BY D. Ross
J. Caudill

TEST NO. **8**

SPINDLE FACE RADIAL RUNOUT

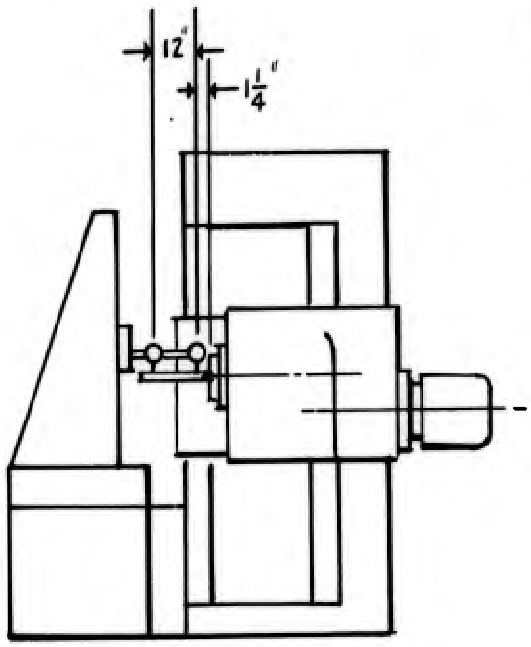
TOLERANCES max. 0.0004"



RESULT 0.0001

CHECKED BY D. Ross
J. Caudill

TEST NO. **9** - SPINDLE RUNOUT



TOLERANCES 1 1/4" from face, max. 0.0005"
12" from face, max. 0.001"

RESULT 1 1/4" from face - .0004
12" from face - .001

CHECKED BY D. Ross & J. Caudill

TEST NO. **10** - DISPLACEMENT OF ANY SLIDE DURING LOCKING

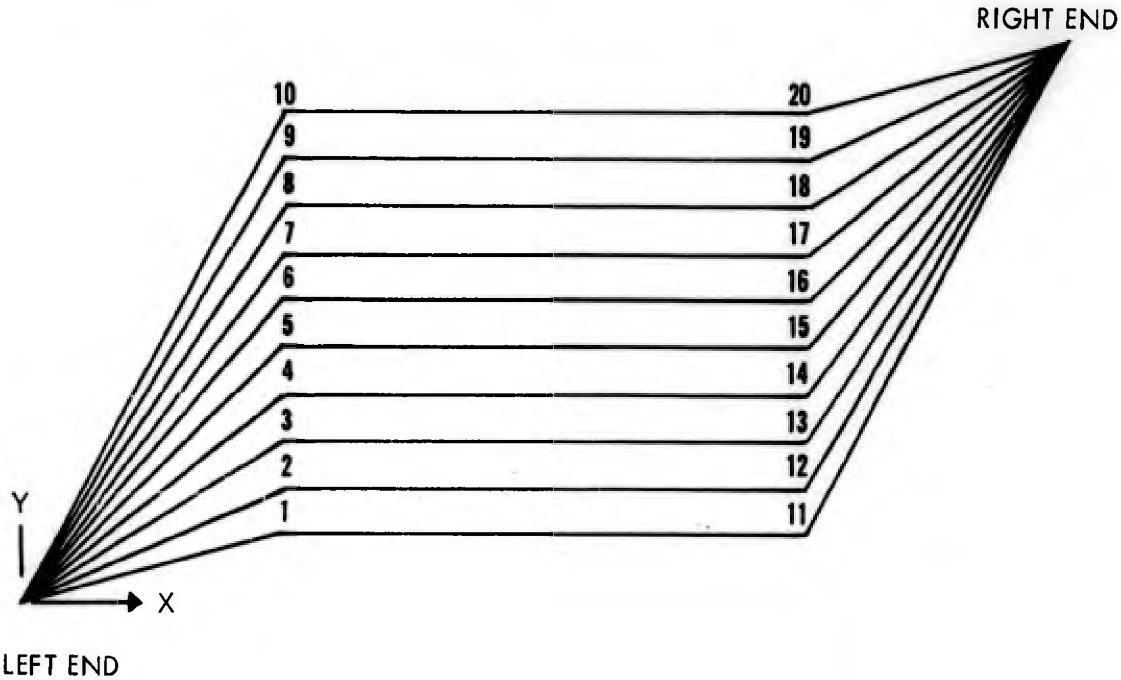
TOLERANCES max. 0.001" at 12" from spindle nose

RESULT no movement when handwheels are locked

CHECKED BY D. Ross & J. Caudill

TEST NO. **11** - REPETITIVE POSITIONING ACCURACY

Check repetitive positioning accuracy of machine by making a total of 10 separately interpolated paths, criss-crossing and diagonally across work surface, between target points located one in lower left and one in upper right corner.



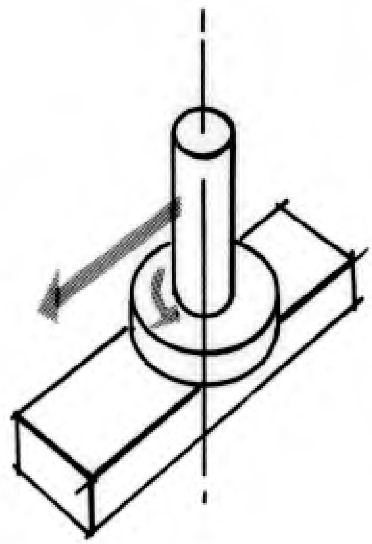
Evaluate: Positioning accuracy - (Max. T.I.R. - .005")

	RIGHT END		LEFT END	
TRIP NUMBER	X-AXIS DEVIATION	Y-AXIS DEVIATION	X-AXIS DEVIATION	Y-AXIS DEVIATION
1	0.0000	0.0000	.0000	.0000
2	-.0001	.0000	.0000	.0000
3	-.0001	.0000	.0000	.0000
4	-.0002	.0000	.0000	.0000
5	-.0001	.0000	.0000	.0000
6	-.0007	-.0001	.0000	.0000
7	-.0002	.0000	.0000	-.0001
8	-.0000	.0000	.0000	-.0001
9	-.0005	-.0001	.0000	-.0001
10	-.0006	-.0001	.0000	-.0001

TEST NO. **12** - CUTTER COMPENSATION

DIAL SETTING	INDICATOR READING	ERROR
0	0	0
.002	.00097	-.00003
.004	.00185	-.00015
.006	.00285	-.00015
.008	.00395	-.00005
.010	.00505	+.00005
.016	.008	.000
.020	.010	.000
.050	.0255	+.0005
.100	.0502	+.0002
.400	.202	+.002
.999	.505	+.0055

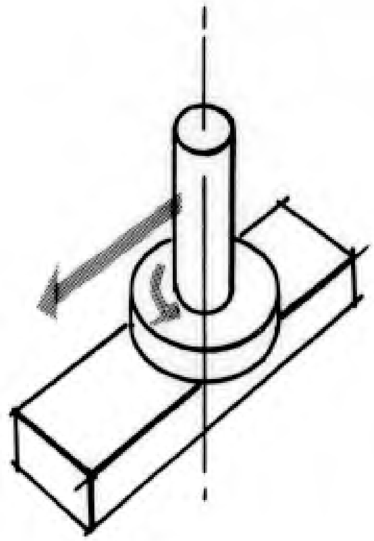
(Readings taken using tooling bar in spindle and .0001 indicator)



TEST NO. **13** - MAXIMUM RATED HORSEPOWER

	FULL RATED H.P. REQUIREMENTS	REMARKS X-PLANE	Y-PLANE
CUTTER	8"T.C. face mill	8"T.C. 10 tooth	8"T.C. 10 tooth
SPINDLE SPEED	150 RPM	151 RPM	106 RPM
FEED RATE	5"/min.	9.5"/min.	7.5"/min.
DEPTH OF CUT	as req'd (width optional)	.300 depth x 6" wide	.250 depth x 8" wide
MATERIAL	4130 or 4140 steel alloy bar or plate stock	4130	4130
BRINELL HARDNESS	250-300	250-300	250-300
SURFACE FINISH REQUIRED	150 RMS	80-130	40-60
FLATNESS ERROR	.002" per foot .006" full length		
FLATNESS RESULT		.001/foot .002 total 22.3 H.P.	.001/foot .003 total 21.5 H.P.

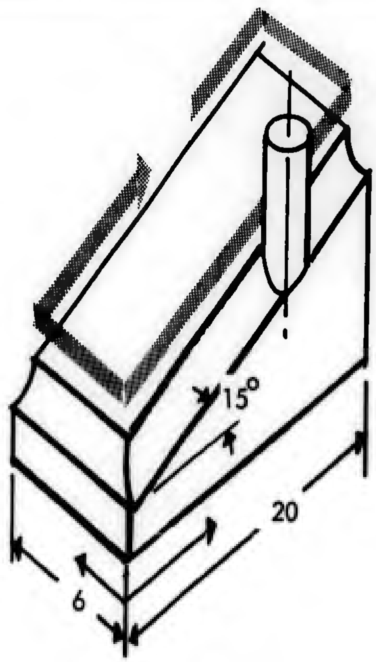
Checked By Dave Ross
Jim Caudill



TEST NO. **14** - MAXIMUM FEED RATE

	50% OF FULL RATED H.P. REQUIREMENTS	REMARKS X-PLANE	REMARKS Y-PLANE
CUTTER	8"T.C. face mill	8"T.C. 10 tooth	8"T.C. 10 tooth
SPINDLE SPEED	200 RPM	151 RPM	106 RPM
FEED RATE	25"/min.	25"/min.	24"/min.
DEPTH OF CUT	optional (width optional)	.060" x 6"wide	.060" x 6"wide
MATERIAL	4130 or 4140 steel alloy bar or plate stock	4130	4130
BRINELL HARDNESS	250-300	250-300	250-300
SURFACE FINISH REQUIRED	60 RMS	60-120	50-60
FLATNESS ERROR	.002" per foot .006" full length	.001/foot .002 total	.001/foot .003 total
FLATNESS RESULT		.001/foot .002 total	.001/foot .003 total 13.6 H.P.

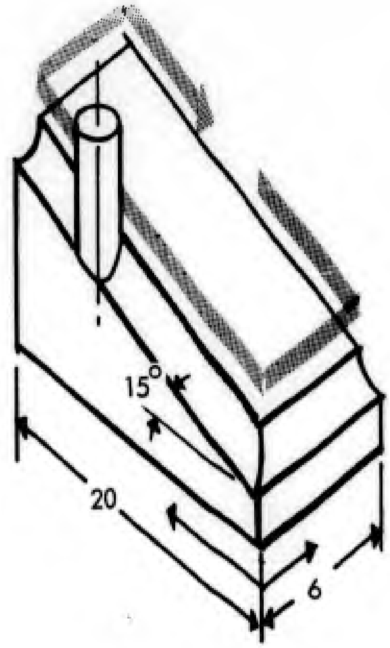
CHECKED BY Dave Ross
Jim Caudill



TEST NO. **15** - 360° PLUS DEPTH TRACING (3 DIMENSIONAL)

X-PLANE	REQUIREMENTS	REMARKS
END MILL	1 1/4" H.S.S. ball nose	
SPINDLE SPEED	320 RPM	430 RPM
FEED RATE	10 IPM	9.5"/min.
DEPTH OF CUT	.050" x .020"	.060 x .020
MATERIAL	4130 or 4140 steel alloy bar or plate stock	
BRINELL HARDNESS	250-300	250-300
SURFACE FINISH REQUIRED	60 RMS	
SURFACE FINISH RESULT		20-40 RMS
PERIPHERY TOLERANCE	.003" per foot	
PERIPHERY RESULT		.001 for X .001 for Y
DEPTH TOLERANCE	± 0.005" per foot	
DEPTH RESULT		.0035 total
SQUARENESS TOLERANCE	.003" per foot	
SQUARENESS RESULT		.0000/high end .001/6" low end

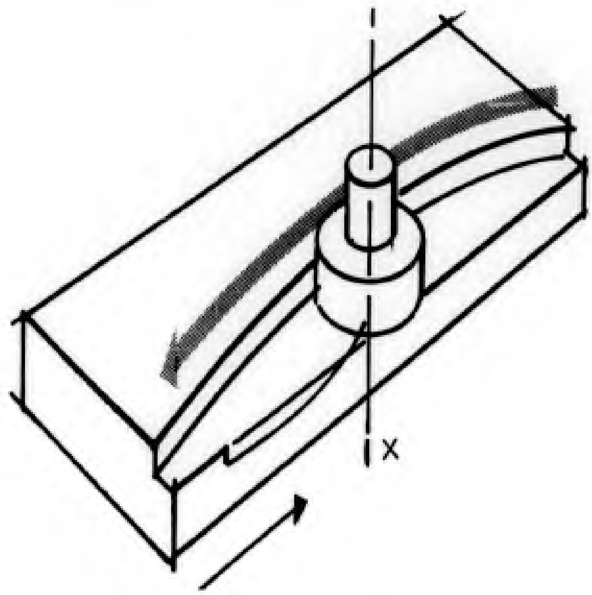
CHECKED BY Dave Ross
Jim Caudill



TEST NO. **16** - 360° PLUS DEPTH TRACING (3 DIMENSIONAL)

Y-PLANE	REQUIREMENTS	REMARKS
END MILL	1 1/4" H.S.S. ball nose	
SPINDLE SPEED	320 RPM	430 RPM
FEED RATE	10 IPM	9.5"/min
DEPTH OF CUT	.050" x .020"	.060 x .020
MATERIAL	4130 or 4140 steel alloy bar or plate stock	
BRINELL HARDNESS	250-300	250-300
SURFACE FINISH REQUIRED	60 RMS	
SURFACE FINISH RESULT		20-40 RMS
PERIPHERY TOLERANCE	.003" per foot	
PERIPHERY RESULT		.001 for X .001 for Y
DEPTH TOLERANCE	$\pm$ 0.005" per foot	
DEPTH RESULT		.0035 total
SQUARENESS TOLERANCE	.003" per foot	
SQUARENESS RESULT		.0000/high end .001/6" low end

CHECKED BY Dave Ross
Jim Caudill

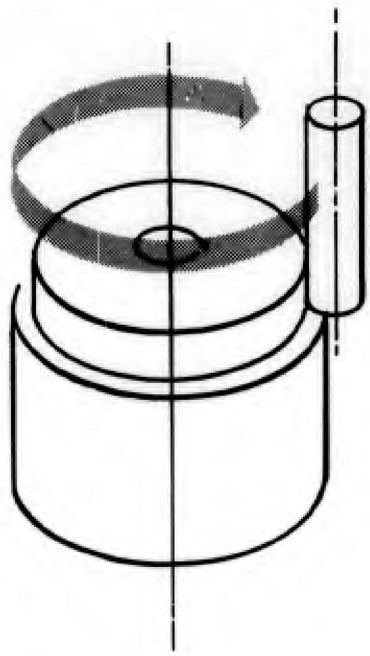


TEST NO. 17 - 360° TRACING (CIRCULAR SEGMENT)

24" chord length
.480" chord height
(approx. radius of 150")

	REQUIREMENTS	REMARKS
END MILL	2" dia. 4 flute T.C. end mill	2" H.S.S.
SPINDLE SPEED	900 RPM	420 RPM
FEED RATE	10"/min.	10"/min.
WIDTH OF CUT	.3125"	.500
DEPTH OF CUT	.250"	.250
MATERIAL	4130 or 4140 steel alloy bar or plate stock	4130
BRINELL HARDNESS	250-300	
SURFACE FINISH REQUIRED	150 RMS	
SURFACE FINISH RESULT		10-20 RMS
TOLERANCE OVERALL	± 0.005"	.003 error with template
OVERALL RESULT		.001 chord height error
TOLERANCE AT CROSSOVER POINT	± .003"	
CROSSOVER POINT RESULT		No error detectable

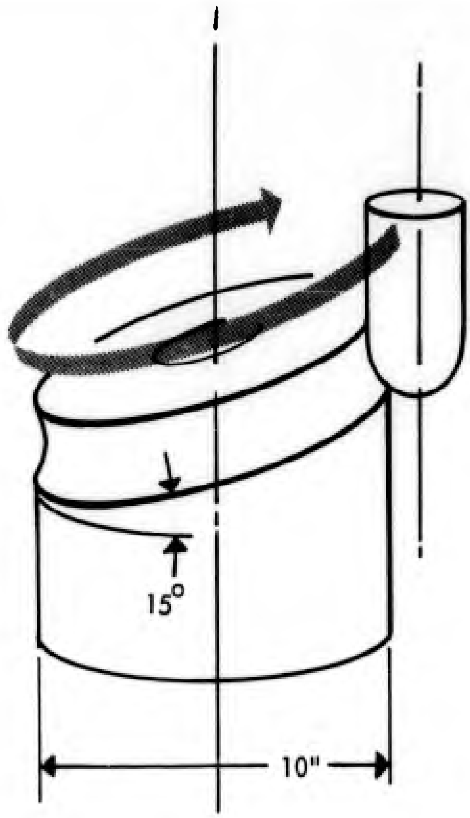
CHECKED BY D. Ross
J. Caudill



TEST NO. **18** - 360° TRACING (CIRCULAR)

	REQUIREMENTS	REMARKS
CUTTER	2" dia. T.C.	1 1/4 H.S.S.
SPINDLE SPEED	800 RPM	430 RPM
FEED RATE	10"/min.	10"/min.
DEPTH OF CUT	.020"	.035 x .500
MATERIAL	4130 or 4140 steel	4140
BRINELL HARDNESS	250-300	250-300
SURFACE FINISH REQUIRED	60 RMS	
SURFACE FINISH RESULT		20-40 RMS
PERIPHERY TOLERANCE	$\pm$ 0.005"	
PERIPHERY RESULT		.002 .004 T.I.R.
CIRCLE DIAMETER		10.000 nominal

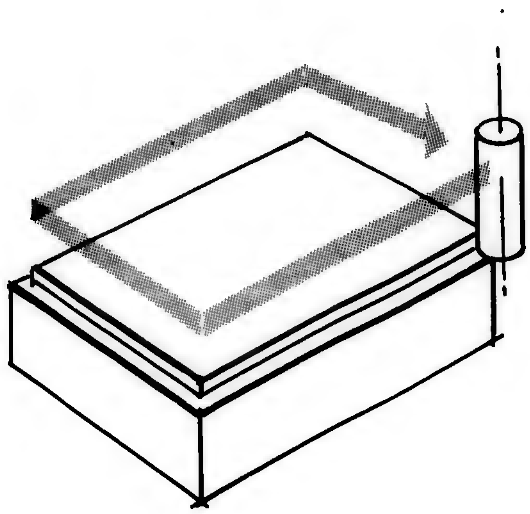
CHECKED BY Dave Ross
J. Caudill



TEST NO. **19**- 360° PLUS DEPTH (3 DIMENSIONAL)

	REQUIREMENTS	REMARKS
END MILL	1 1/4" H.S.S. ball nose	
SPINDLE SPEED	185 RPM	430 RPM
FEED RATE	8"/min.	10"/min.
DEPTH OF CUT	.015" x .020" radial	.040 x .020
MATERIAL	4130 or 4140 steel	4130
BRINELL HARDNESS	250-300	
SURFACE FINISH REQUIRED	60 RMS	
SURFACE FINISH RESULT		30-40 RMS
PERIPHERY TOLERANCE	$\pm$ 0.005"	
PERIPHERY RESULT		.0045 total error
DEPTH TOLERANCE	$\pm$ 0.005"	
DEPTH RESULT		.003 total error

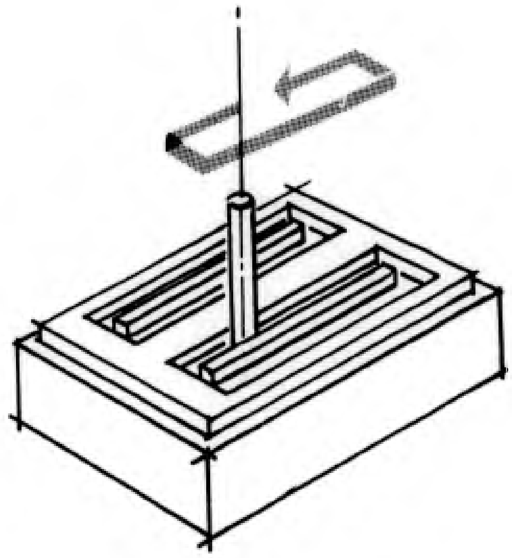
CHECKED BY Dave Ross & J. Caudill



TEST NO. **20** 360° TRACING (RECTANGULAR) - PERIPHERY CUTS WITHOUT PROGRAMMED SLOWDOWN OR PARABOLIC DECELERATION

	REQUIREMENTS	REMARKS
END MILL	1 1/4" H.S.S. end mill	4 flute
RPM	525 RPM	430 RPM
DEPTH OF CUT	.020"	.020
MATERIAL	4130 or 4140 steel	4130
BRINELL HARDNESS	250-300	
FEED RATE	25"/min.	22"/min.
MAXIMUM OVERSHOOT	.006	
OVERSHOOT RESULT		.000
SURFACE FINISH REQUIRED	60 RMS	
SURFACE FINISH RESULT		60 RMS

CHECKED BY Dave Ross
J. Caudill

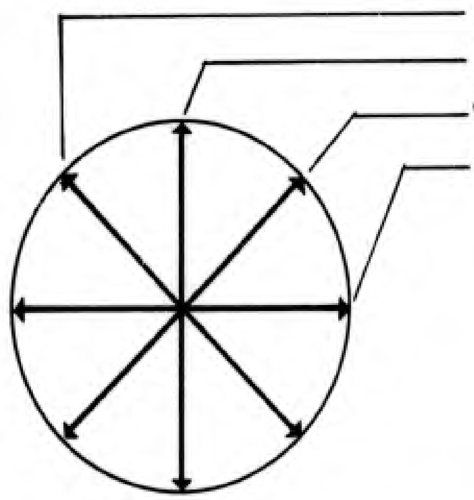


TEST NO. **21**- 360° TRACING (RECTANGULAR) - CHANNEL CUTS WITHOUT PROGRAMMED SLOWDOWN OR PARABOLIC DECLERATION

	REQUIREMENTS	REMARKS
END MILL	1 1/4" H.S.S. end mill	2" T.C. 4 flute 525 RPM
RPM	525 RPM	430 RPM
DEPTH OF CUT	.020	.040 x .500
MATERIAL	4130 or 4140 steel	4130
BRINELL HARDNESS	250-300	
FEED RATE	25"/min.	
MAXIMUM UNDERCUT	.008"	.006
SURFACE FINISH REQUIRED	60 RMS	
SURFACE FINISH RESULT		50-60 RMS

CHECKED BY D. Ross
J. Caudill

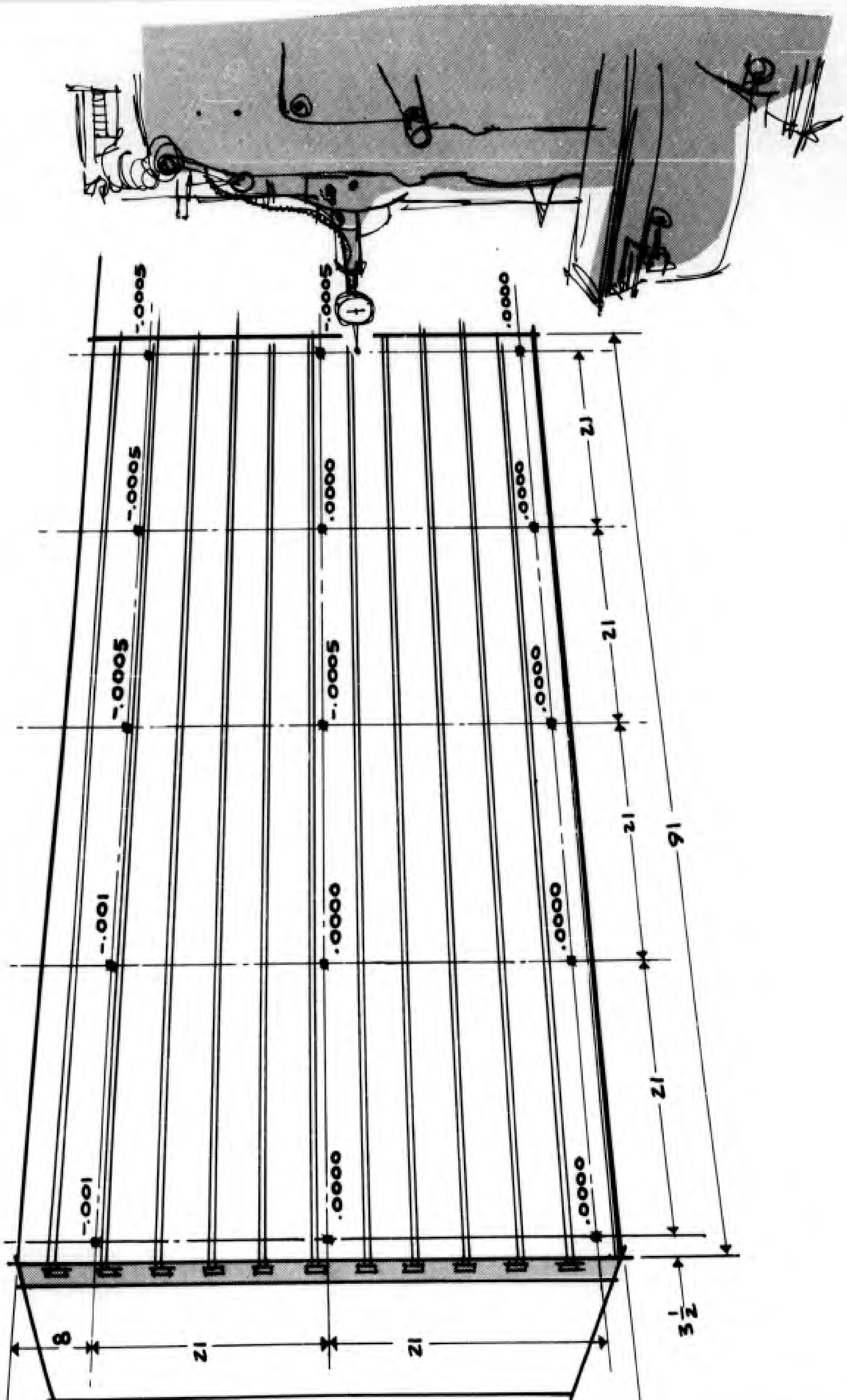
TEST NO. **22** CUTTER COMPENSATION



BEFORE C.C.	AFTER C.C.
9.978	9.968
9.975	9.9645
9.978	9.968
9.974	9.964

.010 cutter compensation dialed in

RUNOUT SPINDLE TO WORKING SURFACE



ATTACHMENT #1

STATE OF OHIO) Dayton, Ohio
) s.s.
MONTGOMERY COUNTY) April 11, 1960

This is to certify the 1 forging PT# YB-412877-1 supplied to the Cincinnati Milling Machine Company, Cincinnati 9, Ohio on their P.O. #44748 was produced from 4130 E.F. steel billets of the following chemical analysis:

C-.29, Mn-.55, P-.011, S-.018, Ni-.22, Cr-.96, Sil-.27, Mo-.22, Cu-.11
Heat No. 10123

It is further certified that the parts were heat treated to 250-300 BR.

THE DAYTON FORGING & HEAT TREATING CO.

Frank A. Schopler (signed)
Forge Supt.

Sworn to and subscribed before me, a notary, this 11th day of April, 1960

George W. Jones (signed)
Notary Public
In and for Montgomery County, Ohio
My Commission Expires Feb. 3, 1963

STATE OF OHIO) Dayton, Ohio
) s.s.
MONTGOMERY COUNTY) April 11, 1960

This is to certify the 1 forging PT # YD-412877-1 supplied to The Cincinnati Milling Machine Company, Cincinnati 9, Ohio on their P.O. #55758 was produced from 4130 E.F. steel billets of the following chemical analysis:

C-.29, Mn-.52, P-.014, S-.020, Cr-.96, Sil-.30, Mo-.20
Heat No. 5971

It is further certified that the parts were heat treated to 250-300 BR.

THE DAYTON FORGING & HEAT TREATING CO.

Frank A. Schopler (signed)
Forge Supt.

Sworn to and subscribed before me, a notary, this 11th day of April, 1960

George W. Jones (signed)
Notary Public
In and for Montgomery County, Ohio
My Commission Expires Feb. 3, 1963

ATTACHMENT #2

STATE OF OHIO)
) s.s.
MONTGOMERY COUNTY)

Dayton, Ohio

April 11, 1960

This is to certify the 1 forging PT# YB-412877-2 supplied to The Cincinnati Milling Machine Company, Cincinnati 9, Ohio on their P.O. #44748 was produced from 4130 E.F. steel billets of the following chemical analysis:

C-.29, Mn-.55, P-.011, S-.018, Ni-.22, Cr-.96, Sil-.27, Mo-.22, Cu-.11
Heat No. 10123

It is further certified that the parts were heat treated to 250-300 BR.

THE DAYTON FORGING & HEAT TREATING CO.
Frank A. Schopler (signed)
Forge Supt.

Sworn to and subscribed before me, a notary, this 11th day of April, 1960

George W. Jones (signed)
Notary Public
In and for Montgomery County, Ohio
My Commission Expires Feb. 3, 1963

STATE OF OHIO)
) s.s.
MONTGOMERY COUNTY)

Dayton, Ohio

September 16, 1960

This is to certify the 2 forgings PT# YB-412877-4 supplied to The Cincinnati Milling Machine Co., Cincinnati 9, Ohio on their P.O. 55758, our job #63788, were produced from 4130 EF steel billets of the following chemical analysis:

C-.29, Mn-.52, P.-14, S-.020, Cr-.96, Sil-.30, Mo-.20
Heat No. 5971

THE DAYTON FORGING & HEAT TREATING CO.
Frank A. Schopler (signed)
Forge Supt.

Sworn to and subscribed before me, a notary, this 16th day of September, 1960

George W. Jones (signed)
Notary Public
In and for Montgomery County, Ohio
My Commission Expires Feb. 3, 1963

ATTACHMENT #2

STATE OF OHIO)
) s.s.
MONTGOMERY COUNTY)

Dayton, Ohio

April 11, 1960

This is to certify the 1 forging PT# YC-412877-2 and 1 forging PT# YE-412877-1 supplied to The Cincinnati Milling Machine Company, Cincinnati 9, Ohio on their P.O. #55758 were produced from 4130 E.F. steel billets of the following chemical analysis:

C-.29, Mn-.55, P-.011, S-.018, Ni-.22, Cr-.96, Sil-.27, Mo-.22, Cu-.11
Heat No. 10123

It is further certified that the parts were heat treated to 250-300 BR.

THE DAYTON FORGING & HEAT TREATING CO.

Frank A. Schopler (signed)
Forge Supt.

Sworn to and subscribed before me, a notary, this 11th day of April, 1960

George W. Jones (signed)
Notary Public
In and for Montgomery County, Ohio
My Commission Expires Feb. 3, 1963

4.0 acceptance test results

APPLICABLE SPECIFICATIONS

PERFORMANCE RESULTS

SUPPLEMENTARY OBSERVATIONS

ACCEPTANCE TEST RESULTS

4.1 APPLICABLE SPECIFICATIONS

Specifications for this retrofit project are listed in North American Specification H-59-11. A copy of this specification is contained in 2.2.

4.2 PERFORMANCE RESULTS

Due to the successful test results obtained at the Cincinnati Milling plant, as reported in 3.2, performance testing of the retrofitted machine after installation at the North American plant was held to a minimum. Three cutting tests were run: Test No. 13 - Maximum Rated Horsepower Cut in Both X and Y Axes; Test No. 18 - 360° Full Circle Cut, and Test No. 20 - 360° Rectangular Cut. A complete description of these tests is contained in 3.2.

Test No. 13 was run due to the chatter problem which developed during the test at the Cincinnati Milling plant. The test conditions and specifications were the same as those described in 3.2. During the performance of a full horsepower cut, in the vertical (Y) axis, a failure occured in the spindle gear train. Two spin gears were broken and one spline shaft bent. Investigation disclosed that the work piece shifted, causing an excessive chip load and cutter failure; this resulted in the spindle gear train failure. Repairs were accomplished by Cincinnati Milling after which the test was re-run with very satisfactory results.

Test results for Test Nos. 18 and 20 were in all respects acceptable and were nearly identical to results obtained in 3.2

4.3 SUPPLEMENTARY OBSERVATIONS

An analysis of test results indicates that the subject retrofitted machine successfully met all of the specification requirements. In the majority of cases the machine error was less than half of the allowable tolerance. The minor difficulties noted in this report are not peculiar to a retrofit machine. These problems could be experienced equally as well with a new piece of equipment.

5.0 production part evaluation

DESCRIPTION OF SELECTED PARTS

FACTORS INFLUENCING PART EVALUATION

PREPARATION

MACHINING

RESULTS

COMPARISON WITH OTHER N/C MACHINES

PRODUCTION PART EVALUATION

5.1 DESCRIPTION OF SELECTED PARTS

Three production parts were selected for the production part evaluation phase of this project:

a. Part No. 263-315217-5 - This part is made from H-11 steel alloy. Photograph No. 1 shows the part both before and after machining. Photograph No. 2 shows the part during machining.

b. Part No. 247-32348-6 - This part is made from 7079F aluminum alloy die forging. Photographs No. 3 and No. 4 show the part before and after machining.

c. Part No. 247-323350-4 - This part is made from 7079F aluminum alloy hand forging. Photograph No. 5 shows the forging before machining. Photographs No. 6 and No. 7 show the part after machining.

5.2 FACTORS INFLUENCING PART SELECTION

The primary criteria in the selection of parts were the part complexity and the type of material. It was determined to use one steel part, one simple aluminum part, and one complex aluminum part. Other considerations included part quantity, existing tooling, programming time, and production schedules within the machining department.

5.3 PREPARATION

Production planning for all three test parts was prepared for both conventional machining and numerical control machining. All of the test parts have been machined by both methods. Within practicable limitations, the data presented represents actual production conditions.

5.3.1 Time and Effort - Numerical Control Program

The time and effort expended in the preparation of numerical programs for the test parts is contained in the following chart:

OPERATION	HOURS BY OPERATION AND TEST PART NUMBER		
	247-323340-4	263-315217-5	247-32348-6
Part Analysis	87.8	577.2	39.8
Master Dimension Drawing	73.8	26.2	34.8
Part Redrawing	175.6	56.4	79.5
Methods Planning	97.8	30.2	45.8
Part Programming	965.8	310.3	437.2
Computer Operation (704)	17.6	4.7	17.2
Computer Operation (Other)	93.1	28.7	36.3
Tape Preparation and Checking	93.1	34.7	43.2
Debugging and Error Correction	168.2	56.4	73.4
Tool Design	* 12	15	*12
TOTAL	1773	577.2	808.4

*The same tool was used for both parts. Total design time of this tool was 24 hours.

5.3.2 Comparative Data for Conventional Machining

The time and effort expended for planning the conventional machining of the test parts is contained in the following chart:

OPERATION	HOURS BY OPERATION AND TEST PART NUMBER		
	247-323350-4	263-315217-5	247-32348-6
Part Analysis	8	2	6
Methods Planning	6	2	4
Tool Design	120	15	120
Checking and Error Correction	2	1	1
TOTAL	136	20	131

5.3.3 Special Considerations

Programming the retrofit numerical control machine tool did not present any problems that would not normally be encountered. Each numerical control machine tool has individual characteristics which necessitate a familiarization period during which programming requires slightly more effort and time than normal. The production test parts were the first to be programmed on the machine tool.

Recently a part similar to test part 247-323350 was programmed on the retrofitted machine tool. This part was larger and required more metal removal, but was of similar design and complexity. The programming time for this part was 1,153 hours. This represents a reduction in programming time of 620 hours or nearly 35%. This is typical of the reduction in programming which can be expected as personnel become familiar with a particular machine tool.

The punched card method of data input as used on this machine tool facilitates proofing the program and the correction of minor errors. The punched card input is in digital form permitting direct reading. That portion of the program to be corrected can be easily located and changed without disturbing the remainder of the program.

5.4 MACHINING

The test parts were machined under normal production conditions, utilizing three shifts with a minimum of three different machine operators. Production times are based on normal release quantities to insure a rational comparison with previously machined production parts.

5.4.1 Time and Effort - Numerical Machining

The operational sequence and machining times required to machine the test parts is contained in attachments 1, 2 and 3. During the numerical machining operations, 454 pounds of material was removed from part #247-323350, 23.3 pounds from part #263-315217 and 16.5 pounds from part #247-32348.

5.4.2 Comparative Data

A comparison between conventional and numerical machining of test parts is contained in the following chart. The hours contained in this chart are total machine hours for a completed part. Some variation in hours will be evident since operations differ slightly for numerical planning. Generally, the numerical profiling has reduced mill time and conventional profile time.

OPERATION	HOURS BY OPERATION AND TEST PART NUMBER					
	247-323350-4		263-315217-5		247-32348-6	
	NC	Conv	NC	Conv	NC	Conv
Mills	85.59	119.31	4.75	48.38	9.08	17.75
Drills	2.52	1.10	-	-	1.18	1.68
Profile (non NC)	-	104.92	-	-	4.22	15.25
Profile (NC)	22.80	-	8.75	-	3.35	-
Jig Bore	5.88	7.37	-	-	2.50	2.50
Saw	-	-	.20	.20	-	-
Grind	-	-	2.24	-	-	-
Bench	1.21	2.67	.45	.95	.50	1.00
TOTAL MACHINING	118.00	235.37	16.39	49.53	20.82	38.18
TOOL FABRICATION	95	275	30	30	206	334

6.4.3 Special Considerations

The test parts used in this project were inspected by regular production inspection procedures. On these particular parts no reduction in inspection time was noted. Prior experience with numerically machined parts indicates a reduction in inspection time of up to 50% can be expected. This reduction can be attributed to part-to-part repeatability and the resulting confidence in the machine tool to produce a quality part consistently. As of the date of this report, sufficient parts have not been machined to realize a reduction in inspection time.

5.5 RESULTS

A complete inspection was performed on the first production part, in each of the three test part groups, machined on the retrofitted machine tool. The data obtained by this inspection was used to verify the numerical control program. Succeeding parts in each group were inspected for critical dimensions, general part tolerance, and configuration. All of the surfaces machined by numerical control were within design tolerances and showed very little variation between parts. Dimensions generally were on the plus side of nominal. A major deviation occurred on one part (247-323350-4), due to the failure of a component in the numerical control system, which resulted in a scrapped part.

In comparison, those parts machined conventionally were within design tolerances; however, they did not have the part-to-part repeatability of the numerical parts. Errors were more erratic and more difficult to detect. This condition places greater responsibility on inspection, since every detail must be checked. The surface finish for numerically machined parts and conventionally machined parts were within design specifications with no noticeable difference between the two methods.

The parts used for this evaluation were regular production parts. These parts were produced on a scheduled basis as required to sustain assembly operations. It was not possible to perform a detailed inspection, as required to determine nominal dimensions and maintain schedule position. As a result it was only possible to determine that the parts were within design tolerances for both numerical machining and conventional machining.

5.6 COMPARISON WITH OTHER NUMERICALLY CONTROLLED MACHINES

The Columbus Division of North American has eight (8) numerically controlled machine tools. Only one of these machines has sufficient similarity to justify any degree of comparison. This machine is a Cincinnati 4' x 14' low-speed numerically controlled profiling and contouring machine. Acceptance tests were conducted on this machine at Cincinnati Milling in December 1958. A comparison of the test results of the 4' x 14' machine and the retrofitted machine test performance was equal to or exceeded the test performance of the 4' x 14' new machine.

It was not possible to compare production performance. The programming technique differs slightly for each of our numerical machines, thus any comparison would of necessity illustrate differences in programming and machine operating characteristics and not a comparison of retrofit vs new identical machine. It is our considered opinion that the subject retrofitted machine tool is equivalent in every respect to a new similar type machine.

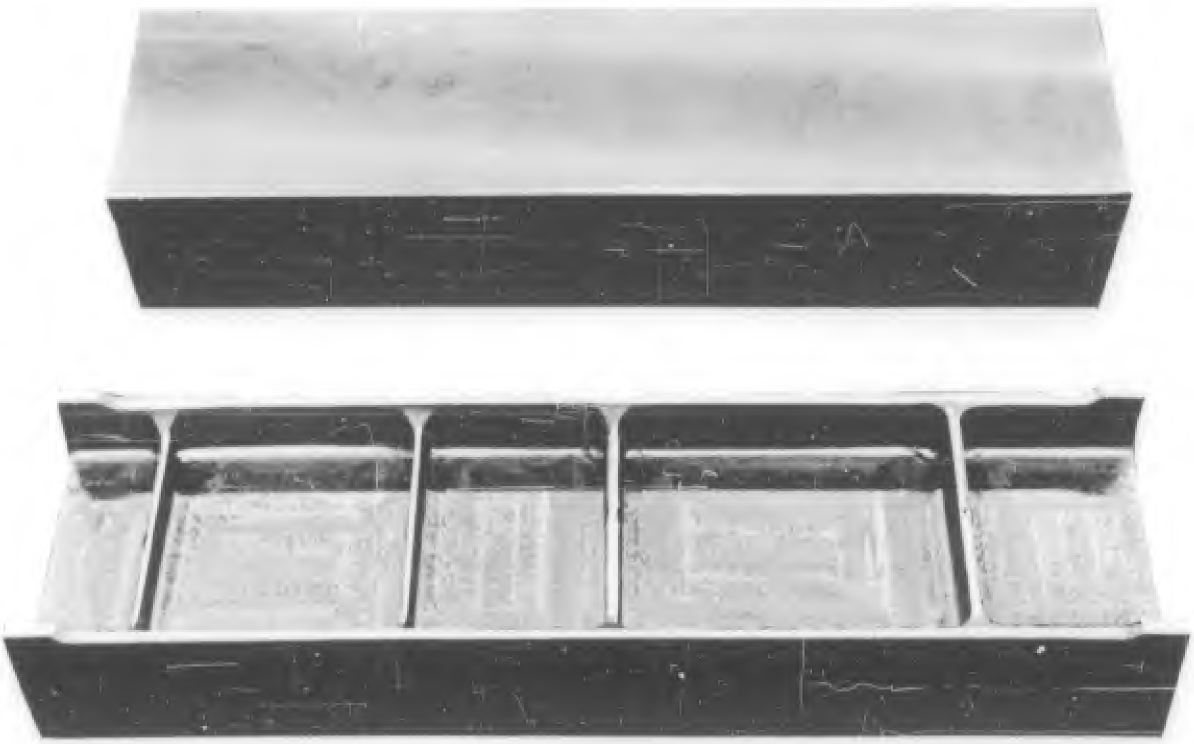
ATTACHMENT #1

PART NO. 263-315217-5 PHOTOGRAPHS 1 AND 2

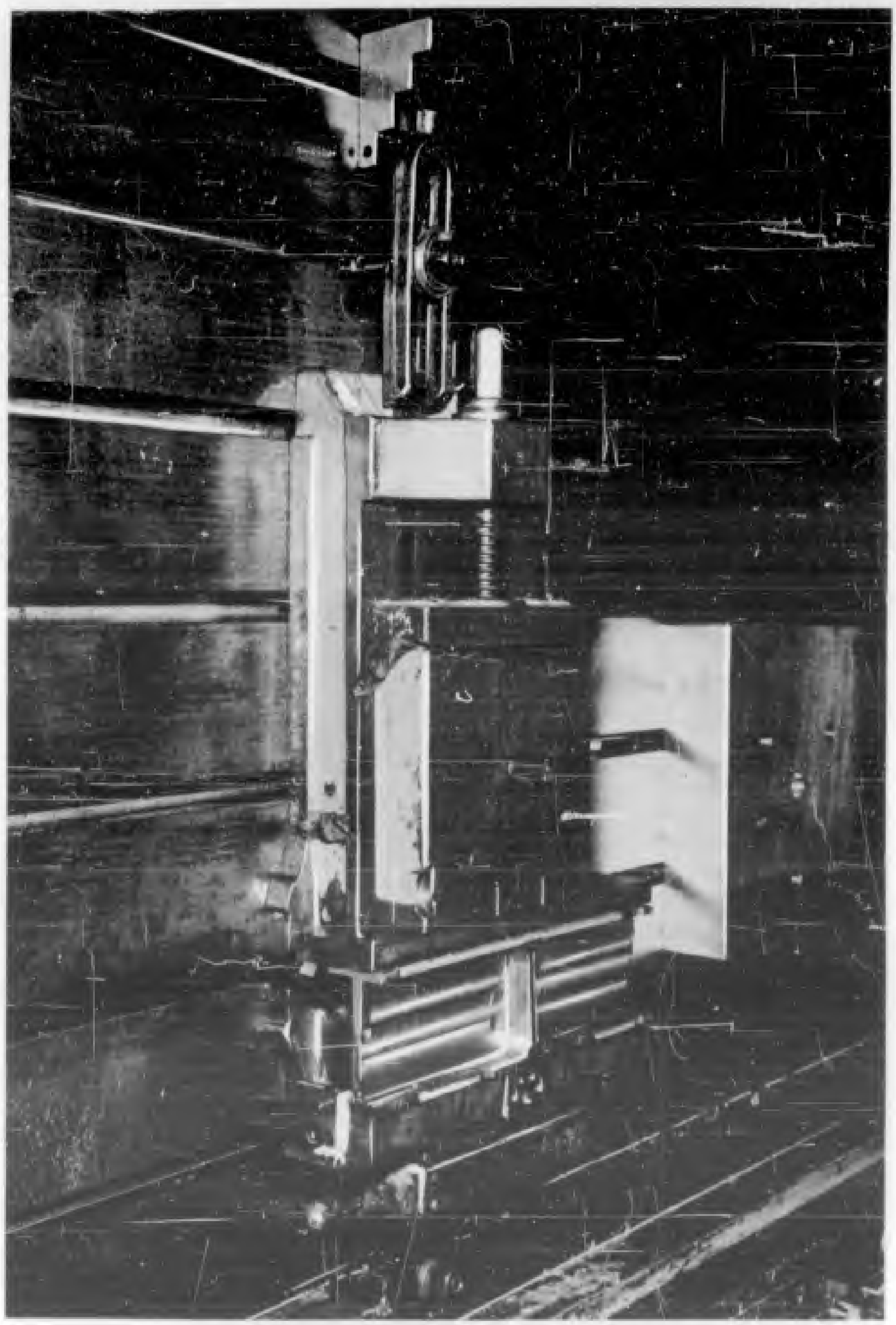
OPER. NO.	NAME OF OPERATION	RUN TIME MINUTES
	Load Part in Vise	4.0
1	Insert Cutter	3.6
1	Load Cards	1.0
1	Align Machine, Set Depth	2.0
1	Finish Mill tops of Ribs & Flanges	33.7
2	Change Cutter	2.0
2	Load Cards	1.0
2	Align Machine, Set Depth	1.0
2	Finish Mill 3/8" and 1/2" Radii Top of Tibs and Flanges	8.7
3	Change Cutter	1.0
3	Change Cards	1.0
3	Align Machine, Set Depth	1.0
3	Rough Mill Pockets	31.6
3	Change Cards	1.0
3	Rough Mill Pockets	42.7
4	Change Cutter	3.6
4	Change Cards	2.0
4	Align Machine, Set Depth	1.0
4	Rough Mill Web Surface	41.6
4	Change Cards	1.0
4	Finish Mill Web Surface	23.2
5	Change Cutter	2.0
5	Change Cards	1.0
5	Align Machine, Set Depth	1.0
5	Rough Mill Corners	10.5
5	Change Cards	1.0
5	Finish Mill Sides and Corners of Pockets	14.8
	Turn Part Over	7.0
6	Change Cutters	3.1
6	Change Cards	2.0
6	Align Machine, Set Depth	1.0
6	Finish Mill Top of Rib and Flanges	11.2
7	Change Cutter	2.1
7	Change Cards	1.0
7	Align Machine, Set Depth	1.0
7	Rough Mill Pockets and Ribs	26.1
7	Change Cards	1.0
7	Rough Mill Tops of Flanges	32.4
7	Change Cards	1.0
7	Finish Mill Flanges	30.6
8	Change Cutter	2.3
8	Change Cards	1.0
8	Align Machine, Set Depth	1.0
8	Finish Mill Web Surfaces	24.9
8	Change Cards	1.0
8	Finish Mill Web Surfaces	21.6
9	Change Cutter	2.1

PART NO. 263-315217-5 PHOTOGRAPHS 1 AND 2

OPER. NO.	NAME OF OPERATION	RUN TIME MINUTES
9	Change Cards	1.0
9	Align Machine, Set Depth	1.0
9	Rough Corners, Finish Sides & Corners	23.3
9	Remove Part from Vise	2.5
	TOTAL TIME - FLOOR TO FLOOR	525.0 Minutes 8.75 Hours



1 PART NO. 263-315217-5 BEFORE AND AFTER MACHINING



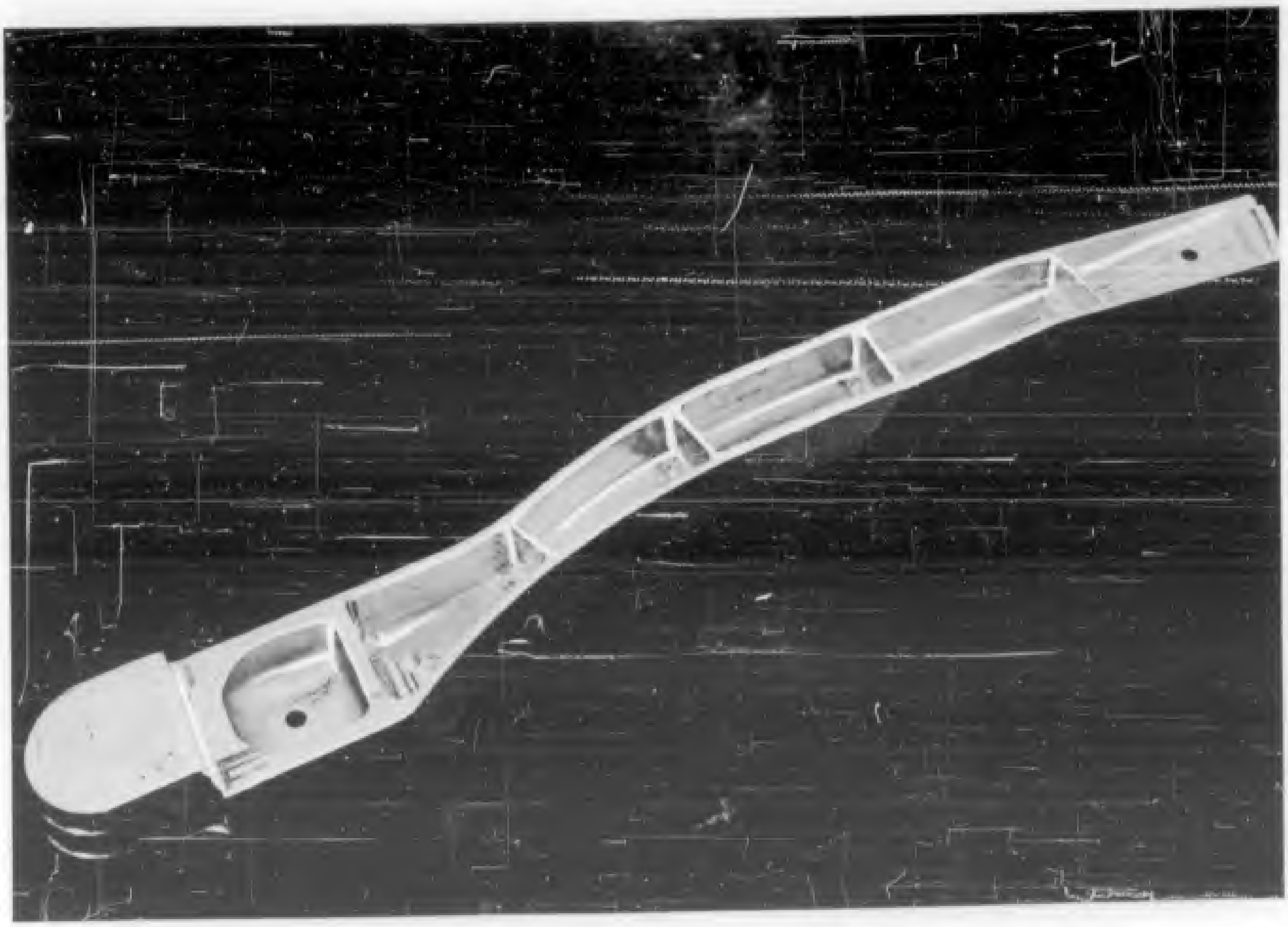
2 PART NO. 263-315217-5 DURING MACHINING

ATTACHMENT #2

PART NO. 247-32348-6   PHOTOGRAPHS 3 AND 4

OPER. NO.	NAME OF OPERATION	RUN TIME MINUTES
	Change Parts - Remove Lower Clamps	9.0
	Put in Cutter and Set Depth	6.0
1	Rough & Finish Top & Side Lower Flange	19.5
1	Change Cards	2.0
1	Rough & Finish Top & Side Lower Flange	10.5
	Change Clamps	6.8
2	Rough & Finish Top & Side Upper Flange	10.0
2	Change Cards	2.0
2	Rough & Finish Top & Side Upper Flange	10.6
2	Change Cards	2.0
2	Rough & Finish Top & Side Upper Flange	14.7
	Change Clamps	4.0
3	Rough & Finish Top of Webs	14.5
3	Rough Pockets	17.3
3	Change Cards	2.0
3	Rough Pockets	7.0
3	Change Cards	2.0
3	Rough Pockets	4.5
4	Change Cutter & Cards	5.0
4	3/8" Radii in Corners	12.0
5	Change Cutter & Cards	5.0
5	Finish Pockets	10.0
5	Change Cards	2.0
5	Finish Pockets	11.2
5	Change Cards	2.0
5	Finish Pockets	7.3
	TOTAL TIME - FLOOR TO FLOOR	200.9 Minutes 3.35 Hours

3 PART NO. 247-32348-6 BEFORE AND AFTER MACHINING



4 PART NO. 247-32348-6 AFTER MACHINING

ATTACHMENT #3

PART NO. 247-323350 PHOTOGRAPHS 5, 6 AND 7

OPER. NO.	NAME OF OPERATION	RUN TIME MINUTES
	Load Part	15.0
	Put in Cutter and Set Depth	5.0
1	Rough Cut Area "A" Periphery	15.5
	Change Clamps	4.0
2	Change Cards	2.0
2	Rough Cut Area "B" Periphery	8.0
	Change Clamps	6.8
3	Change Cards	2.0
3	Rough Cut Area "C" Periphery	44.2
4	Change Cutter & Set Depth	8.0
4	Rough Pockets	25.0
4	Change Cards	2.0
4	Rough Pockets	16.0
4	Change Cards	2.0
4	Rough Pockets	13.0
4	Change Cards	2.0
4	Rough Pockets	6.0
4	Change Cards	2.0
4	Rough Pockets	15.5
4	Change Cards	2.0
4	Rough Pockets	15.5
4	Change Cards	2.0
4	Rough Pockets	15.5
4	Change Cards	2.0
4	Rough Pockets	15.5
5	Change Cards	2.0
5	Set Depth	3.0
5	Rough Tops of Stringers	12.5
5	Change Cards	2.0
5	Rough Tops of Stringers	9.9
5	Change Cards	2.0
5	Rough Tops of Outside Walls	7.1
5	Change Cards	2.0
5	Rough Angles on Ribs and 1 3/8" Cut-Out	4.9
	Turn Part Over	20.0
6	Set Depth	2.6
6	Rough Top of Lug	7.2
6A	Change Cards, Set Depth	2.3
6A	Rough BP and Sides of Ribs	15.7
6A	Change Cards	2.0
6A	Rough BP 58.093 and Flanges	13.4
6A	Change Cards	2.0
6A	Rough BP 58.093 Flanges & Pocket	17.7
	Remove Clamps	1.3
7	Set Depth	1.4

PART NO. 247-323350 PHOTOGRAPHS 5, 6 AND 7

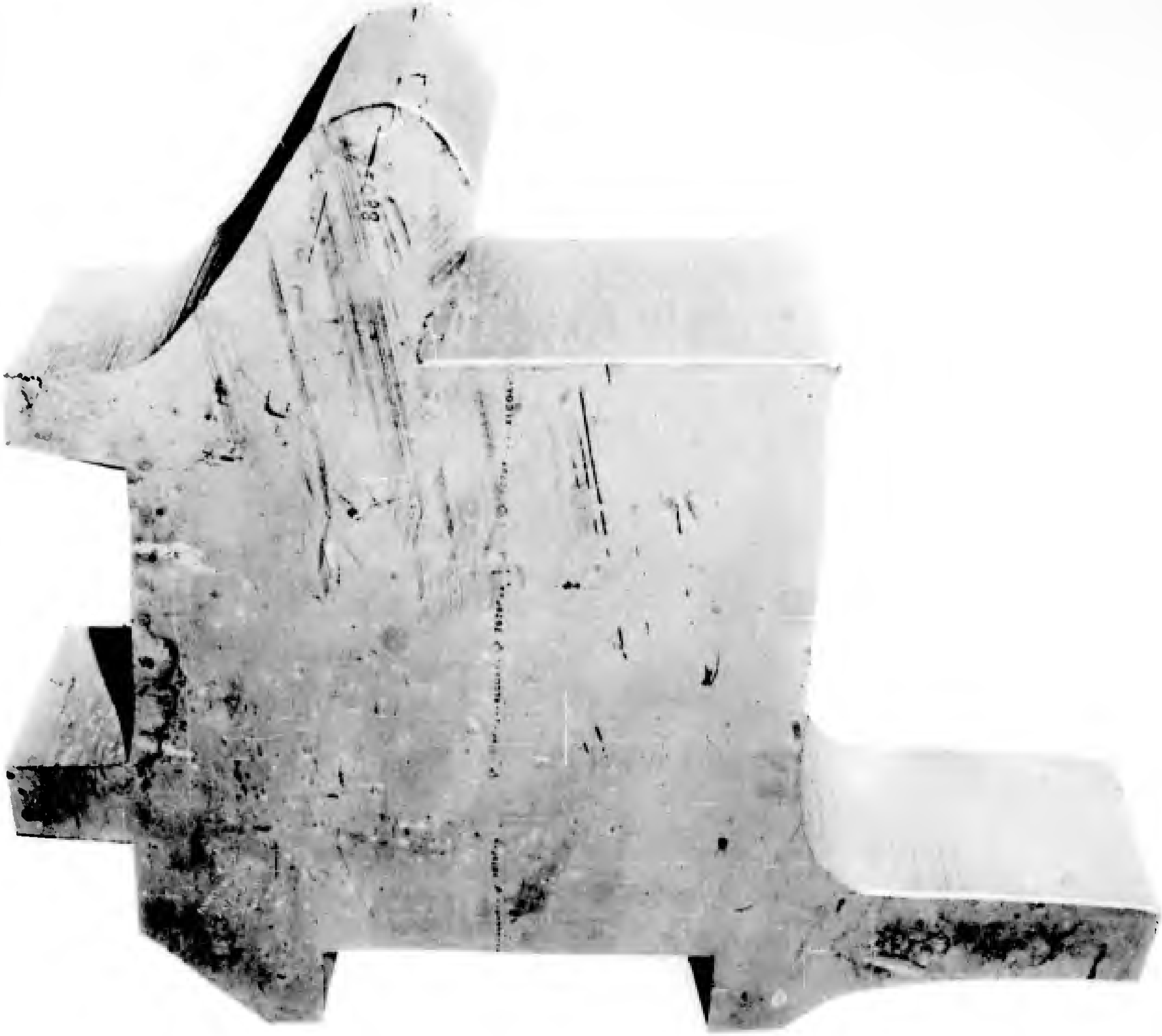
OPER. NO.	NAME OF OPERATION	RUN TIME MINUTES
7	Rough Tops of Flanges	15.6
7	Change Cards	2.0
7	Rough Tops of Flanges	18.7
	Remove Part from Fixture for H.T.	6.7
	Load Part	15.0
8	Put in Cutter and Set Depth	4.0
8	Face Locating Pads	16.0
8	Change Cards	2.0
8	Face Locating Pads	8.6
	Remove Part, Load in Opposite Position	20.0
9	Change Cutter and Set Depth	4.5
9	Finish Cut Periphery	31.3
	Change Clamps	2.5
10	Set Depth	2.0
10	Change Cards	2.0
10	Finish Cut Periphery	25.0
10	Change Cards	2.0
10	Finish Cut Periphery	24.5
10	Change Cards	2.0
10	Finish Cut Periphery	20.5
10	Change Cards	2.0
10	Finish Cut Periphery	10.5
	Change Clamps	2.6
11	Align Machine, Set Depth	2.0
11	Finish Cut Periphery	25.0
	Change Clamps	10.0
12	Change Cutter	15.0
12	Change Cards	2.0
12	Finish Cut BP 58.093	81.0
	Change Clamps	4.0
13	Change Cards	2.0
13	Align Machine, Set Depth	4.4
13	Blend Pads to BP 58.093, Mill Surface	12.6
	Change Clamps	2.6
14	Change Cards	2.0
14	Align Machine, Set Depth	4.4
14	Finish Cut Tops of Flanges & Lugs	47.0
14	Change Cards	2.0
14	Finish Cut Area "C"	31.6
	Change Clamps	2.0
14A	Change Cards	2.0
14A	Align Machine, Change Cutter, Set Depth	8.0
14A	Finish Cut 1/8" Radius	23.0
15	Change Cutter	2.0
15	Change Cards	2.0
15	Align Machine, Set Depth	2.0
15	Finish Mill Pocket	4.2

PART NO. 247-323350 PHOTOGRAPHS 5, 6 AND 7

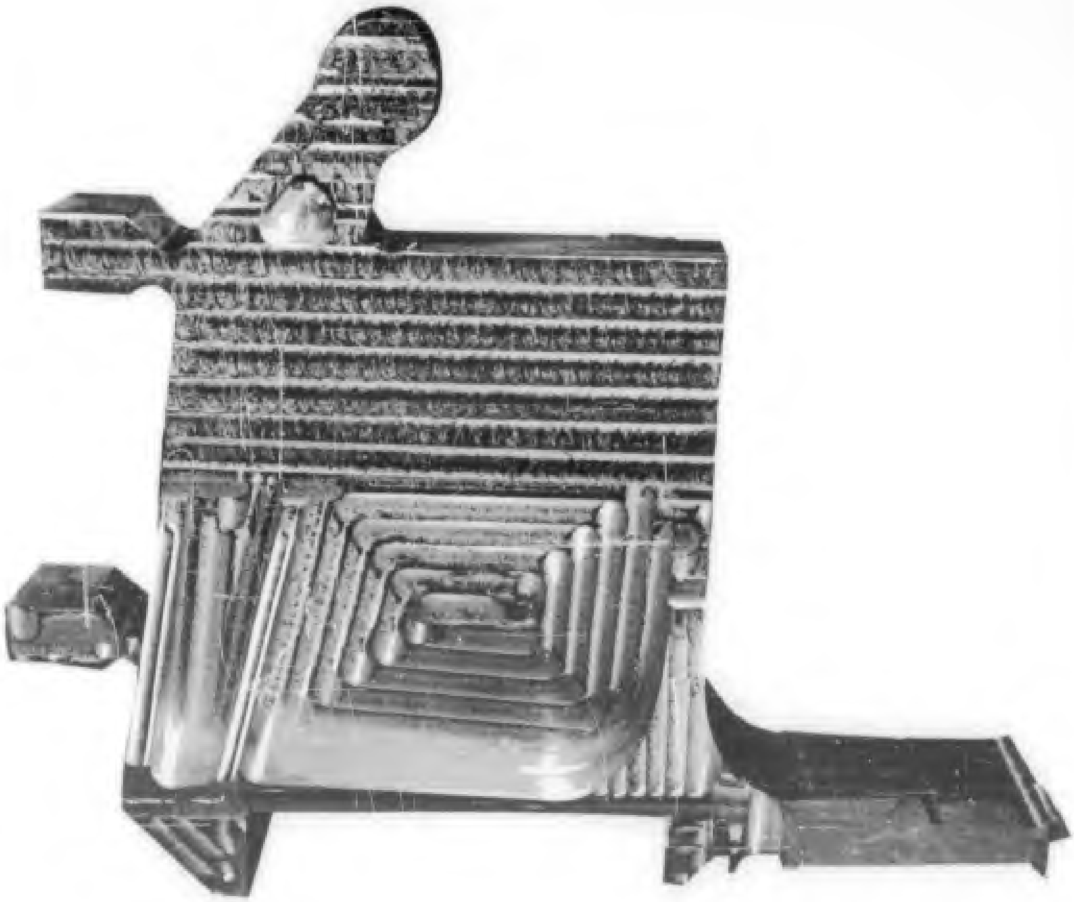
OPER. NO.	NAME OF OPERATION	RUN TIME MINUTES
16	Change Cutter	2.0
16	Align Machine, Set Depth	2.0
16	Align Machine, Set Depth	2.0
16	Finish 1/2" Radius in Pocket	7.0
17	Change Cutter	2.0
17	Change Cards	2.0
17	Align Machine, Set Depth	3.1
17	Finish Cut Angle Clearance	14.0
18	Change Cutter	2.5
18	Change Cards	2.0
18	Align Machine, Set Depth	2.0
18	Blend 1/8" Radius	7.2
19	Change Cutter	3.2
19	Change Cards	2.0
19	Align Machine, Set Depth	2.0
19	Mill 45° Champfer, 3 Places	28.2
	Turn Part Over	20.0
20	Change Cutter	2.0
20	Change Cards	2.0
20	Align Machine, Set Depth	3.0
20	Finish Cut Tops of Stringers and Flanges	25.0
20	Change Cards	2.0
20	Finish Cut Tops of Stringers and Flanges	15.0
	Change Clamps	12.0
21	Change Cards	2.0
21	Align Machine, Set Depth	2.0
21	Finish Mill Top of ML Flange	10.5
	Change Clamps	2.0
22	Change Cards	2.0
22	Align Machine, Set Depth	1.0
22	Finish Cut Pockets	32.0
22	Change Cards	2.0
22	Finish Cut Pockets	33.4
22	Change Cards	2.0
22	Finish Cut Pockets	9.0
23	Change Cutter	3.0
23	Change Cards	2.0
23	Align Machine, Set Depth	2.0
23	Mill 1/4" and 3/4" Radii	14.3
24	Change Cutter	3.6
24	Change Cards	1.0
24	Align Machine, Set Depth	1.0
24	Finish Cut 1/2" Corner Radii	15.1
24	Change Cards	1.0
24	Finish Cut 1/2" Corner Radii	14.3
24	Change Cards	1.0
24	Finish Cut 1/2" Corner Radii	12.7

PART NO. 247-323350 PHOTOGRAPHS 5, 6 AND 7

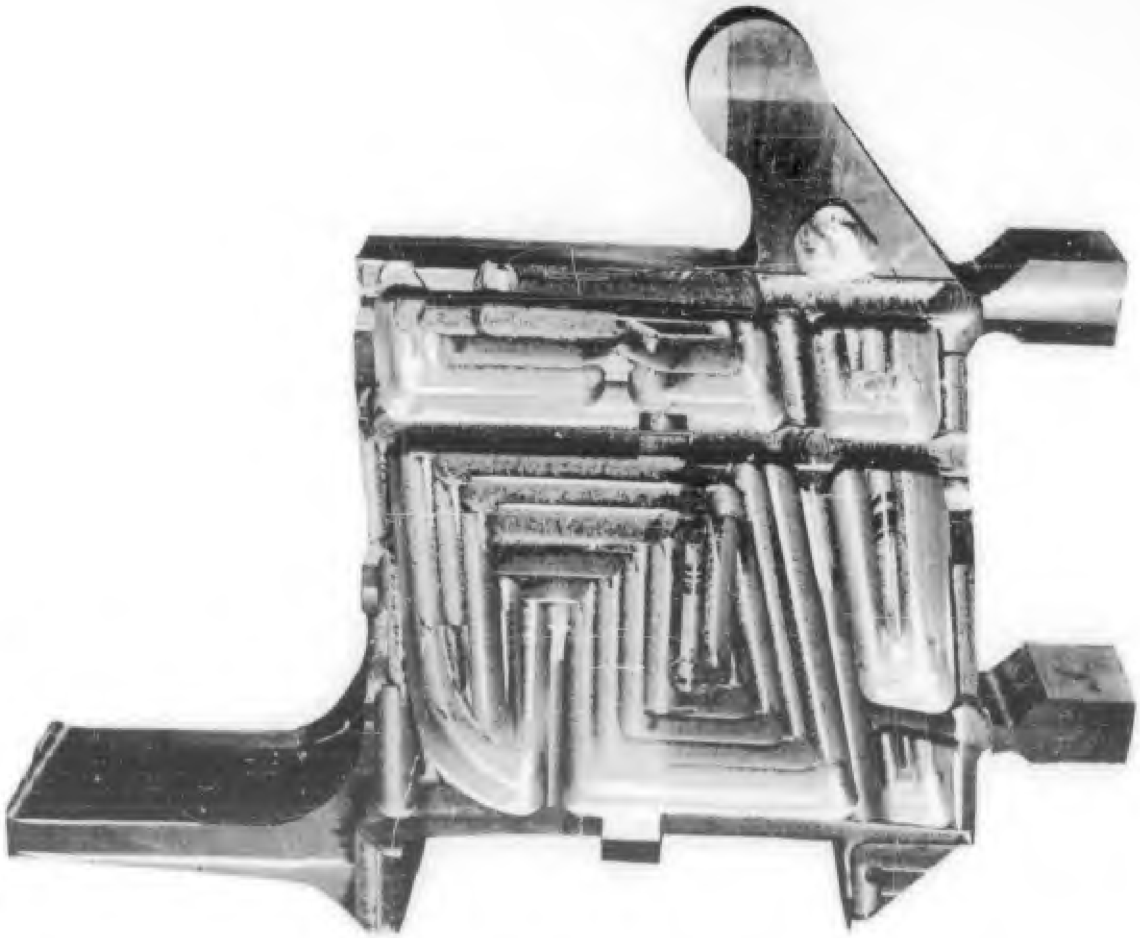
OPER. NO.	NAME OF OPERATION	RUN TIME MINUTES
24	Change Cards	1.0
24	Finish Cut 1/2" corner radii	17.6
24A	Change Cutter	3.1
24A	Change Cards	1.0
24A	Align Machine, Set Depth	1.0
24A	Finish Cut 1/2" Corner Radius	5.0
25	Change Cutter	3.1
25	Change Cards	1.0
25	Align Machine, Set Depth	1.0
25	Finish Cut 2" Radius	10.4
26	Change Cutter	2.0
26	Change Cards	1.0
26	Align Machine, Set Depth	1.0
26	Finish Cut 1/4" Radius	4.1
	Change Clamps	5.1
27	Change Cutter	3.4
27	Change Cards	1.0
27	Align Machine, Set Depth	1.0
27	Finish Cut Pocket and Top of Lug	11.0
28	Change Cutter	1.5
28	Change Cards	1.0
28	Align Machine, Set Depth	1.0
28	Finish Cut 1/2" Radius and 1 3/8" Radius Cut-Out	16.7
	Change Clamps	1.5
29	Change Cutter	2.3
29	Change Cards	1.0
29	Align Machine, Set Depth	1.0
29	Cut 45° Champfer	12.5
30	Change Cutter	2.5
30	Change Cards	1.0
30	Align Machine, Set Depth	1.0
30	Cut 30° Champfer	4.2
	Remove Part from Fixture	5.0
	TOTAL TIME - FLOOR TO FLOOR	1,369.4 Minutes 22.8 Hours



5 PART NO. 247-323350-4 BEFORE MACHINING



6 PART NO. 247-323350-4 AFTER MACHINING



7 PART NO. 247-323350-4 AFTER MACHINING

6.0 plant operation & maintenance

PLANT ORGANIZATION FOR NUMERICAL CONTROL

SPECIAL CONSIDERATIONS FOR RETROFIT

DESCRIPTION OF PARTS PROGRAMMING AND TAPE PREPARATION

PERFORMANCE QUESTIONNAIRE - PART II

MAINTENANCE EXPERIENCE

PLANT OPERATION & MAINTENANCE

6.1 PLANT ORGANIZATION FOR NUMERICAL CONTROL

The flow chart contained in attachment #1 outlines the numerical control programming and departmental responsibilities as they existed at the Columbus Division of North American during the time the retrofitted machine was being programmed. Under this organization, blueprints of the parts recommended for numerical machining may be submitted to the Manufacturing Division Numerical Control Screening Committee by Manufacturing, Engineering, or the screening committee members. The screening committee is composed of members from Tooling, Planning, and Manufacturing. It is their responsibility to select all parts for numerical machining. They consider such factors as part configuration, required tolerances, schedules, machine loading and available engineering data in making their selections. Whenever possible, these selections are made during the part design stages in Engineering. By this method, design modifications beneficial to numerical programming may be incorporated which would normally be lost if selection is made after the design is complete.

The blueprints of parts selected for numerical machining by the screening committee are forwarded to the Part Planning Committee. This committee has members from Manufacturing, Planning, and the programming group. This committee determines the numerical machine operations, sequence of numerical operations, cutter selection, and fixture selection. This information is used by the Planning Department to prepare tool orders and operation sheets. These orders are authority for the Tooling Division to charge time and material.

Within the Tooling Division is a numerical control programming group. This group is composed of personnel competent in higher mathematics and extensive shop experience relating to machining, part planning, and tool design. This group programs parts based on orders issued by the Planning Department. The programming group designs the holding fixture or specifies detail design configuration; specifies material size, set up instructions, cutter material, and geometry; specifies exact cutter path, spindle rotation, speeds and feeds, and horsepower. This information is presented graphically by the numerical control machine data drawings as contained in attachment #2. This information is also converted to computer language utilizing automatic programmed tooling commonly referred to as APT.

APT encompasses two very important points:

a. It permits the fully automatic processing of data for all major control systems through the incorporation of suitable "post-processors".

b. It permits the coding of the computer by the use of a relatively simple, English-like language.

At the Columbus Division of North American a 709 computer, in the Financial Division, is used for APT processing. The output of the 709, in card form, is returned to the programming group and converted to a tape or card form, as required by the machine tool, on the appropriate "post-processor". The Columbus Division does not have equipment for converting 709 cards to magnetic tape. In this case the 709 cards are converted to punched tape which is shipped by air to the Los Angeles Division for conversion to magnetic tape.

6.2 SPECIAL CONSIDERATIONS FOR RETROFIT

No special considerations were required for the retrofitted machine.

6.3 DESCRIPTION OF PARTS PROGRAMMING AND TAPE PREPARATION

The basic programming steps followed for the retrofitted machine tool are as follows:

a. Receive part print and programming order

b. Prepare detail planning sheet for fabrication of part

c. Prepare coordinate drawing of part from engineering print

d. Prepare holding fixture design

e. Prepare set-up sheets

f. Plot cutter-path on coordinate drawing

g. Prepare APT manuscript

h. 709 computer processing

1. Transfer APT manuscript to IBM cards
2. Transfer card data to magnetic input tape
3. Computer process through input translation, arithmetic calculations, and post processing
4. Record computer output via on-line punching of IBM cards or on magnetic tape
5. Transfer magnetic tape data, if so recorded, to IBM cards.
6. Obtain data print-out of IBM cards (in conjunction with on-line punching or off-line magnetic tape to card transfer)
7. Verify IBM card deck to Remington Rand cards

i. Convert IBM card deck to Remington Rand cards

j. Punch identification in Remington Rand card deck

k. Interput (overprint) Remington Rand card deck

l. Proof card deck and tools on machine

Recent advancements in programming techniques and the full utilization of APT programming permits the preparation of control data with less effort and personnel training. As a result, the programming effort has been diversified and the following functional changes made since the retrofitted machine was initially programmed:

a. Coordinate type drawings for numerical parts will be provided by Engineering

b. Preparation of control data, through the APT manuscript stage, will be performed by Planning.

c. Scheduling of all phases of numerical control effort will be performed by Scheduling.

To implement the functional changes listed above, the following responsibilities were defined:

a. Numerical Control Program Group

1. Manuscript processing through computer
2. Verification of computer output
3. Post-computer data conversion

4. Program proofing at machine tool

5. Continued development and documentation of programming techniques

b. Tooling Department

1. Preparation of APT manuscripts for templates and tooling

2. Prepare numerical control machine data drawings and holding fixture designs

c. Planning Department

1. Preparation of APT manuscripts for production parts

2. Issue orders for data processing

d. Scheduling Department

1. Issue monthly machine load charts

2. Issue part, template and tooling schedule

3. Prepare preventive maintenance schedule

4. Issue program schedule for Tooling and Planning Departments

5. Schedule 709 computer time for numerical control manuscripts

6. Issue new equipment installation schedule

e. Training Department

1. Determine and initiate required training for APT manuscript preparation

6.4 PERFORMANCE QUESTIONNAIRE PART II

The retrofitted machine was placed in production on May 3, 1961. A log of machine time was maintained starting May 22, 1961. This log is a continuing thing and will be utilized by our numerical control coordinator for loading purposes. For the purposes of this report, the last date used was October 27, 1961. The total operating time as of October 27, 1961, was 2,434.4 hours. The following information is presented in compliance with Part II of Plant Operation and Maintenance Performance Questionnaire.

1. What control media handling, storage, and usage problems have been encountered and what special precautions are recommended?

   Answer: None. This is a punched card system; only normal care is required with respect to cleanliness, bending and tearing.

2. What auxillary functions are being controlled by the control media?

Answer: Spindle and coolant on and off.

3. Is the card feed rate critical? If so, what are the limits and what are the results when feed is not within limits?

Answer: Card feed rate is not considered critical. The maximum reading reading rate of this machine is 60 cards per minute. This rate is preset and is a function of the numerical system. The control media is coded from 00 to 99. This permits a variation in reading rate depending upon the control media code up to a code of 99, or 60 cards per minute. The maximum feed rate on this machine is 25 inches per minute. In order to attain 25 inches per minute feed rate with reading rate of 60 cards per minute, span length will be 25/60 or .417 inches. This span length is satisfactory for straight cuts; however, on curves much shorter spans are required to maintain tolerance. Under these conditions the card feed rate is not critical; however, the maximum card feed rate can be the limited factor in machine feeds.

4. Does the machine loose synchronization with the card information when stopped in the middle of a cut? If so, how are they resynchronized?

Answer: No. This machine has a positive feedback system which constantly compares the control media directions with the slide displacement for each of the three axes of movement.

5. What card control movements are modified manually without changing the card?

Answer: Mirror image X axis, infinite zero shift X axis, 10 inch zero shift Z axis and slow down of feed rate. Cutter compensation can be controlled manually providing a code for this operation has been programmed.

6. What is the positional static accuracy of each axis of movement?

Answer: The smallest increment which can be programmed is .001 inch. The results of accptance test #11, section 3, indicate a positioning accuracy of .0001 inch.

7. (A) What is the normal tolerance that can be expected from this machine?

Answer: $\pm$ .002 inch. This is a function of the programming technique and tooling used.

(B) What is the best accuracy achieved to date?

Answer: $\pm$ .001 inch.

8. Have tests been run to determine the overshoot encountered at various feed rates when changing direction?

   Answer: No tests other than those used for acceptance. See results of tests 15, 16 and 21, section 3.

9. What is the maximum feed rate that can be used while actually cutting a part (contouring), and what is the quantum (value of one pulse) at this feed rate?

   Answer: Up to 25 inches per minute, depending upon part material configuration and tooling. (see question #3) Pulse data question is not applicable to this system.

10. (A) What is the distance required to accelerate from one speed to another for each axis of movement?

    Answer: We do not know; this is a function of the numerical control system.

    (B) What is the typical programmed slow-down used to minimize overshoot?

    Answer: The movement speed is reduced parabolically to zero.

11. Does the machine seem to oscillate when there is either no required movement or a small required movement?

    Answer: No

12. Does the system move in excessively large steps when a shallow slope is required?

    Answer: No. Not applicable to an analog system.

13. What is the null zone (in inches) of each axis?

    Answer: None. See question #11.

14. What machine warm-up period is required before operating the machine, and is this automatic?

    Answer: The electronic portion of this machine is not shut off. The warm-up period is automatic and requires 1-1/2 minutes.

15. Have there been any machine vibration problems sufficient to affect part finish?

    Answer: No.

16. Has dirty control media or reading heads caused problems?

    Answer: No.

17. What is the backlash error for each axis?

    Answer: Refer to test 21, section 3.

18. Is high acceleration and deceleration causing backlash, machine component failures, or other problems?

    Answer: No.

19. What has been the record of component failure in respect to time for:

A. Electrical?	Number of Failures
(1) Tubes	0
(2) Transistors	0
(3) Relays	2
(4) Condensers	0
(5) Resistors	0
(6) Transformers	1
(7) Magnetic Cores	0
(8) Servo Components	0
(9) Electronic Modules	0
(10) Diodes	16
(11) Stepping Switches	5
B. Mechanical?	
(1) Clutches	1
(2) Card Reader	0
(3) Ways	0
(4) Leadscrews	0
(5) Gearing	0
(6) Bearing	0
(7) Servomotors	1*
(8) Hydraulic	0
(9) Couplings	3

    *Drive on analog positioning unit - Y axis feedback

20. If plug-in electrical circuits are used, give average time required to determine which unit is not functioning properly.

    Answer: Plug-in electrical circuits are not used.

21. What System (machine or controls) modifications have been made in-plant?

    Answer: Rotary switches and cams on switch drive replaced with improved switches and cams. The relay coils and position analog unit circuity modified. All of the above changes were made by Cincinnati and are being incorporated into their design.

22. What modifications do you recommend should be made?

    Answer: The chip collection system should be improved.
    No provisions were made to handle chips and coolant.

23. What features of the machine could be eliminated and not be detrimental to its operation?

    Answer: None

24. Give the approximate average percentage of operating time for the following:

A.	Metal Cutting	63%
B.	Setup	5%
C.	Preventive Maintenance	0%
D.	Breakdown Maintenance	22%
E.	Tests and Measurements	0%
F.	Checking Tapes	2%
G.	Other Work	3%
H.	Idle	5%

The above percentages are based on record logs.

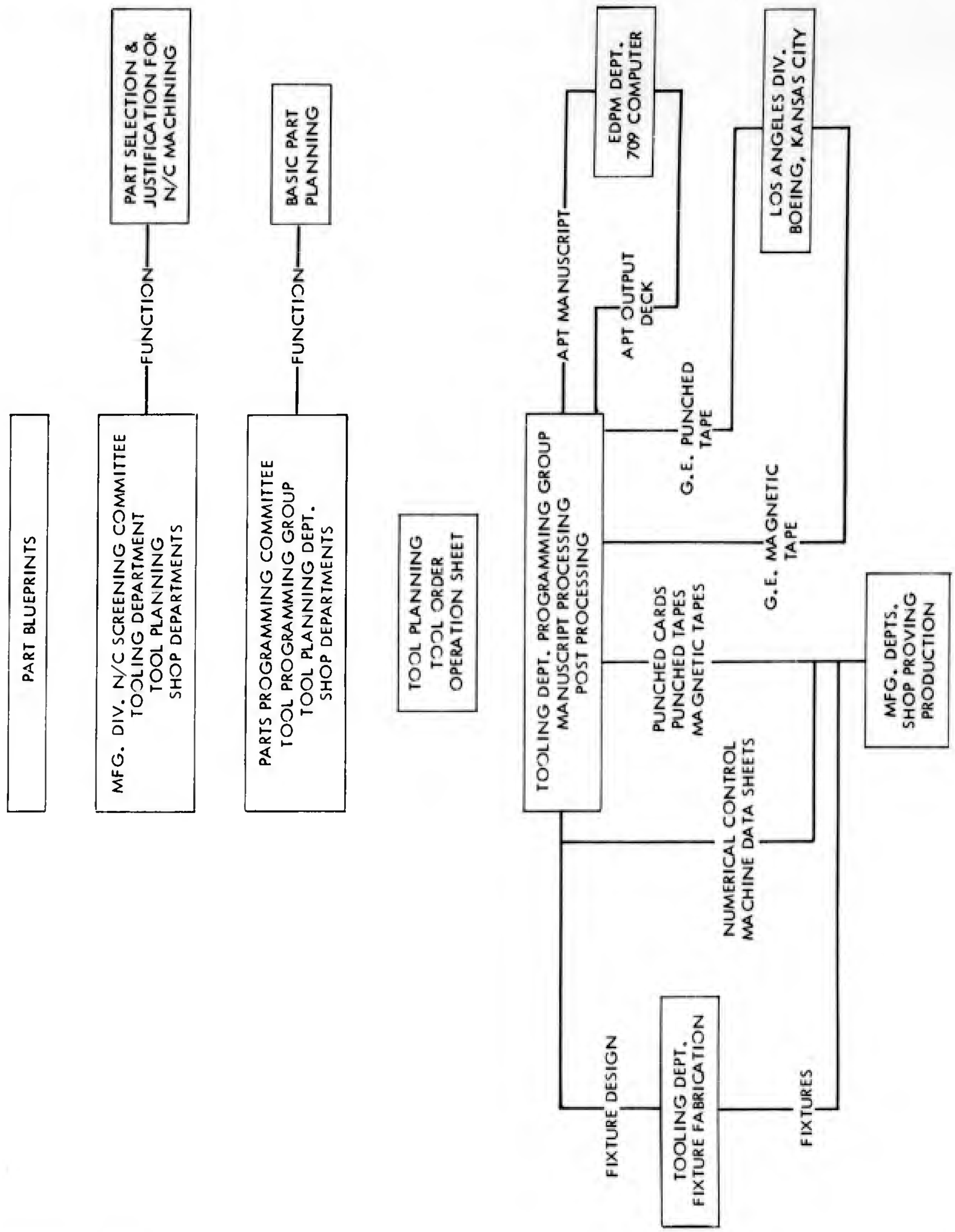
6.5 MAINTENANCE EXPERIENCE

Our maintenance problems to date have been with the numerical control portion of the machine tool. These problems are characterized by failure of components and lack of reliability. The operating times as reported in question 24 of 7.4 require some explanations in order that an accurate evaluation of this machine can be made. These times were taken primarily from record logs on part number 247-323350. This part has been in production on the project machine for 85% of its total operating time. The machining of this part requires a roughing operation, heat treatment and then finish machining. Over half of the 63% metal cutting time was used for roughing operations. During roughing poor finish, due to jumping in the X, Y and Z axes, was tolerated. Finish machining could not be performed under these conditions. As a result, it is estimated that the retrofitted machine was available for full productive use 40% of the total time.

The basic maintenance problem is the mechanical nature of the numerical control-stepping switches, relays, and slipper switches. Contacts require cleaning at least once a shift and replacement at frequent intervals due to wear. There does not appear to be any pattern to the failures making preventive maintenance difficult.

Cincinnati Milling has made numerous modifications to the electronic circuity and the switching arrangement. In some cases a definite improvement in performance and dependability was noted; however, other problems continue to develop resulting in an overall low level of performance.

The problems experienced with the control system do not detract from the cost savings possible by retrofitting a qualified machine tool. These problems are strictly a function of the numerical controls, whether they be installed on a new piece of equipment or a retrofitted machine tool.



ATTACHMENT #1

OPER. NUMBER	SHEET NUMBER	ITEM OR TOOL NUMBER	TOOL TYPE	TOOL DIAMETER	CORNER RADIUS	OAL	NO OF FLUTES	FLUTE LGTH.	CUT AND SPIRAL	REMARKS
1	3	8-1-392-2	HSS ENDMILL	1.000	.250	4.75	2	2.00	RH	
2	4	8-1-401	HSS ENDMILL	2.500	.015	6.50	4	3.00	RH	
3	5	8-1-401	HSS ENDMILL	2.500	.015	6.50	4	3.00	RH	
4	6	8-1-500	SPECIAL 10" R FORM RELIEVED	1.500		7.25	6		RH	
5	7	8-1-384-9	HSS ENDMILL	1.000	.220	4.75	4	1.75	RH	
6	8	8-1-401	HSS ENDMILL	2.500	.015	6.50	4	3.00	RH	
7	9	8-1-384-17	HSS ENDMILL	1.500	.015	4.75	4	2.00	RH	
8	10	8-1-500	SPECIAL 10" R FORM RELIEVED	1.500		7.25	6		RH	
9	11	T-3025656 DET. 101	SPECIAL END MILL				2		RH	
10	12	T-3025656 DET. 201	SPECIAL END MILL				2		RH	
11	13	T-3025656 DET. 301	SPECIAL END MILL				2		RH	
12	14	8-1-388	HSS ENDMILL	.500	BALLNOSE	4.00	2	2.00	RH	
13	15	8-1-392-2	HSS ENDMILL	1.000	.250	4.75	2	2.00	RH	
14	16	8-1-374	HSS ENDMILL	.250	BALLNOSE	2.50	2	.62	RH	
15	17		HSS DRILL	15/32"					RH	
16	18	8-1-388	HSS ENDMILL	.500	.125	4.00	2	2.00	RH	
17	19	8-1-384-17	HSS ENDMILL	1.500	.015	4.75	4	2.00	RH	
18	20	8-1-384-9	HSS ENDMILL	1.000	.015	4.75	4	1.75	RH	
19										
20										

PART NAME	A.I.A. TEST PART NO. 2
PART PROGRAMMED TO	
MATERIAL	61 ST ALUMINUM (See Sheet No. 2)
FOR USE WITH	
SPECIAL CUTTERS	SEE LISTING
NUMBER OF OPERATIONS	18
TOTAL PROGRAM TIME	4 HRS., 59.4 MIN.
TOTAL NUMBER OF SHEETS	20

SHEET NO 1	TITLE SHEET & CUTTER LISTING
SHEET NO 2	MATERIAL PREPARATION
SHEETS NO 3 THRU 20	SEQUENCE OF OPERATIONS

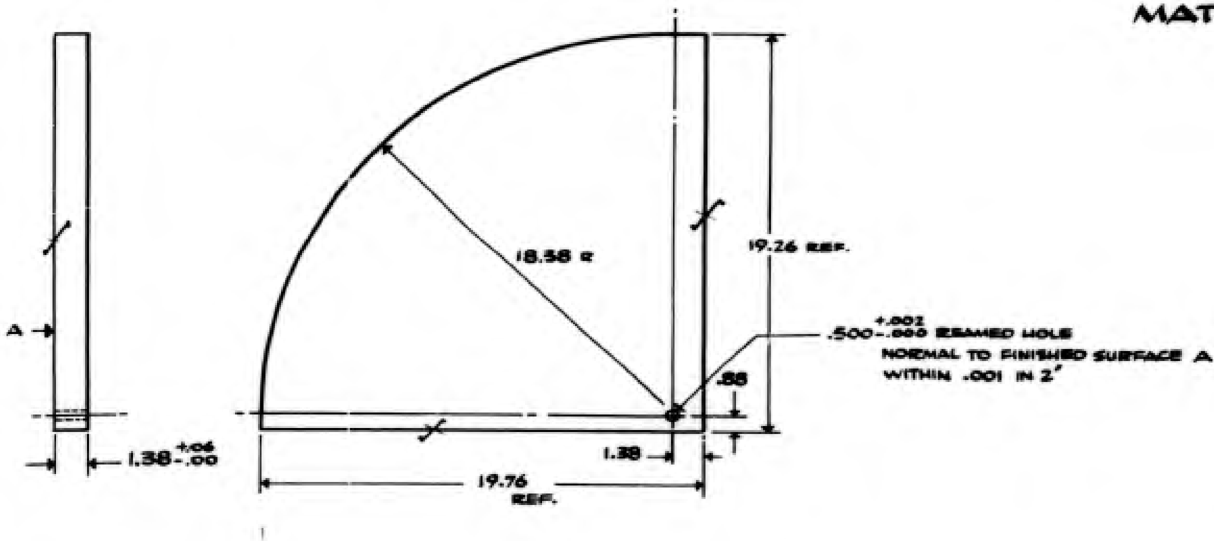
NORTH AMERICAN AVIATION, INC. COLUMBUS, OHIO

NUMERICAL CONTROL MACHINE DATA

CINCINNATI 36 × 72 HORIZONTAL HYDROTEL (RETROFIT)

A.I.A. TEST PART NO 2

ATTACHMENT #2

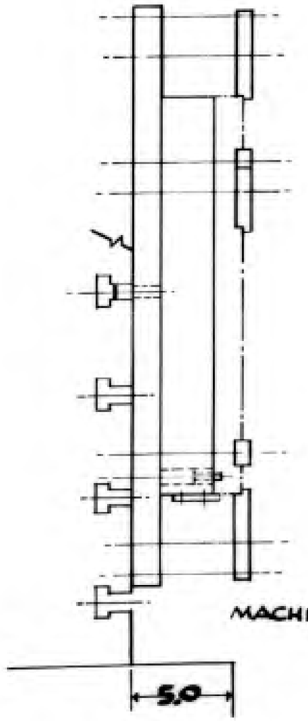


MATERIAL PREPARATION PRIOR TO NUMERICAL CONTROL MACHINING

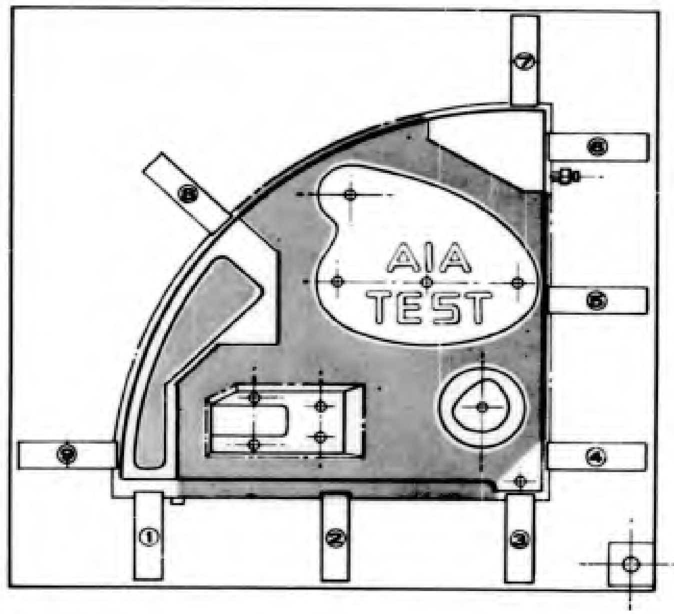
MATERIAL : 61 ST ALUMINUM

NORTH AMERICAN AVIATION, INC. TOOL DESIGN COLUMBUS, OHIO
NUMERICAL CONTROL MACHINE DATA CINCINNATI 36 × 72 HORIZONTAL HYDROTEL RETROFIT
A.I.A. TEST PART Nº 2
SHEET 2 OF 20

ATTACHMENT #2



MACHINE TABLE



STEP	
1	LOAD BILLET ON FIXTURE AND SECURE CLAMPS #1, 3, 4, 6, 7, 8, & 9.
2	ALIGN MACHINE, INSERT CUTTER AND SET Z.
3	START MACHINE. PROGRAM WILL ROUGH CUT SURFACE INDICATED LEAVING .06 MATERIAL ON BOTTOM, AND .03 ON VERTICAL WALLS.

SET POINT/USE 2.500 FEELER

X = 34.000
Y = 7.000
Z = 13.000

OPERATION I

○ Z AXIS LOWERS TO CUTTING POSITION
● Z AXIS LIFTS OUT OF CUTTING POSITION

ATTACHMENT #2

CUTTER DATA

ITEM NUMBER	8-1-392-2
CUTTER DIAMETER	1.000 $^{+.001}_{-.050}$
Nº FLUTES CUT HELIX	2-R.H.-R.H.
CORNER RADIUS	.250 ±.050
MIN. CUT LENGTH	1.0
MIN. LENGTH END OF CUTTER TO HOLDER	1.5

MACHINE DATA

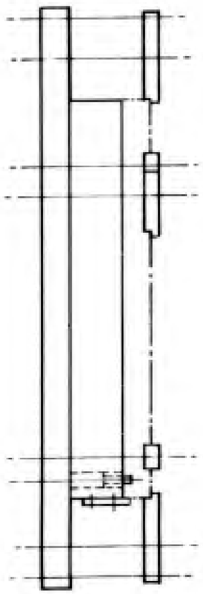
SPINDLE R.P.M.	900
PROGRAMMED FEED RATE I.P.M.	22
MACHINING SPEED / S.F.M.	240
FEED PER TOOTH / MAX.	.012
HORSEPOWER / MAX.	3.0
EXECUTION TIME / MIN.	58.9

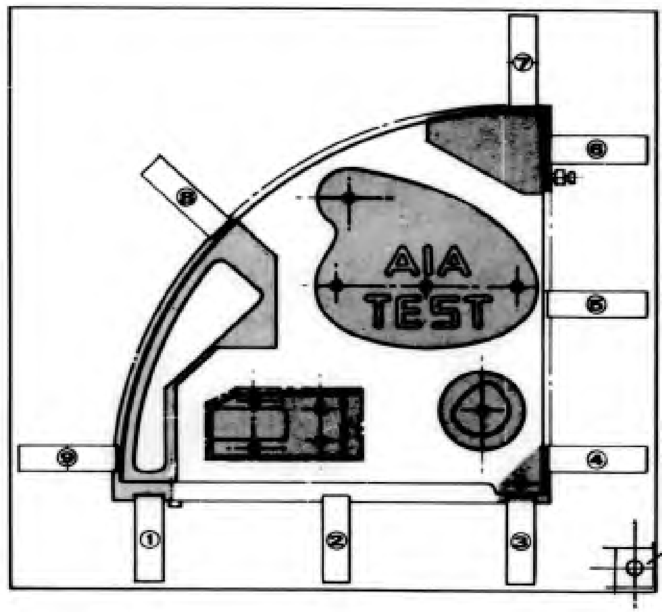
NORTH AMERICAN AVIATION, INC.
TOOL DESIGN COLUMBUS, OHIO

NUMERICAL CONTROL MACHINE DATA
CINCINNATI 36 x 72 HORIZONTAL HYDROTEL RETROFIT

A.I.A TEST PART Nº 2

SHEET 3 OF 20





STEP	
1	SECURE CLAMPS #2 & 5. REMOVE CLAMPS #4, 7 & 9.
2	ALIGN MACHINE, CHANGE CUTTER AND SET Z.
3	START MACHINE. PROGRAM WILL ROUGH CUT SURFACE INDICATED LEAVING .03 MATERIAL, MOVE MACHINE TO RIGHT OF FIXTURE AND STOP.
4	SECURE CLAMPS #4, 7 & 9. REMOVE CLAMPS #1, 3, 6, & 8.
5	START MACHINE. PROGRAM WILL BLEND AREAS AT CLAMPS 1, 3, 6, & 8 TO ROUGH CUT SURFACE.

SET POINT/USE 2.500 FEELER
X = 34.000
Y = 7.000
Z = 13.000

OPERATION 2

○ Z AXIS LOWERS TO CUTTING POSITION
● Z AXIS LIFTS OUT OF CUTTING POSITION

ATTACHMENT #2

CUTTER DATA

ITEM NUMBER	8-1-401
CUTTER DIAMETER	2.500 +.001 -.000
Nº FLUTES CUT HELIX	4-R.H.-R.H.
CORNER RADIUS	.015 +.000 -.015
MIN. CUT LENGTH	1.0
MIN. LENGTH END OF CUTTER TO HOLDER	1.5

MACHINE DATA

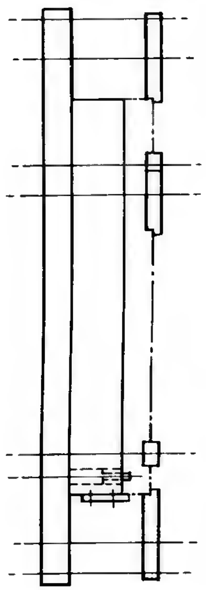
SPINDLE R.P.M.	525
PROGRAMMED FEED RATE I.P.M.	22
MACHINING SPEED / S.F.M.	350
FEED PER TOOTH / MAX.	.010
HORSEPOWER / MAX.	1.2
EXECUTION TIME / MIN.	16.2

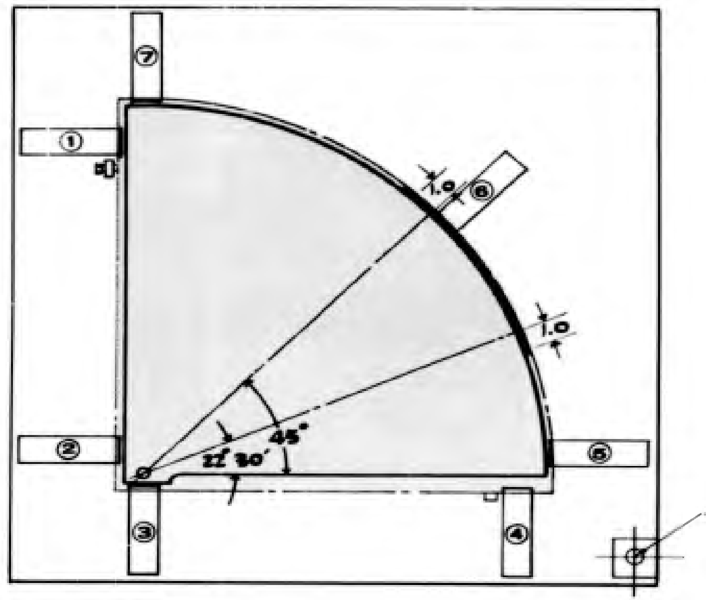
NORTH AMERICAN AVIATION, INC.
TOOL DESIGN COLUMBUS, OHIO

NUMERICAL CONTROL MACHINE DATA
CINCINNATI 36 x 72 HORIZONTAL HYDROTEL RETROFIT

A.I.A TEST PART Nº 2

SHEET 4 OF 23





STEP	
1	TURN RISER PLATE AND PART OVER AND SECURE CLAMPS #1, 3, 4, & 6.
2	ALIGN MACHINE AND SET Z.
3	START MACHINE. PROGRAM WILL FINISH CUT SURFACE INDICATED, MOVE MACHINE TO RIGHT OF FIXTURE AND STOP.
4	SECURE CLAMPS #2, 5 & 7. REMOVE CLAMPS #1, 3, 4 & 6. REMOVE STUDS AT CLAMP #6.
5	START MACHINE. PROGRAM WILL BLEND AREAS AT CLAMPS #1, 3, 4, && 6 TO FINISH SURFACE AND ROUGH PERIPHERY IN AREA INDICATED.

SET POINT/USE 2.500 FEELER

X = 34.000
Y = 7.000
Z = 13.000

OPERATION 3

○ Z AXIS LOWERS TO CUTTING POSITION
● Z AXIS LIFTS OUT OF CUTTING POSITION

ATTACHMENT #2

CUTTER DATA

ITEM NUMBER	8-1-401
CUTTER DIAMETER	$2.500^{+.001}_{-.030}$
Nº FLUTES CUT HELIX	4-R.H.-R.H.
CORNER RADIUS	$.015^{+.000}_{-.015}$
MIN. CUT LENGTH	1.0
MIN. LENGTH END OF CUTTER TO HOLDER	1.5

MACHINE DATA

SPINDLE R.P.M.	900
PROGRAMMED FEED RATE I.P.M.	18
MACHINING SPEED / S.F.M.	600
FEED PER TOOTH / MAX.	.005
HORSEPOWER / MAX.	2.5
EXECUTION TIME / MIN.	26.3

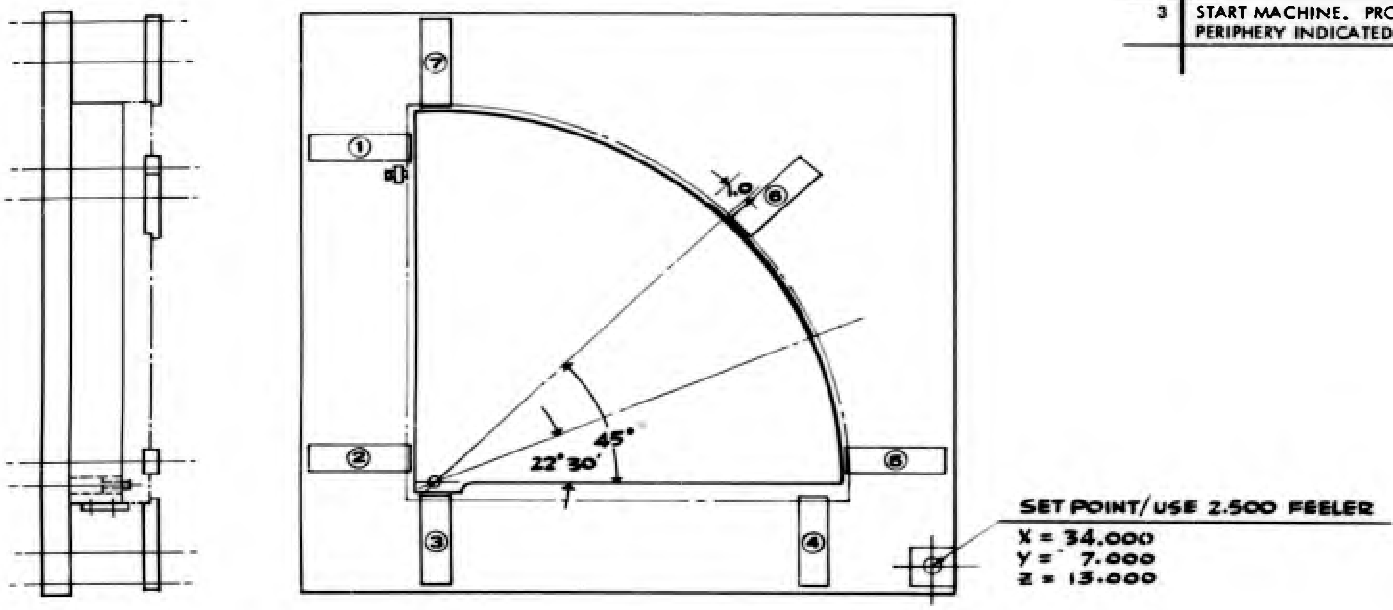
NORTH AMERICAN AVIATION, INC.
TOOL DESIGN COLUMBUS, OHIO

NUMERICAL CONTROL MACHINE DATA
CINCINNATI 36 x 72 HORIZONTAL HYDROTEL RETROFIT

A.I.A TEST PART Nº 2

SHEET 5 OF 20

STEP	
1	SECURE CLAMPS #1, 3 & 4.
2	ALIGN MACHINE, CHANGE CUTTER AND SET Z.
3	START MACHINE. PROGRAM WILL FINISH MILL PORTION OF PERIPHERY INDICATED.



OPERATION 4

○ Z AXIS LOWERS TO CUTTING POSITION
● Z AXIS LIFTS OUT OF CUTTING POSITION

ATTACHMENT #2

CUTTER DATA

ITEM NUMBER	8-1-500
CUTTER DIAMETER	SPECIAL 10" E. M. CUTTER
Nº FLUTES CUT HELIX	6- R.H.-R.H.
CORNER RADIUS	
MIN. CUT LENGTH	
MIN. LENGTH END OF CUTTER TO HOLDER	

MACHINE DATA

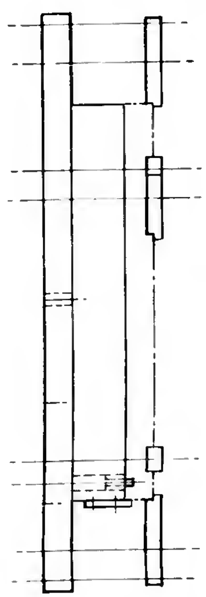
SPINDLE R.P.M.	735
PROGRAMMED FEED RATE I.P.M.	22
MACHINING SPEED / S.F.M.	300
FEED PER TOOTH / MAX.	.005
HORSEPOWER / MAX.	1.0
EXECUTION TIME / MIN.	9.3

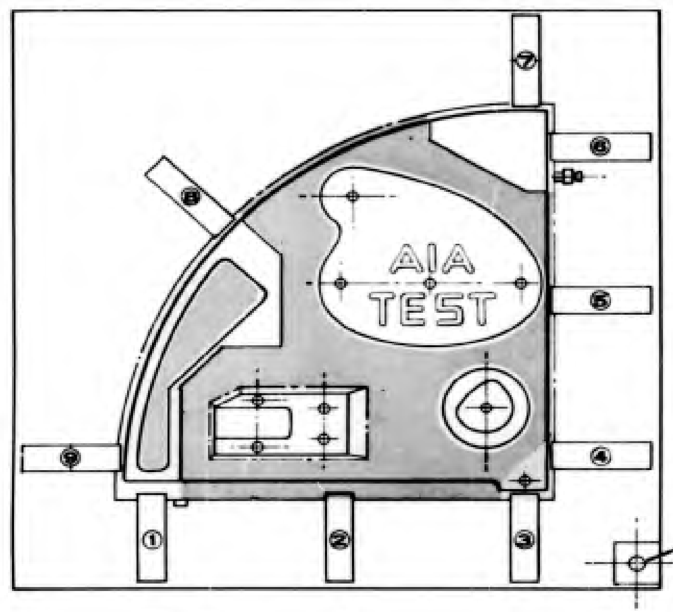
NORTH AMERICAN AVIATION, INC.
TOOL DESIGN COLUMBUS, OHIO

NUMERICAL CONTROL MACHINE DATA
CINCINNATI 36 x 72 HORIZONTAL HYDROTEL RETROFIT

A.I.A TEST PART Nº 2

SHEET 6 OF 20





STEP	
1	TURN RISER PLATE AND PART OVER AND SECURE CLAMPS #1, 3, 6, 7, 8 & 9.
2	ALIGN MACHINE, CHANGE CUTTER AND SET Z.
3	START MACHINE. PROGRAM WILL FINISH SURFACE INDICATED AND VERTICAL WALLS, MOVE MACHINE TO RIGHT OF FIXTURE AND STOP.
4	SECURE CLAMPS #2, 4, & 5. REMOVE CLAMP #3
5	START MACHINE. PROGRAM WILL BLEND AREA AT CLAMP #3 TO FINISHED SURFACE.

SET POINT/USE 2.500 FEELER

X = 34.000
Y = 7.000
Z = 13.000

OPERATION 5

○ Z AXIS LOWERS TO CUTTING POSITION
● Z AXIS LIFTS OUT OF CUTTING POSITION

ATTACHMENT #2

CUTTER DATA

ITEM NUMBER	8-1-384-9
CUTTER DIAMETER	1.000 ±.001
Nº FLUTES CUT HELIX	4 - R.H.-R.H.
CORNER RADIUS	.220 ±.005
MIN. CUT LENGTH	1.0
MIN. LENGTH END OF CUTTER TO HOLDER	1.5

MACHINE DATA

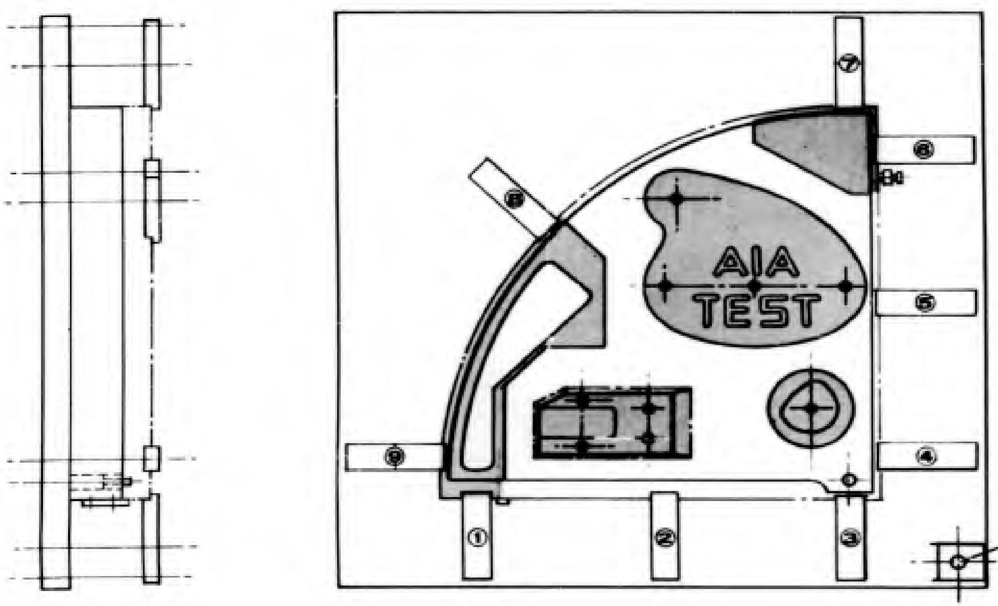
SPINDLE R.P.M.	900
PROGRAMMED FEED RATE I.P.M.	18
MACHINING SPEED / S.F.M.	240
FEED PER TOOTH / MAX.	.005
HORSEPOWER / MAX.	2.5
EXECUTION TIME / MIN.	75.4

NORTH AMERICAN AVIATION, INC.
TOOL DESIGN COLUMBUS, OHIO

NUMERICAL CONTROL MACHINE DATA
CINCINNATI 36 x 72 HORIZONTAL HYDROTEL RETROFIT

A.I.A TEST PART Nº 2

SHEET 7 OF 20



STEP	
1	SECURE CLAMP #3. REMOVE CLAMPS #7 & #9.
2	ALIGN MACHINE, CHANGE CUTTER AND SET Z
3	START MACHINE. PROGRAM WILL FINISH SURFACE INDICATED, MOVE MACHINE TO RIGHT OF FIXTURE AND STOP.
4	SECURE CLAMPS #7 & #9. REMOVE CLAMPS 1, 6 & 8.
5	START MACHINE. PROGRAM WILL BLEND AREAS AT CLAMPS 1, 6, & 8 TO FINISHED SURFACE.

SET POINT/USE 2.500 FEELER
X = 34.000
Y = 7.000
Z = 13.000

OPERATION 6

○ Z AXIS LOWERS TO CUTTING POSITION
● Z AXIS LIFTS OUT OF CUTTING POSITION

ATTACHMENT #2

CUTTER DATA

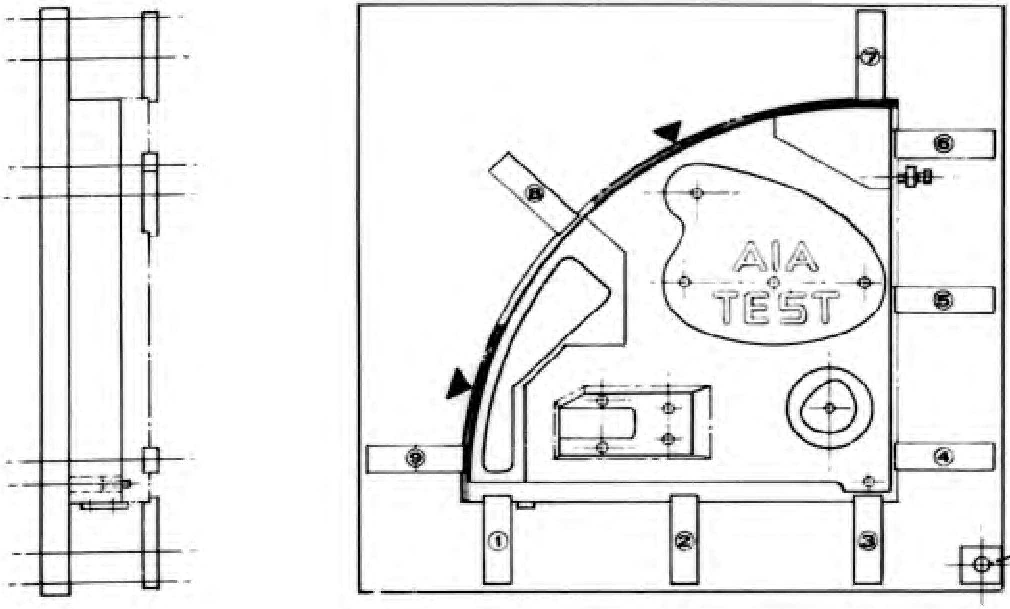
ITEM NUMBER	8-1-401
CUTTER DIAMETER	$2.500^{+.001}_{-.030}$
Nº FLUTES CUT HELIX	4-R.H.-R.H.
CORNER RADIUS	$.015^{+.000}_{-.015}$
MIN. CUT LENGTH	1.0
MIN. LENGTH END OF CUTTER TO HOLDER	1.5

MACHINE DATA

SPINDLE R.P.M.	900
PROGRAMMED FEED RATE I.P.M.	18
MACHINING SPEED / S.F.M.	600
FEED PER TOOTH / MAX.	.005
HORSEPOWER / MAX.	.4
EXECUTION TIME / MIN.	18.1

NORTH AMERICAN AVIATION, INC.
TOOL DESIGN COLUMBUS, OHIO
NUMERICAL CONTROL MACHINE DATA
CINCINNATI 36 x 72 HORIZONTAL HYDROTEL RETROFIT
A.I.A TEST PART Nº 2
SHEET 8 OF 20

STEP	
1	SECURE CLAMPS #1, 6 & 8. REMOVE CLAMP #7 STUDS.
2	ALIGN MACHINE, CHANGE CUTTER, AND SET Z.
3	START MACHINE. PROGRAM WILL ROUGH AND FINISH 90° PORTION OF 18" RADIUS, MOVE MACHINE TO RIGHT OF FIXTURE, AND STOP.
4	SECURE CLAMP #7. REMOVE CLAMP #9 AND STUDS.
5	START MACHINE. PROGRAM WILL ROUGH CUT REMAINING SWARFED AREA OF PERIPHERY.



SET POINT/USE 2.500 FEELER
X = 34.000
Y = 7.000
Z = 13.000

OPERATION 7

○ Z AXIS LOWERS TO CUTTING POSITION
● Z AXIS LIFTS OUT OF CUTTING POSITION

ATTACHMENT #2

CUTTER DATA

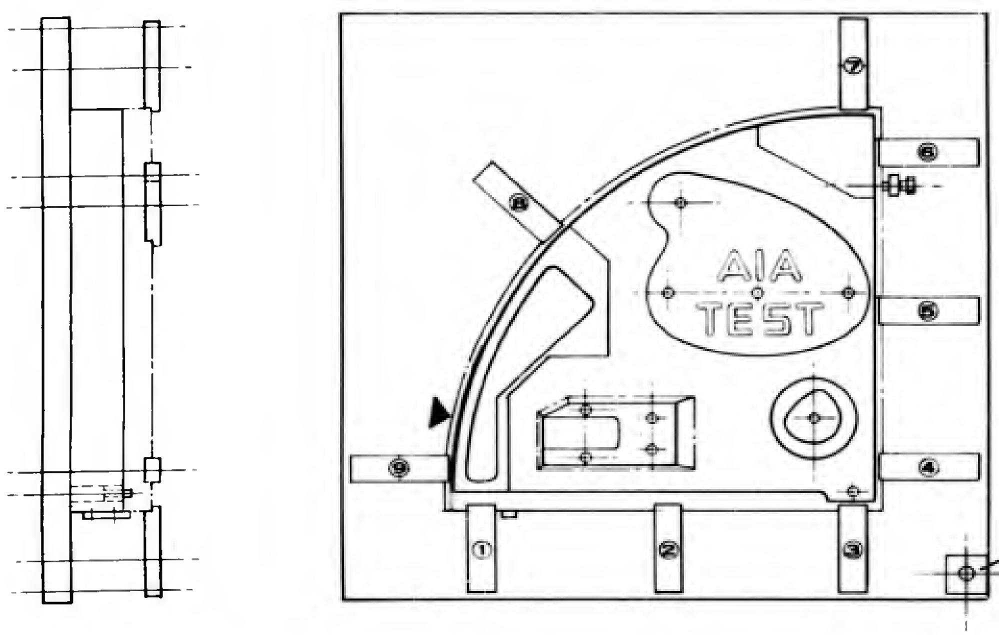
ITEM NUMBER	8-1-384-17
CUTTER DIAMETER	1.500 ±.001
Nº FLUTES CUT HELIX	4 - R.H.-R.H.
CORNER RADIUS	.015 ±.015
MIN. CUT LENGTH	1.5
MIN. LENGTH END OF CUTTER TO HOLDER	2.5

MACHINE DATA

SPINDLE R.P.M.	900
PROGRAMMED FEED RATE I.P.M.	18
MACHINING SPEED / S.F.M.	350
FEED PER TOOTH / MAX.	.005
HORSEPOWER / MAX.	2.5
EXECUTION TIME / MIN.	13.0

NORTH AMERICAN AVIATION, INC.
TOOL DESIGN COLUMBUS, OHIO
NUMERICAL CONTROL MACHINE DATA
CINCINNATI 36 x 72 HORIZONTAL HYDROTEL RETROFIT
A.I.A TEST PART Nº 2
SHEET 9 OF 20

STEP	
1	ALIGN MACHINE, CHANGE CUTTER AND SET Z
2	START MACHINE. PROGRAM WILL FINISH 90°-95° SWARFED PERIPHERY



SET POINT/USE 2.500 FEELER
X = 34.000
Y = 7.000
Z = 13.000

OPERATION 8

○ Z AXIS LOWERS TO CUTTING POSITION
● Z AXIS LIFTS OUT OF CUTTING POSITION

ATTACHMENT #2

CUTTER DATA

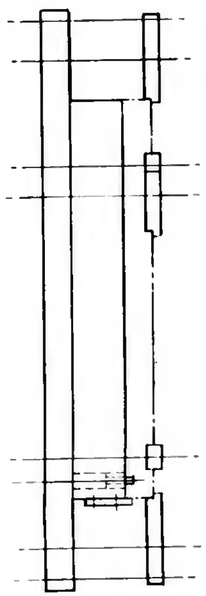
ITEM NUMBER	8-1-500
CUTTER DIAMETER	SPECIAL IO ML CUTTER
Nº FLUTES CUT HELIX	6-R.H.-R.H.
CORNER RADIUS	
MIN. CUT LENGTH	
MIN. LENGTH END OF CUTTER TO HOLDER	

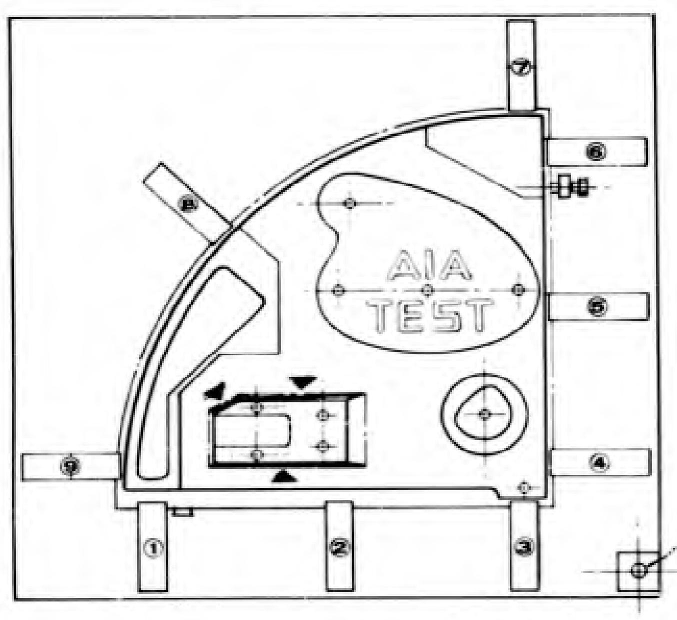
MACHINE DATA

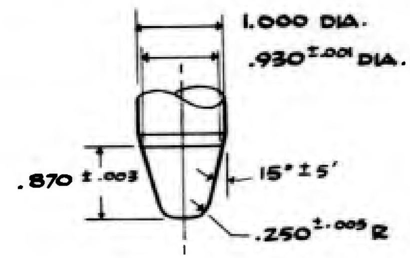
SPINDLE R.P.M.	735
PROGRAMMED FEED RATE I.P.M.	22
MACHINING SPEED / S.F.M.	300
FEED PER TOOTH MAX.	.005
HORSEPOWER MAX.	1.0
EXECUTION TIME / MIN.	9.3

NORTH AMERICAN AVIATION, INC.
TOOL DESIGN COLUMBUS, OHIO
NUMERICAL CONTROL MACHINE DATA
CINCINNATI 36 x 72 HORIZONTAL HYDROTEL RETROFIT
A.I.A TEST PART Nº 2
SHEET 10 OF 20

STEP	
1	SECURE CLAMP #9.
2	ALIGN MACHINE, CHANGE CUTTER, AND SET Z.
3	START MACHINE. PROGRAM WILL FINISH 75° ANGLED WALL (3) PLACES.







T- 3025656 DET. 101

SET POINT/USE 2.500 FEELER
X = 34.000
Y = 7.000
Z = 13.000

OPERATION 9

○ Z AXIS LOWERS TO CUTTING POSITION
● Z AXIS LIFTS OUT OF CUTTING POSITION

ATTACHMENT #2

CUTTER DATA

ITEM NUMBER	SEE SKETCH ABOVE
CUTTER DIAMETER	
Nº FLUTES CUT HELIX	2 - R.H.-R.H.
CORNER RADIUS	.250 ±.005
MIN. CUT LENGTH	1.0
MIN. LENGTH END OF CUTTER TO HOLDER	1.2

MACHINE DATA

SPINDLE R.P.M.	900
PROGRAMMED FEED RATE I.P.M.	9
MACHINING SPEED / S.F.M.	240
FEED PER TOOTH / MAX.	.005
HORSEPOWER / MAX.	5
EXECUTION TIME / MIN.	5.7

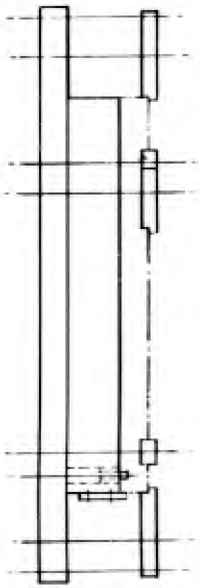
NORTH AMERICAN AVIATION, INC.
TOOL DESIGN COLUMBUS, OHIO

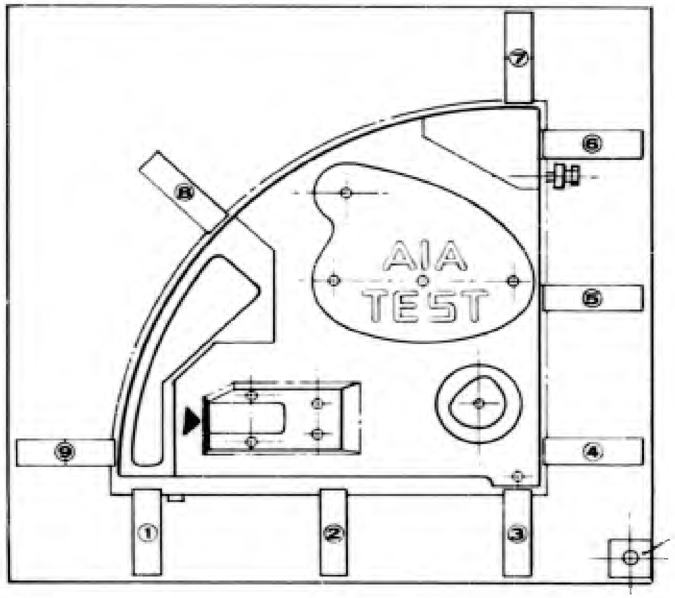
NUMERICAL CONTROL MACHINE DATA
CINCINNATI 56 x 72 HORIZONTAL HYDROTEL RETROFIT

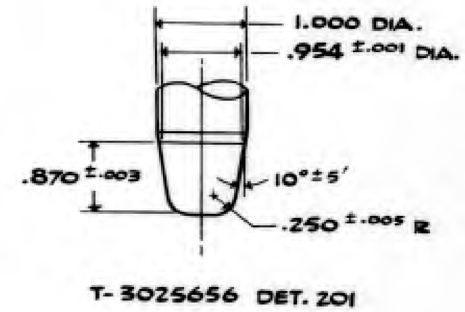
A.I.A TEST PART Nº 2

SHEET 11 OF 20

STEP	
1	ALIGN MACHINE, CHANGE CUTTER, AND SET Z.
2	START MACHINE. PROGRAM WILL FINISH 30° ANGLED WALL.







T-3025656 DET. 201

SET POINT/USE 2.500 FEELER

X = 34.000
Y = 7.000
Z = 13.000

OPERATION 10

○ Z AXIS LOWERS TO CUTTING POSITION
● Z AXIS LIFTS OUT OF CUTTING POSITION

ATTACHMENT #2

CUTTER DATA

ITEM NUMBER	SEE SKETCH ABOVE
CUTTER DIAMETER	
Nº FLUTES CUT HELIX	2-R.H.-R.H.
CORNER RADIUS	.250 ±.005
MIN. CUT LENGTH	1.0
MIN. LENGTH END OF CUTTER TO HOLDER	1.2

MACHINE DATA

SPINDLE R.P.M.	900
PROGRAMMED FEED RATE I.P.M.	9
MACHINING SPEED / S.F.M.	240
FEED PER TOOTH MAX.	.005
HORSEPOWER / MAX.	5
EXECUTION TIME / MIN.	2.4

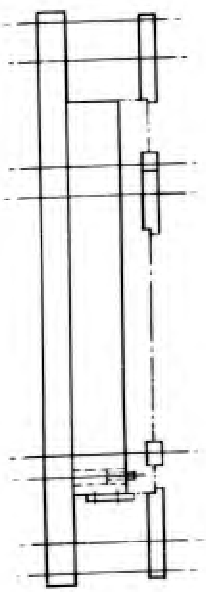
NORTH AMERICAN AVIATION, INC.
TOOL DESIGN COLUMBUS, OHIO

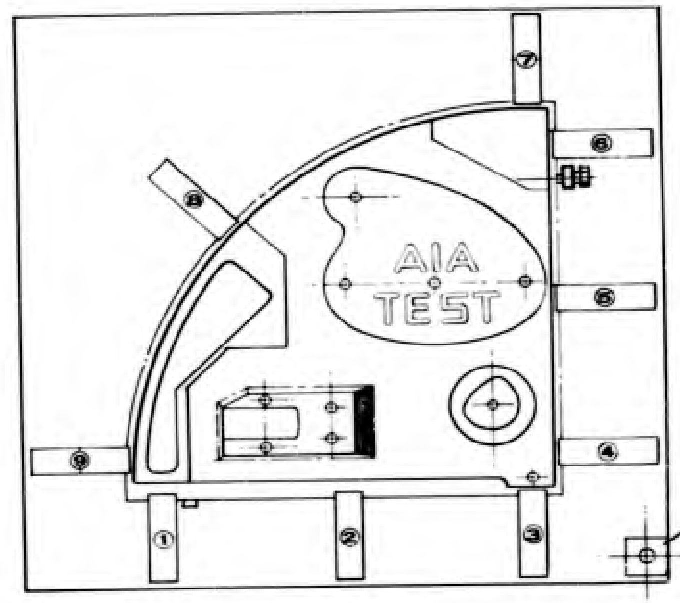
NUMERICAL CONTROL MACHINE DATA
CINCINNATI 36 x 72 HORIZONTAL HYDROTEL RETROFIT

A.I.A TEST PART Nº 2

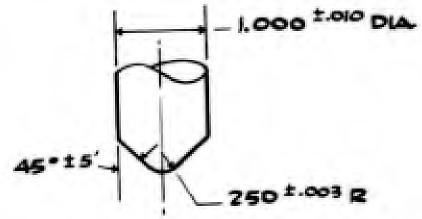
SHEET 12 OF 20

STEP	
1	ALIGN MACHINE, CHANGE CUTTER AND SET Z.
2	START MACHINE. PROGRAM WILL FINISH 45° ANGLED WALL.





SET POINT/USE 2.500 FEELER
X = 34.000
Y = 7.000
Z = 13.000



T-3025656 DET. 301

OPERATION II

○ Z AXIS LOWERS TO CUTTING POSITION
● Z AXIS LIFTS OUT OF CUTTING POSITION

ATTACHMENT #2

CUTTER DATA

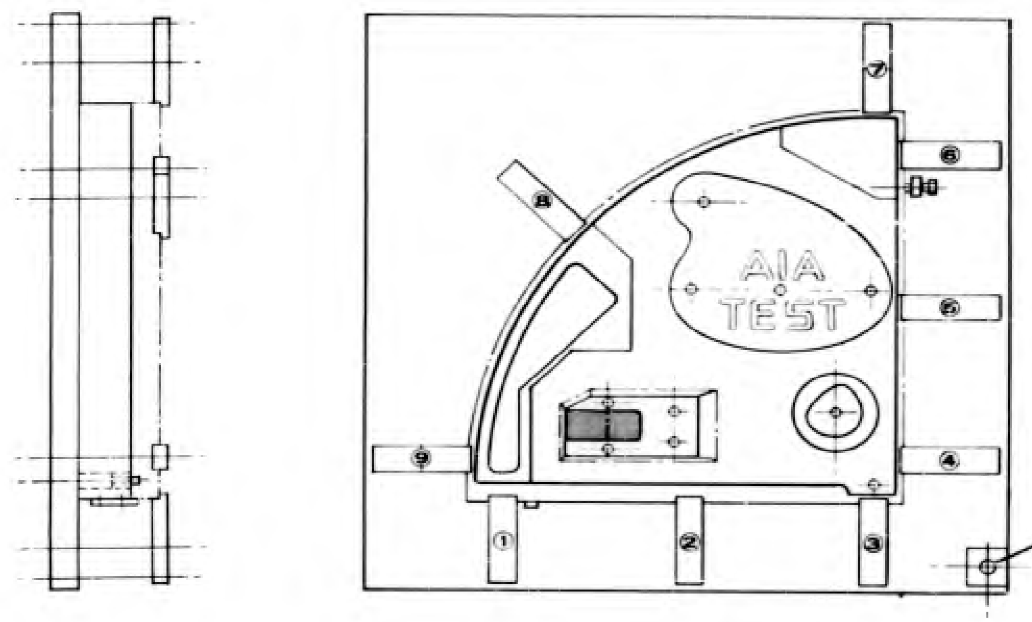
ITEM NUMBER	SEE SKETCH ABOVE
CUTTER DIAMETER	
Nº FLUTES CUT HELIX	2-R.H.-R.H.
CORNER RADIUS	.250 ± .003
MIN. CUT LENGTH	1.0
MIN. LENGTH END OF CUTTER TO HOLDER	1.2

MACHINE DATA

SPINDLE R.P.M.	900
PROGRAMMED FEED RATE I.P.M.	9
MACHINING SPEED / S.F.M.	240
FEED PER TOOTH / MAX.	.005
HORSEPOWER / MAX.	5
EXECUTION TIME / MIN.	6.1

NORTH AMERICAN AVIATION, INC.
TOOL DESIGN COLUMBUS, OHIO
NUMERICAL CONTROL MACHINE DATA
CINCINNATI 36 x 72 HORIZONTAL HYDROTEL RETROFIT
A.I.A TEST PART Nº 2
SHEET [illegible] OF 20

STEP	
1	ALIGN MACHINE, CHANGE CUTTER, AND SET Z.
2	START MACHINE. PROGRAM WILL FINISH 2" INCLINED PLANE POCKET.



SET POINT/USE 2.500 FEELER
X = 34.000
Y = 7.000
Z = 13.000

OPERATION 12

○ Z AXIS LOWERS TO CUTTING POSITION
● Z AXIS LIFTS OUT OF CUTTING POSITION

ATTACHMENT #2

CUTTER DATA

ITEM NUMBER	8-1-388
CUTTER DIAMETER	.500±.001
Nº FLUTES CUT HELIX	2-R.H.-R.H.
CORNER RADIUS	BALLNOSE
MIN. CUT LENGTH	1.0
MIN. LENGTH END OF CUTTER TO HOLDER	1.0

MACHINE DATA

SPINDLE R.P.M.	900
PROGRAMMED FEED RATE I.P.M.	9
MACHINING SPEED / S.F.M.	120
FEED PER TOOTH / MAX.	.005
HORSEPOWER / MAX.	.6
EXECUTION TIME / MIN.	18.1

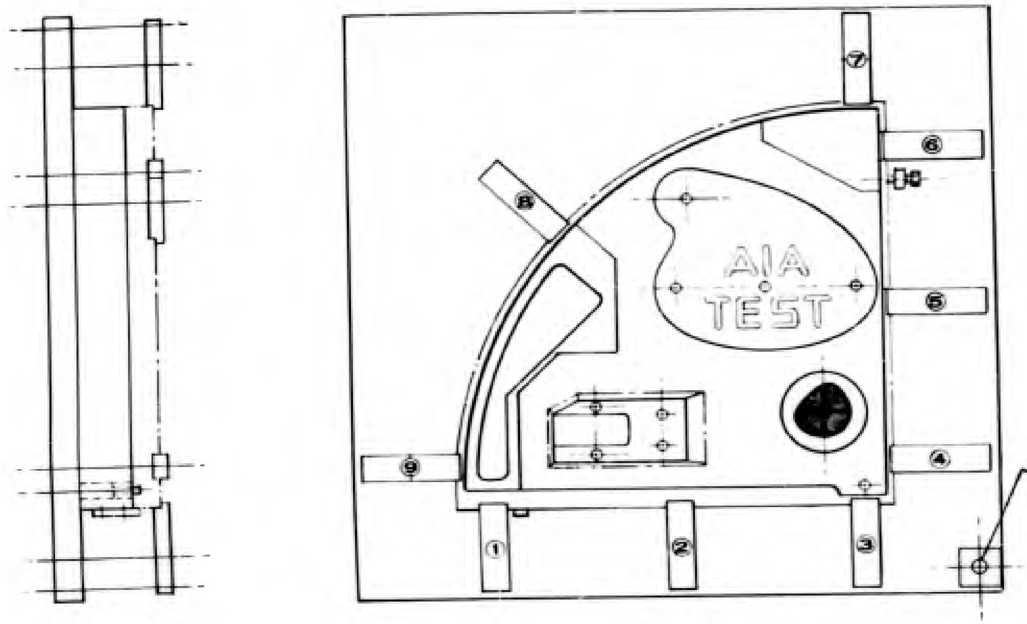
NORTH AMERICAN AVIATION, INC.
TOOL DESIGN COLUMBUS, OHIO

NUMERICAL CONTROL MACHINE DATA
CINCINNATI 36 x 72 HORIZONTAL HYDROTEL RETROFIT

A.I.A TEST PART Nº 2

SHEET 14 OF 20

STEP	
1	ALIGN MACHINE, CHANGE CUTTER, AND SET Z.
2	START MACHINE. PROGRAM WILL FINISH POCKET INDICATED.



SET POINT/USE 2.500 FEELER
X = 34.000
Y = 7.000
Z = 13.000

OPERATION 13

○ Z AXIS LOWERS TO CUTTING POSITION
Z AXIS LIFTS OUT OF CUTTING POSITION

ATTACHMENT #2

CUTTER DATA

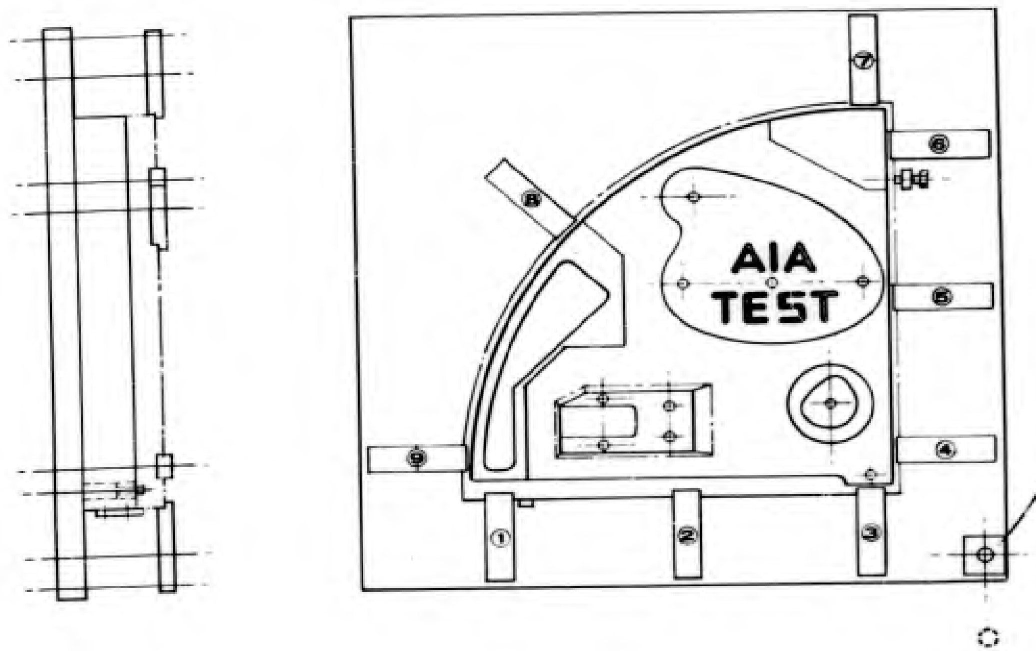
ITEM NUMBER	8-1-392-2
CUTTER DIAMETER	1,000 ±.001
NO FLUTES CUT HELIX	2-R.H.-R.H.
CORNER RADIUS	.250 ±.005
MIN. CUT LENGTH	1.0
MIN. LENGTH END OF CUTTER TO HOLDER	1.5

MACHINE DATA

SPINDLE R.P.M.	900
PROGRAMMED FEED RATE I.P.M.	9
MACHINING SPEED / S.F.M.	240
FEED PER TOOTH / MAX.	.005
HORSEPOWER / MAX.	5
EXECUTION TIME / MIN.	6.8

NORTH AMERICAN AVIATION, INC.
TOOL DESIGN COLUMBUS, OHIO
NUMERICAL CONTROL MACHINE DATA
CINCINNATI 36 x 72 HORIZONTAL HYDROTEL RETROFIT
A.I.A TEST PART NO 2
SHEET 15 OF 23

STEP	
1	ALIGN MACHINE, CHANGE CUTTER AND SET Z.
2	START MACHINE. PROGRAM WILL MILL LETTERS "AIA TEST".



SET POINT/USE 2.500 FEELER
X = 34.000
Y = 7.000
Z = 13.000

OPERATION 14

○ Z AXIS LOWERS TO CUTTING POSITION
● Z AXIS LIFTS OUT OF CUTTING POSITION

ATTACHMENT #2

CUTTER DATA

ITEM NUMBER	8-1-374
CUTTER DIAMETER	.250 ±.001
Nº FLUTES CUT HELIX	R.H.-R.H.
CORNER RADIUS	BALLNOSE
MIN. CUT LENGTH	.5
MIN. LENGTH END OF CUTTER TO HOLDER	1.0

MACHINE DATA

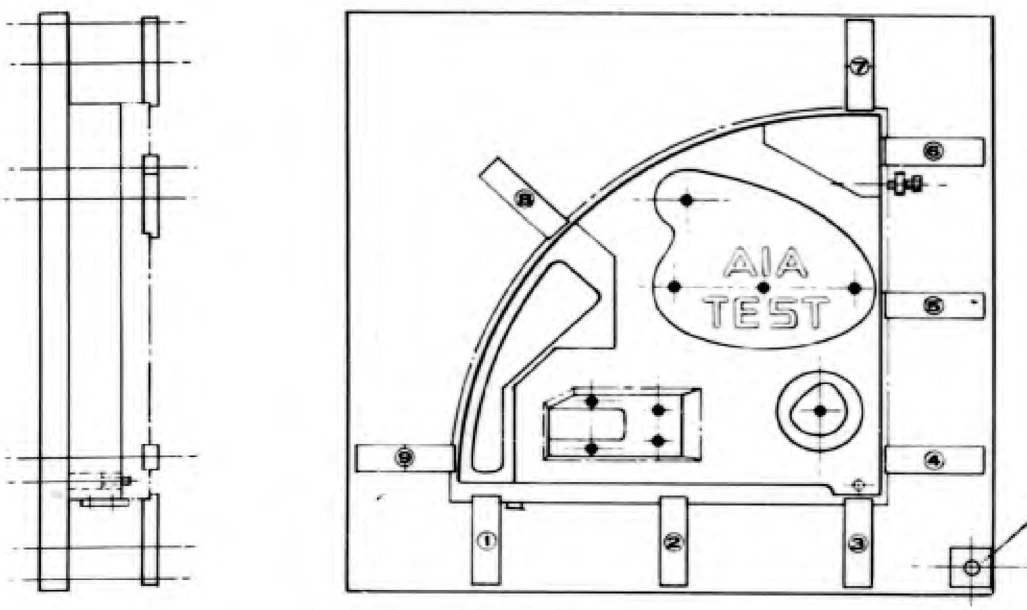
SPINDLE R.P.M.	900
PROGRAMMED FEED RATE I.P.M.	9
MACHINING SPEED / S.F.M.	60
FEED PER TOOTH / MAX.	.005
HORSEPOWER / MAX.	3
EXECUTION TIME / MIN.	7.9

NORTH AMERICAN AVIATION, INC.
TOOL DESIGN COLUMBUS, OHIO

NUMERICAL CONTROL MACHINE DATA
CINCINNATI 36 x 72 HORIZONTAL HYDROTEL RETROFIT

A.I.A TEST PART Nº 2
SHEET 16 OF 20

STEP	
1	ALIGN MACHINE, CHANGE CUTTER, AND SET Z.
2	START MACHINE. PROGRAM WILL DRILL HOLES (9) PLACES.



SET POINT/USE 2.500 FEELER

X = 34.000
Y = 7.000
Z = 13.000

OPERATION 15

○ Z AXIS LOWERS TO CUTTING POSITION
● Z AXIS LIFTS OUT OF CUTTING POSITION

ATTACHMENT #2

CUTTER DATA

ITEM NUMBER	
CUTTER DIAMETER	$\frac{15}{32}$ DIA. DRILL
Nº FLUTES CUT HELIX	
CORNER RADIUS	
MIN. CUT LENGTH	1.5
MIN. LENGTH END OF CUTTER TO HOLDER	1.5

MACHINE DATA

SPINDLE R.P.M.	900
PROGRAMMED FEED RATE I.P.M.	8
MACHINING SPEED / S.F.M.	120
FEED PER TOOTH / MAX.	
HORSEPOWER / MAX.	3
EXECUTION TIME / MIN.	5.0

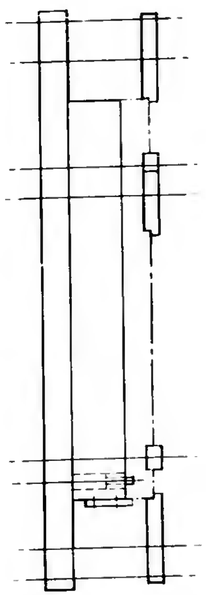
NORTH AMERICAN AVIATION, INC.
TOOL DESIGN COLUMBUS, OHIO

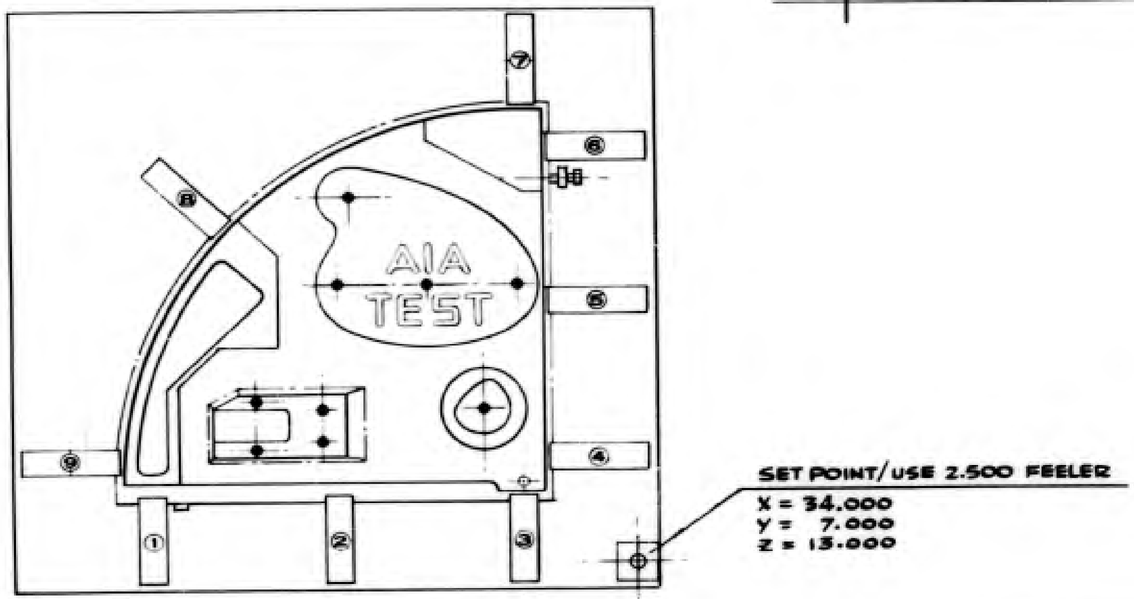
NUMERICAL CONTROL MACHINE DATA
CINCINNATI 36 x 72 HORIZONTAL HYDROTEL RETROFIT

A.I.A TEST PART Nº 2

SHEET 17 OF 23

STEP	
1	ALIGN MACHINE, CHANGE CUTTER AND SET Z.
2	START MACHINE. PROGRAM WILL REAM HOLES (9) PLACES.





OPERATION 16

○ Z AXIS LOWERS TO CUTTING POSITION

● Z AXIS LIFTS OUT OF CUTTING POSITION

ATTACHMENT #2

CUTTER DATA

ITEM NUMBER	8-1-388
CUTTER DIAMETER	.500 ±.0005
Nº FLUTES CUT HELIX	2-R.H.-R.H.
CORNER RADIUS	.125 ±.005
MIN. CUT LENGTH	1.25
MIN. LENGTH END OF CUTTER TO HOLDER	1.5

MACHINE DATA

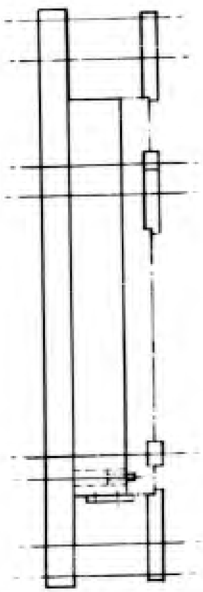
SPINDLE R.P.M.	900
PROGRAMMED FEED RATE I.P.M.	8
MACHINING SPEED / S.F.M.	120
FEED PER TOOTH / MAX.	.005
HORSEPOWER / MAX.	3
EXECUTION TIME / MIN.	5.0

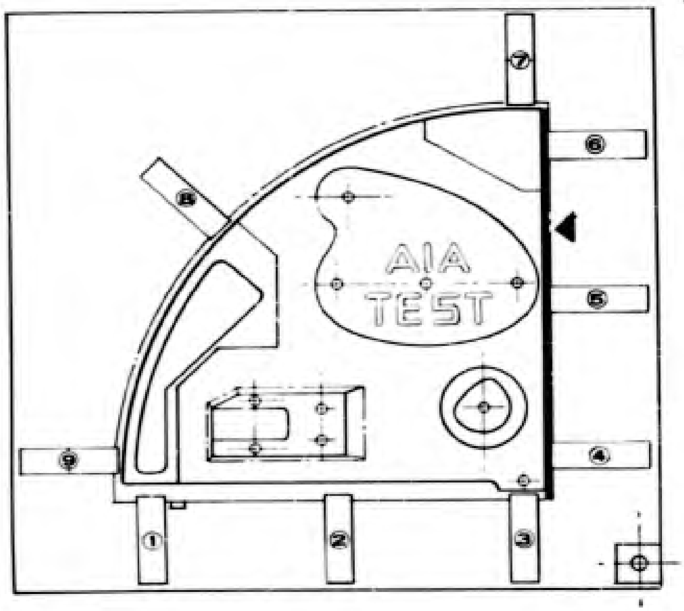
NORTH AMERICAN AVIATION, INC.
TOOL DESIGN COLUMBUS, OHIO

NUMERICAL CONTROL MACHINE DATA
CINCINNATI 36 x 72 HORIZONTAL HYDROTEL RETROFIT

A.I.A TEST PART Nº 2
SHEET 18 OF 20

STEP	
1	REMOVE CLAMPS #4, 5, & 6 AND CLAMPING SCREW AND BLOCK.
2	ALIGN MACHINE, CHANGE CUTTER, AND SET Z.
3	START MACHINE. PROGRAM WILL FINISH MILL PERIPHERY AT RIGHT HAND SIDE OF PART.





SET POINT/USE 2.500 FEELER

X = 34.000
Y = 7.000
Z = 13.000

OPERATION 17

○ Z AXIS LOWERS TO CUTTING POSITION
● Z AXIS LIFTS OUT OF CUTTING POSITION

ATTACHMENT #2

CUTTER DATA

ITEM NUMBER	8-1-384-17
CUTTER DIAMETER	1.500 ±.001
Nº FLUTES CUT HELIX	4-R.H.-R.H.
CORNER RADIUS	.015 ±.015
MIN. CUT LENGTH	1.5
MIN. LENGTH END OF CUTTER TO HOLDER	2.5

MACHINE DATA

SPINDLE R.P.M.	900
PROGRAMMED FEED RATE I.P.M.	18
MACHINING SPEED / S.F.M.	350
FEED PER TOOTH / MAX.	.005
HORSEPOWER / MAX.	10
EXECUTION TIME / MIN.	5.2

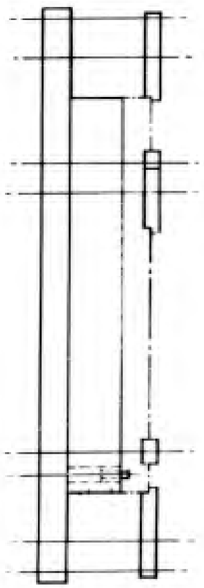
NORTH AMERICAN AVIATION, INC.
TOOL DESIGN COLUMBUS, OHIO

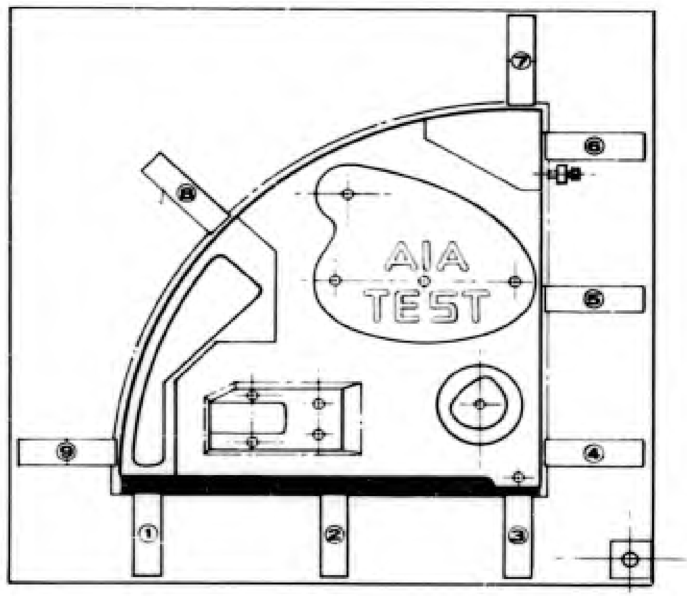
NUMERICAL CONTROL MACHINE DATA
CINCINNATI 36 x 72 HORIZONTAL HYDROTEL RETROFIT

A.I.A. TEST PART Nº 2

SHEET 19 OF 23

STEP	
1	SECURE CLAMPS #4, 5, & 6. REPLACE CLAMP SCREW AND BLOCK. REMOVE CLAMPS #1, 2, & 3 AND THE STOP.
2	ALIGN MACHINE, CHANGE CUTTER AND SET Z.
3	START PROGRAM. MACHINE WILL FINISH MILL LOWER PORTION OF PERIPHERY.





SET POINT/USE 2.500 FEELER

X = 34.000
Y = 7.000
Z = 13.000

OPERATION 18

○ Z AXIS LOWERS TO CUTTING POSITION
● Z AXIS LIFTS OUT OF CUTTING POSITION

ATTACHMENT #2

CUTTER DATA

ITEM NUMBER	8-1-384-9
CUTTER DIAMETER	1.000 ±.001
Nº FLUTES CUT HELIX	4-R.H.-R.H.
CORNER RADIUS	.015 ±.015
MIN. CUT LENGTH	1.5
MIN. LENGTH END OF CUTTER TO HOLDER	2.25

MACHINE DATA

SPINDLE R.P.M.	900
PROGRAMMED FEED RATE I.P.M.	18
MACHINING SPEED / S.F.M.	240
FEED PER TOOTH / MAX.	.005
HORSEPOWER / MAX.	10
EXECUTION TIME / MIN.	6.2

NORTH AMERICAN AVIATION, INC.
TOOL DESIGN COLUMBUS, OHIO

NUMERICAL CONTROL MACHINE DATA
CINCINNATI 36 X 72 HORIZONTAL HYDROTEL RETROFIT

A.I.A TEST PART Nº 2

SHEET 20 OF 20

7.0 costs

MACHINE TOOL
CONTROLS
COMPARISONS

COSTS

7.1 MACHINE TOOL

The machine selected for this project was a 1942 model. Due to the machine age and design conditions a complete rebuild of the machine was considered necessary before the full potential of numerical control retrofitting could be realized.

7.1.1 Actual Rework Costs

This cost includes a complete machine rebuild but does not include the hydraulic drive motor or ball screw assemblies. Price - $43,998.00.

7.1.2 Quotation for Repeat Orders

The work performed is the same as 7.1.1., for repeat orders on identical machines. Price - $60,000.00.

7.1.3 Extras and Nonretrofit Elements

This cost is for a roller table and angle plate. Price - $8,470.00

7.1.4 Resale, Scrap or Salvage Value Before Retrofit

A machine identical to the retrofitted was sold. The sale price was $5,000.

7.1.5 Estimates of Cost Elasticity

7.1.5.1 As a Function of Machine Condition

The machine condition will not change the cost to any extent, providing the basic machine design is compatiable with numerical requirements, and the major castings are sound.

7.1.5.2 As a Function of Performance Requirements

Performance requirements will have a major effect on machine cost. Most machine tools due to their basic design, can easily attain a tolerance level consistent with the machine design. A specified tolerance level lower than this will not result in a lower cost. Tolerance requirements higher than the easily attained level will increase cost considerably. Sufficient facts are not available to reliably estimate the amount of this increased cost.

7.2 CONTROLS

The control used on the retrofit machine is Cincinnati "Acramatic" numerical system. This system reads decimal data card input and features parabolic interpolation, cutter compensation, unlimited zero shift, and mirror image.

7.2.1 Actual Cost

This cost includes the hydraulic drives and ball screw assemblies, and the complete electronic numerical controls. Price - $62,497.00.

7.2.2 Quotation for Repeat Orders

The cost for an identical retrofit is $68,747.00.

7.2.3 Supplementary Equipment

Supplementary equipment is required for the retrofitted machine. This equipment is also used for other numerical machine tools in the plant. This equipment is rented from Remington Rand for $352.00 per month.

7.2.4 Recommended System Spares

The following is a recommended spare parts list:

Unit	CMMCo. Part No.	Quantity To Stock	Unit Price
Interpolator Stage I	EC59M-663711	1	$1,183.00
Light Bulbs Tungsol Lamp No. 48 Type 3-1/4 .06 Amp	DAC-56M-96266	3	.23
Limit Switch Square D Type AW12-B1 Series A, Class 9007	235978	1	17.30
Fuse Fusetron FRN-20	132499	2	.45
Little Fuse, Inc. Type 3AG, Cat. 312005 5 Amp	2EAC-56M-96266-1	2	.07
Little Fuse, Inc. Type 3AG; Cat. 312002 2 Amp	2EAC-56M-96266-6	6	.07

Unit	CMMCo. Part No.	Quantity To Stock	Unit Price
Little Fuse, Inc. Type 3AB, Cat. 314010 10 Amp	2EAC-56M-96266-7	4	.15
Buss Fuse No. BBS-2, 2 Amp	2DJ-60M-664841-5	3	.30
Clutch			
Autotronics Cat. No. MCC-8-4 (Duplex)	3FT-59M-662403-1	1	$ 262.50
Autotronics Cat. No. C-8-9	3FK-59M-662403-4	1	142.50
Relay			
C.P. Clare & Co., Type J	SE-56M-96266-1	1	9.15
C.P. Clare & Co., Type J	SE-56M-96266-4	2	11.20
C.P. Clare & Co., Type J	SE-56M-96266-9	1	7.19
C.P. Clare & Co., Type J	SE-56M-96266-30	1	15.35
C.P. Clare & Co., Type J	SE-56M-96266-31	1	10.05
C.P. Clare & Co., Type J	SE-56M-96266-33	2	12.28
C.P. Clare & Co., Type J	SE-56M-96266-34	1	15.92
Automatic Electric No. PE-1180-B11	SE-56M-96266-46	1	12.15
Automatic Electric Type EQA, Form C	182241-1	1	5.31
Automatic Electric Type EQA, Form C	182241-2	1	7.12
Automatic Electric Type EQA, Form C	182241-3	2	10.98
Automatic Electric Type EQA, Form C	182241-4	4	9.15
Automatic Electric Type EQA, Form C	182241-11	1	9.38
Automatic Electric Type EQA, Form C	182241-13	2	10.32
Automatic Electric Type E, Form C	182241-17	1	12.24
Automatic Electric Type E, Form C	182241-18	4	13.02

Unit	CMMCo. Part No.	Quantity To Stock	Unit Price
Automatic Electric Type EQA, Form AX-B	182242-3	2	9.68
Automatic Electric Type EQA, Form AX-B	182242-13	1	12.25
Automatic Electric Type BQA, Form C	182244-3	1	10.83
Automatic Electric Type BFA, Form C	182244-14	1	11.40
Automatic Electric Type BFA, Form C	182244-15	2	11.85
Automatic Electric Type BFA, Form C	182244-17	2	13.32
Rotary Stepping Switch			
Automatic Electric, Type 44	DZ-56M-96266-4	2	26.60
Automatic Electric, Type 44	DZ-56M-96266-14	2	39.15
Automatic Electric, Type 44	DZ-56M-96266-15	5	31.70
Automatic Electric, Type 45	EP-56M-96266-2	2	67.70
Of-Normal Spring Combination Automatic Electric PP-2897-5		1	4.95
Interrupter Automatic Electric PP-2797-7		1	4.95
Rectifier - Diode			
Sylvania (crystal) Type 1N38	2ABD-56M-96266	4	1.85
Sarkes-Tarzian Type S-5017		2	19.50
Texas Instrument Type 1N 1131		2	16.80
Texas Instrument Type 1N 588		2	12.15
Westinghouse Cat. 302-B	2EAF-56M-96266	3	9.75
Sarkes-Tarzian Type M-500	166712-A	4	1.50
Servo Motor - Tachometer			
Diehl Cat. FPE-25L-105-1T (SW)	FAT-58M-99240-B	1	189.00
Diehl Cat. FPE-25L-105-1T (SW)	FAT-58M-99240-A	1	180.00

Unit	CMMCo. Part No.	Quantity To Stock	Unit Price
Potentiometer			
Helipot Div. R10K-CTL5 Dual Gang Model 5703R1K-CT-1K-10K	FH-59M-662403	1	81.00
Helipot Div. Model 7603RS1K	180572	1	63.75
Rotary Switch			
Daven No. 11-BB-10	RAJ-56M-96266	1	9.45
Daven No. 217-BB-4	PK-58M-99240	1	22.50
Daven No. 217-BB-8	PF-58M-99240	1	27.00
Synchro			
Pioneer-Eclipse Cat. No. AY-2025-57B	162947-C	3	65.00
Linear Induction Potentiometer			
Diehl No. 23P1-2	180594	1	675.00
Rotary Solenoid			
Ledex No. BD65-R-25-28-X3-X9-X4		1	10.50
Electronic Tubes			
6201	12AT7	8	4.50
5751	12AX7	6	4.50
6005	6AQ5	4	5.95
5727	2D21	10	1.95
6135	6C4	2	3.60
6913	12BH7	4	2.50
6550		4	7.50
6136	6AU6	4	4.20
5881	6L6	5	5.25
5814-A	12AU7	2	5.00
6073	OA2	2	4.50
5749	6BA6 W	4	3.30

Item	CMMCo. Part No.	Quantity To Stock	Unit Price
6072	12AY7	2	$ 5.85
	12B4	4	2.25
		TOTAL	$5,456.12

7.2.5 Extra or Optional Features

Mirror image and zero shift - $2,620.00
Cutter compensation - $3,500.00

7.3 COMPARISONS

The following prices are for comparable equipment of the same type, size, and capabilities as the retrofitted machine.

7.3.1 Price of Comparable Standard Tool

7.3.1.1 Conventional machine with manual controls. No provisions for later conversion to numerical control. Price - $82,000.00

7.3.1.2 Manual control machine arranged to accept numerical control at a later date. Includes motors and controls with hand telephase control, ball screw and nut drive. Price - $152,000.00.

7.3.2 Price of Comparable Numerically Controlled Machine Tool

7.3.2.1 Numerical controls for machine listed in 7.3.1.2. This price includes only the card reader and the interpolation functions since the mechanical provisions are included in 7.3.1.2. Price - $38,000.00

7.3.3 Tracer Conversion

This includes complete equipment for 3 dimensional tracer control applied to the basic machine listed in 7.3.1.1. Price - $24,000.00

8.0 other information

OTHER INFORMATION

The retrofit machine has been operating for approximately seven months. During that time considerable trouble has been experienced with the control system. Cincinnati Milling Machine Company has cooperated fully in attempting to resolve the trouble. The following list contains items replaced by Cincinnati:

1. 2 axis position analog unit coupling failed on several occasions. This coupling was replaced by a solid coupling which has eliminated the problem.
2. Diodes failed due to high peak voltage and cabinet heat. Replacement was made and resistors added to reduce peak voltage values.
3. Second stage interpolator switching replaced with improved design.
4. Second stage interpolator cam switching changed to commutator type.
5. Constant voltage transformer added to aid voltage regulation.
6. Three hundred volt disconnect added to reduce burning of resistors and relays.
7. X and Y stepper switches in first stage interpolator replaced.
8. Stepping switches in stores replaced due to baked on dirt.
9. Air conditioning installed in control cabinet to reduce and maintain temperature. Temperature before installation was 130° F.
10. Electric pacer clutches replaced (Y axis).
11. Mechanical linkage in card reader replaced.
12. Triggering solenoid in card reader replaced.
13. Second stage interpolator relay panel replaced due to arcing of switches.
14. Dust cover installed over all stepping switches.
15. One KVA transformer installed to operate air conditioning.
16. Heavy duty relays, connected in parallel, installed on relay panel for triggering card reader solenoid.

There has been remarkably little trouble with the basic machine or with the compatibility of the controls and the basic machine. Even though considerable down time has been experienced, it is our opinion that equal trouble would have been experienced with a new machine. For this reason the retrofit machine is technically practicable.

Economically this particular retrofit shows a savings of 33%. Quoted price for repeat orders, of identical machines, reduces possible savings to 11%. It is in this area that retrofitting must be carefully considered. Factors such as work that the machine is presently performing, down time during retrofitting and the loss of present capabilities after conversion will affect the desirability of retrofitting.

An apparent reluctance exists on the part of machine tool manufacturers to retrofit machine tools. The machine manufacturer is the best source for retrofitting, particularly when extensive rebuilding is required. A careful analysis of quoted repeat retrofit costs should be made to determine if this cost actually represents a true comparative value or an attempt on the part of the machine tool builder to discourage retrofitting.

Machine tools manufactured to numerical control standards will undoubtedly offer a more attractive economic approach to retrofitting, since major rebuilding of the basic machine would not be required. The machine retrofitted on this project represents the maximum amount of rebuild effort on an acceptable basic machine. As the basic machine condition improves, a like improvement can be expected in the anticipated savings.

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