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Bendix

Kansas City
Division

UC-38

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Technical Communications

Bendix

Kansas City Division

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Approved by:

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D/800

THE BENDIX CORPORATION
KANSAS CITY DIVISION
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ABSTRACTS

INVESTMENT CASTING TO ENHANCE PRODUCIBILITY--A CASE STUDY

Effectively applying the ancient art of investment casting to AEC production can open the door to improved product integrity and potential cost savings. This report describes a case in fact, where the investment casting process was successfully applied as a production method, replacing a formed sheet-metal welded assembly. The casting approach not only sharply improved the probability of insuring conformance with required design limitations, but also resulted in substantial program cost savings. When the geometry of a required metal product indicates potential fabrication problems or excessive machining cost, the investment casting approach may be the means to a successful product.

DEEP DRAWN STAINLESS STEEL CONTAINER

Development of a process to produce a deep-drawn stainless steel container to tolerances approaching those required of machined parts has enhanced metal forming capabilities at Bendix. Determination of the final process depended upon elimination of as-drawn wrinkles. A special material study resulted in an acceptable annealing cycle, a requirement for maximum grain size in the raw stock, and a new material specification. A new metal forming concept and a special shaped hydroforming diaphragm resulted from the metal forming investigations.

LONGITUDINAL AND SPIRAL MILLING ON A GISHOLT CENTER DRIVE LATHE

A design requirement for internal longitudinal and spiral milling of cable grooves in a long aluminum case could not be met with available milling equipment. While internal milling with a right angle head is a common practice in most machine shops, the length of this part and low production lead time required development of the unusual, low cost process described in this report.

DESIGN EVALUATION OF INSULATOR PIN

The ability of a metal and plastic switching pin to withstand an operational shock in excess of one million g's was significantly improved through configuration change and change of the insulating material from nylon to polycarbonate. An extensive test program was required to determine the magnitude of shock imparted to the pin by an explosive motor, followed by evaluation of a number of material/configuration combinations to select the most suitable option.

INVESTMENT CASTING TO ENHANCE PRODUCIBILITY - A CASE STUDY

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SUMMARY

In the early component development phase of a program, a product design was released which defined a structural component made from 0.032 stainless steel sheet metal, formed into a cylindrical shell, with three pierced rectangular holes, and three mounting pads welded in position. This assembly required secondary machining operations to produce the functional tolerances required. During initial development it became apparent that the required precision machining of this sheet-metal weldment would present a producibility problem resulting in excessive end product cost.

The design requirements were reviewed by Bendix Mechanical Product Engineering, and it was decided to consider this product for a Casting Feasibility Study.

Four major questions required careful consideration.

- Could a casting reliably offer the functional strength required?
- Could a 17-4 PH corrosion-resistant steel casting be produced which would remain stable during and after considerable removal of material?
- Would the density of cast 17-4 PH steel be sufficient to retain the required pressure for sustained periods?
- Would the end product weight be increased by the use of a casting?

The feasibility study results indicated a potential program savings of approximately $800,000 with effective application of the investment casting approach.

After a casting design was completed, a development order was released for procurement of a small lot of castings for testing and evaluation.

The first castings received were subjected to a thorough dimensional and metallurgical examination and then finish-machined to the final product design requirements. The finished units were again dimensionally inspected to verify the predicted dimensional stability, after removal of approximately 60 percent of the original casting mass. Results indicated slight tolerance variation, ascribed mostly to residual stresses induced during the casting straightening process. Machined sample castings were also subjected to contolled laboratory pressure and strength tests, and found to be acceptable.

At this time all the testing and evaluation results were reviewed and it was concluded the investment casting approach would indeed be the most advantageous approach to mass production of this specific product. An all out

effort, directed at further refinement of the casting process, was authorized and production quantities were ordered to support current production requirements.

To date, more than 1000 investment castings have been procured, which are being successfully machined and electron-beam welded into the next assembly.

The basic reason for this successful result was the manner in which the casting concept was guided through a precise controlled development phase. Close coordination between the Design Agency, Bendix, and the Investment Casting Industry was extremely essential to such success.

DISCUSSION

INTRODUCTION

The primary purpose in applying current casting technology, in this case, was to achieve the most advantageous design consistent with the stringent system requirements.

The benefits possible from application of castings as a means for arriving at a functional end product had not been fully explored. It was felt that the subject component, (Case Section, Rear) would be a prime candidate to show the potential of the investment casting approach as related to the AEC Weapons Program.

PRIOR WORK

Bendix first became heavily involved in the use of investment castings with the advent of the program. Because of inexperience with the benefits and limitations of the process, it was necessary to procure development and production castings simultaneously. Experience gained by Bendix in this program has led to a much improved sequence of developing investment casting as a method of product fabrication.

Up to this time, activity involving castings at Bendix had for the most part been limited to the other fields of casting, such as sand, permanent mold, or die casting. All of these have their specific place in supporting metal product needs, but the investment casting process appears to offer broader advantages with respect to certain precision product design requirements.

ACCOMPLISHMENTS

During the development phase of the rear, case section, techniques were established that may be of considerable use in establishing future cast products.

The original casting design was based on strict functional product requirements, with only minimal consideration given to the casting producer. This design was then subjected to a very detailed review between Bendix and the potential casting foundries. Every feature was discussed from standpoints of:

- Castability with respect to finish tolerance required;
- Repeatability of casting; and

- Type of casting tooling required based on probable total castings to be produced.

From answers obtained and action taken as a result of these discussions, many potential problems which in the past had not been discovered until well into production of the castings were avoided.

In the early casting fabrication process development, it was discovered that precise controls applied at the following operations sharply improved dimensional consistency:

- Wax pattern injection. Secondary fixturing for controlled post curing of the wax patterns (restraining fixtures).
- Hot straightening steel casting. Controlled development of: Casting temperature and soak time required, time cycle from oven to straightening fixture, and pressure (tonnage) applied to move metal to desired position in relation to time cycle within straightening fixture.

An investment casting which replaced a formed sheet metal welded assembly was designed, developed, procured, and finish-machined. This casting achieved the end product design requirements with improved producibility and sharply reduced end product cost.

ACTIVITY

The sheet metal welded assembly design was the starting point from which the investment casting concept evolved. Early development attempts indicated several problems would need to be solved before Bendix production commitments could be satisfied.

- The sheet metal drawing and piercing operations were yielding units with elongated connector holes and excessive variation in the close tolerances required (Figure 1).
- The welding of the three mounting pads in position caused excessive dimensional variations in the 0.030 thick sheet metal structure (Figure 2).
- It was extremely difficult to locate and control the sheet metal structure during required secondary precision machining operations because of its flexibility.

Successful solutions to these problems inevitably involve the investment of a great deal of machine time and probable high scrap rates, which in turn would lead to high end product cost.

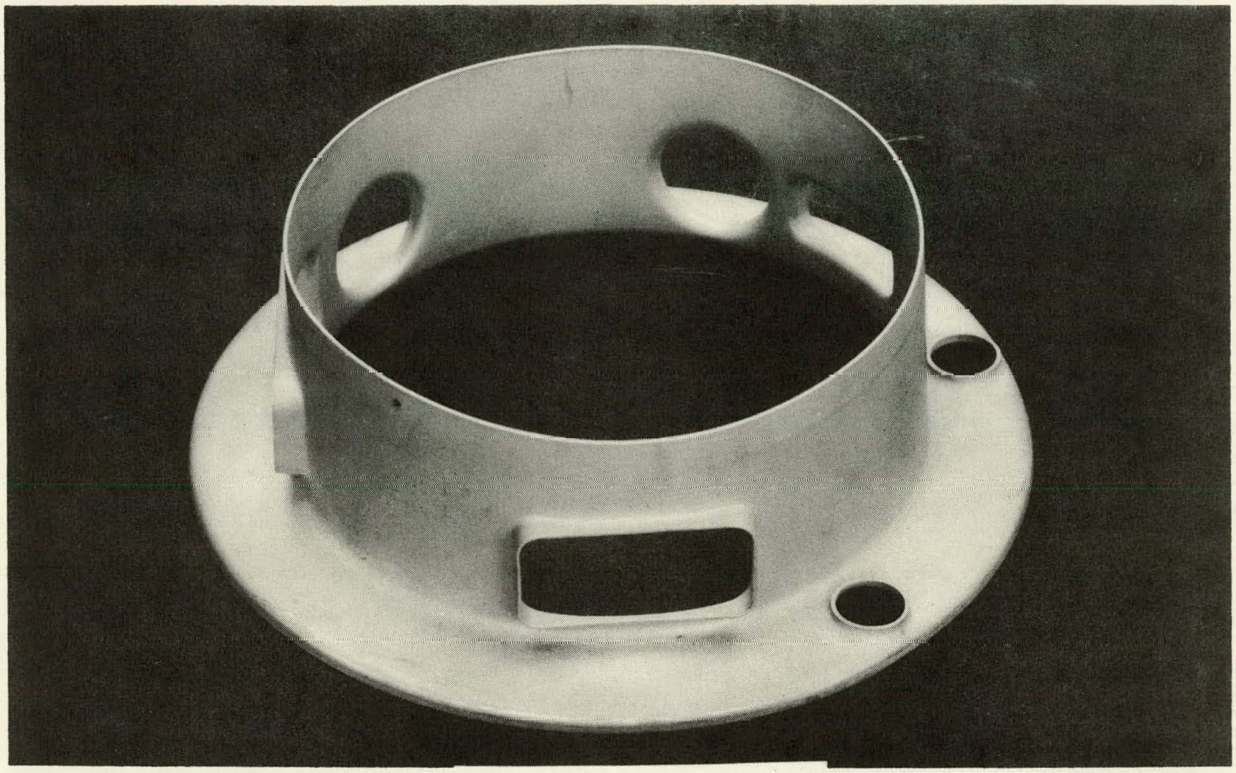

Figure 1. Formed Sheet Metal Aft Section

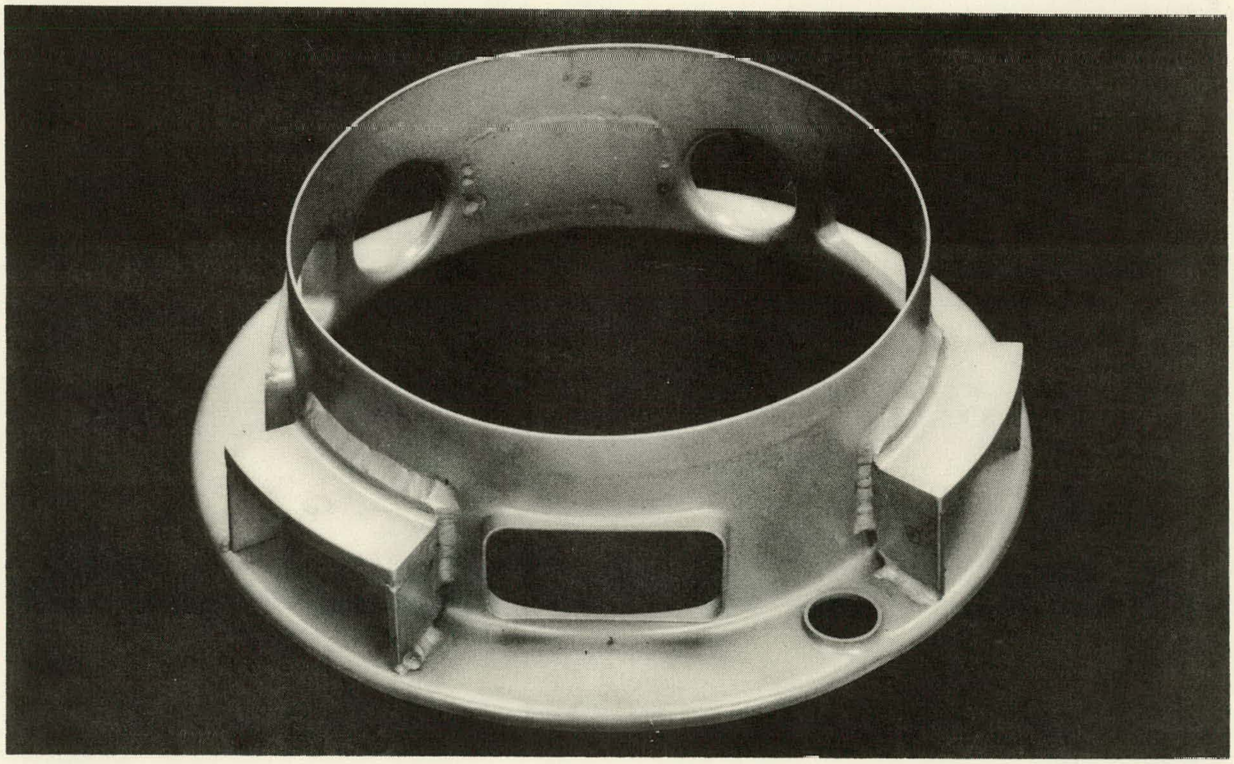

Figure 2. Formed Sheet Metal Welded Assembly

In the analysis of the pending problems and possible solutions, it became apparent that an investment casting (Appendix A-1 and A-2) would perhaps provide the answer, not only as a means of improving the producibility, but doing so at less end product cost. An investment casting design was prepared by Bendix (Appendix B-1) and several suppliers were contacted concerning castability and cost. This casting would be produced using 17-4 PH corrosion resistant steel, which was felt to be machinable into the final product configuration. The design concept was aimed at yielding a finished component with a constant 0.030 inch minimum wall thickness, needed for optimum electron-beam welding characteristics, without compromising the strength required. The casting concept was then subjected to the Casting Feasibility Study (Appendix D) for comparison in cost between the casting and fabrication from raw stock (sheet metal, bar stock). The report resulting from this study, plus the casting design, was submitted to the Design Agency (Sandia Corporation, Albuquerque) for consideration.

There was some question as to whether or not a casting would completely satisfy four major functional requirements:

- End product strength,
- Dimensional stability after machining,
- Ability to retain pressure for sustained periods, and
- Limited end product weight.

These questions could only be answered by subjecting actual castings to controlled testing and evaluation. The Design Agency agreed that the proposal warranted further investigation, and authorized Bendix to procure several development castings.

A development order was placed with United Casting Company, Van Nuys, California, and tooling was started. The material (17-4 PH corrosion-resistant steel) was selected for the following specific reasons:

- The strength and corrosion resistance features possible with simple heat treatment.
- Its ability to remain relatively stable during and after secondary machining, and
- Its high-fluidity rating which was necessary to fill thin sections and insure casting soundness.

Because of the complex external configuration of the finished product, it was necessary that any secondary machining (to size) be limited to the internal surfaces of the rectangular ports, flat surfaces, and the major ID. Only by this approach could there be any hope for success in maintaining stability and minimizing labor and tooling costs for machining.

All of the first castings produced to the original design (Figure 3) were subjected to dimensional and metallurgical examination (layout inspection, tensile testing, and X ray). The castings were then completed and subjected to the following:

- The machined castings were weighed. The representative weight was 202 grams. The comparable finished sheet metal welded assembly weighed 197 grams..

- Two machined castings were subjected to a controlled leak rate test. All ports and openings were sealed, a vacuum of approximately 1.6×10^{-5} mm Hg applied to the inside, and 75 psi differential (+ 10 percent - 15 percent) pressure applied to the outside. The results indicated less than 21.5×10^{-8} cc/sec leakage. This was considered to be well within the design requirements.

- Units were subjected to electron beam welding, which yielded acceptable results.

- Two units were welded into finished assemblies (MC2429) and shipped to Sandia Corporation for environmental testing, including shock vibration and containment.

The castings passed all testing successfully. The containment test indicated that the cast features were structurally balanced.

Based on the favorable results in development, it was decided to incorporate the casting into the production definition.

The basic problem in the casting development was to achieve the "as cast" dimensional consistency required to insure repeatability of the finish-machined product. In order to solve the problem, a concentrated effort was directed at refining the two basic areas in the casting process which directly effect dimensional stability: Wax pattern mold and hot straightening of the semi-finished castings.

- The wax pattern mold was reworked to yield patterns with less dimensional variation.

- Fixtures were produced for use in controlling the degree of wax pattern shrinkage during the curing cycle.

- The hot-straightening fixture was reworked and a precise straightening process was developed to ensure dimensional repeatability.

During the casting evolution process, unexpected problems concerning component assembly and welding operations on the final assembly became apparent which required four major design changes (Figure 4):

1. Flange Configuration Change. The original machined casting configuration provided a lip on the major diameter of the flange portion of the unit that fitted into the container at final assembly. The container edge was then lap welded to the flange around the circumference of the interface. This forward turned lip resulted in welding adjacent to internal components. The possibility of resulting heat damage was eliminated by turning the lip in the opposite direction.

   The angle of the flange was also changed from a tapered configuration to a perpendicular configuration to reduce the overall length of the final assembly. The connector window locations were also changed at this time to bring them closer to the flange to further reduce the overall length.

2. Mounting Pad Configuration Change. Environmental tests on the final assembly indicated a need for additional strength within the machined casting in the areas of the three mounting pads. Additional material was added to the pad surface. The diametrical locator features of the final assembly were extended to increase contact area by extending the boss on the casting. The mounting pad area was also stiffened by increasing the fillet radii within the space under the mounting pads.

3. Connector Size Change. When the desired connectors for the finished assembly became available, the casting was changed to accept their larger size. These connectors were larger than the substitutes used on the early development units. The casting was changed to add more material on the outside surfaces of the connector areas to assure that a minimum wall remained around each connector after finish machining of the casting.

4. Major Diameter Change. The printed wire harnesses used within the final assembly were replaced with conventional wire of greater cross section. The major diameter of the flange on the casting was increased to provide more space internally to accept the larger wire. Simultaneously, one of the connector bosses in the flange was relocated to provide additional clearance within the assembly.

These changes significantly complicated the casting fabrication to the extent it was necessary to scrap the original wax pattern mold and fabricate a much more complex mold. This new mold (Figure 5) consisted of 26 separate parts, whereas the original mold (Figure 6) consisted of 10 parts.

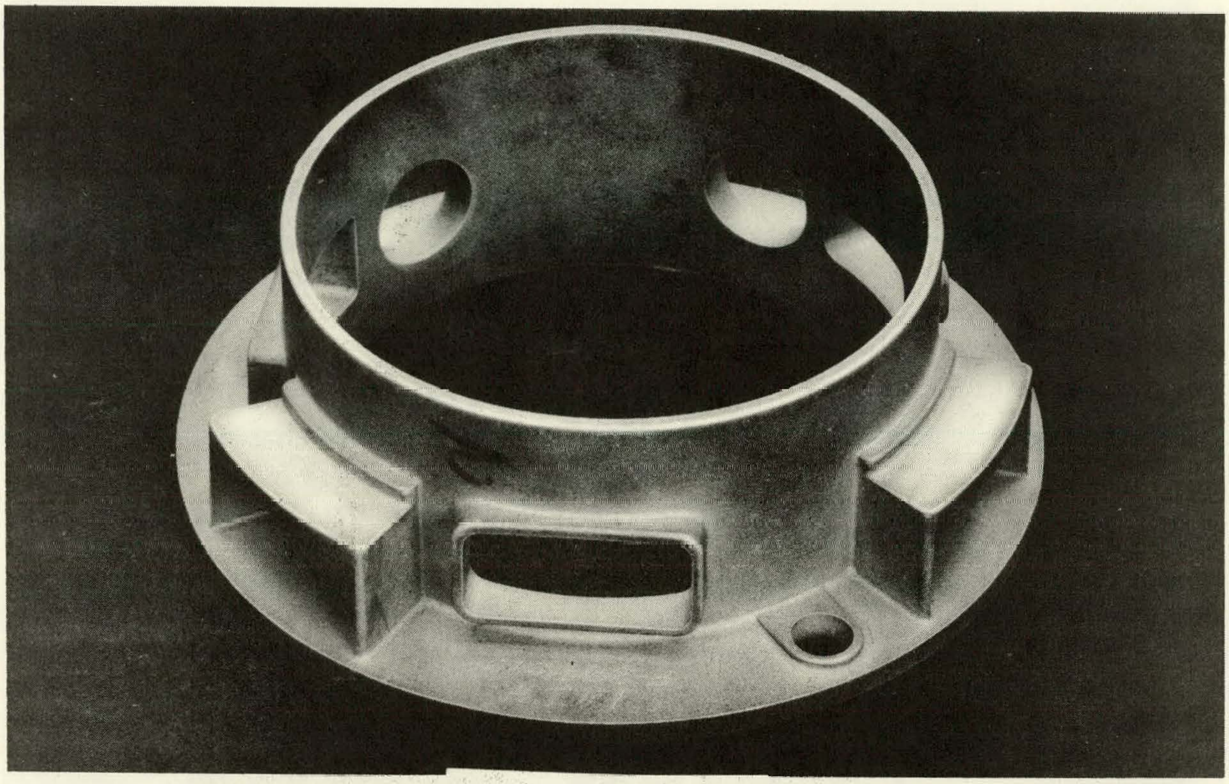

Figure 3. Original Aft Section Casting

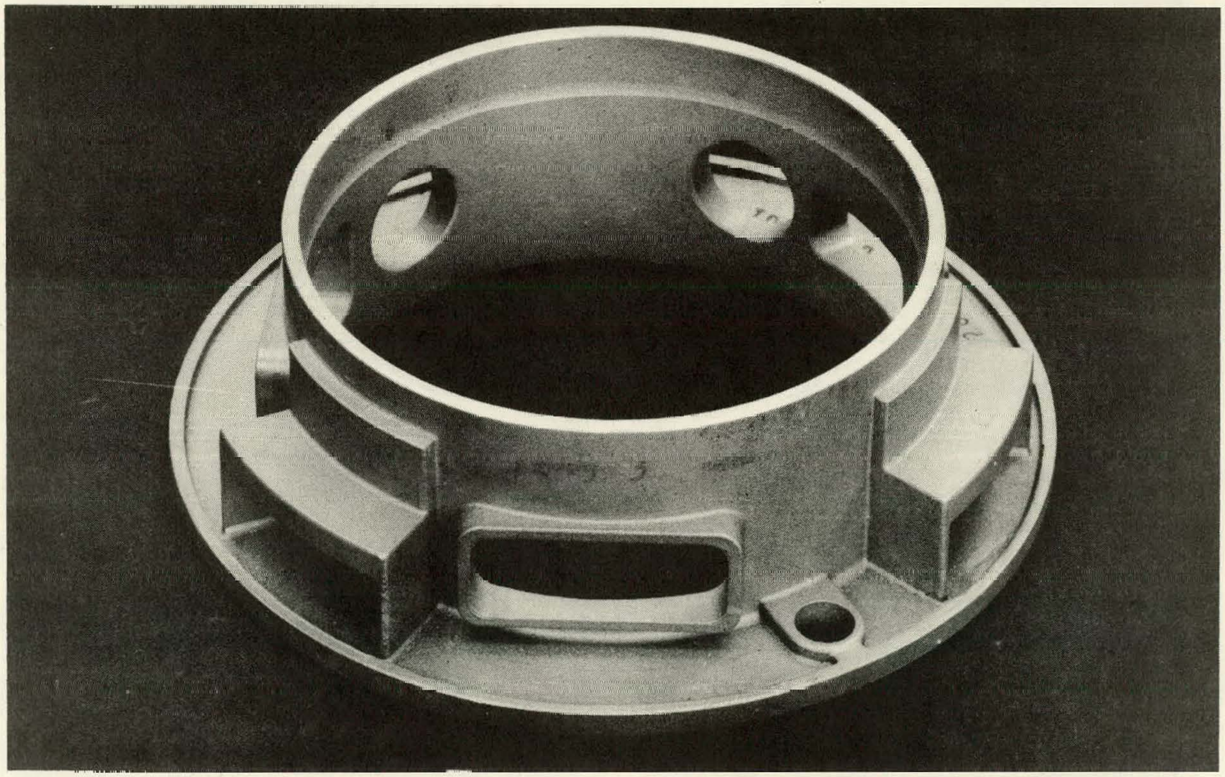

Figure 4. Final Design Aft Section Casting

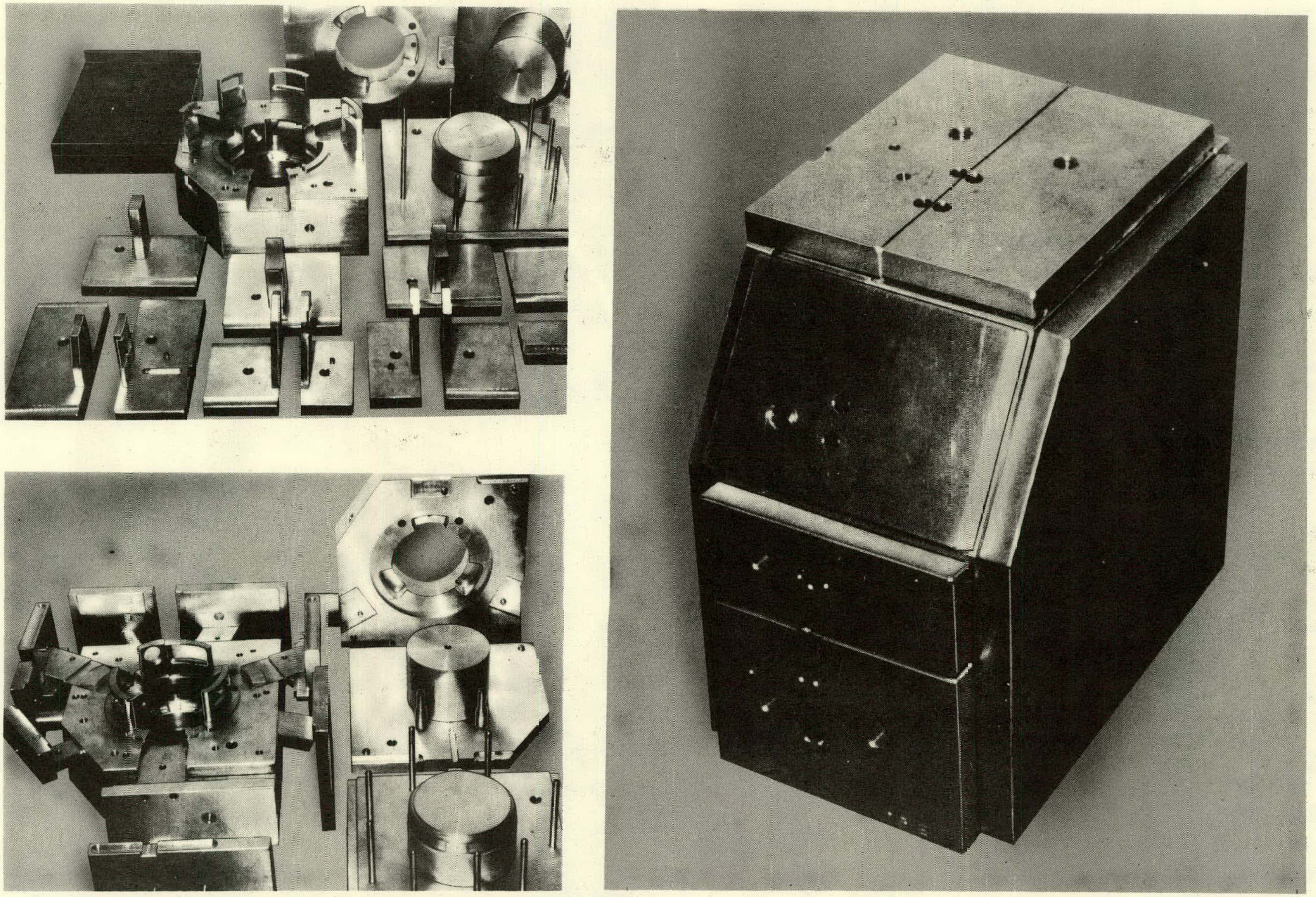

Figure 5. Wax Pattern Mold for Final Design Casting

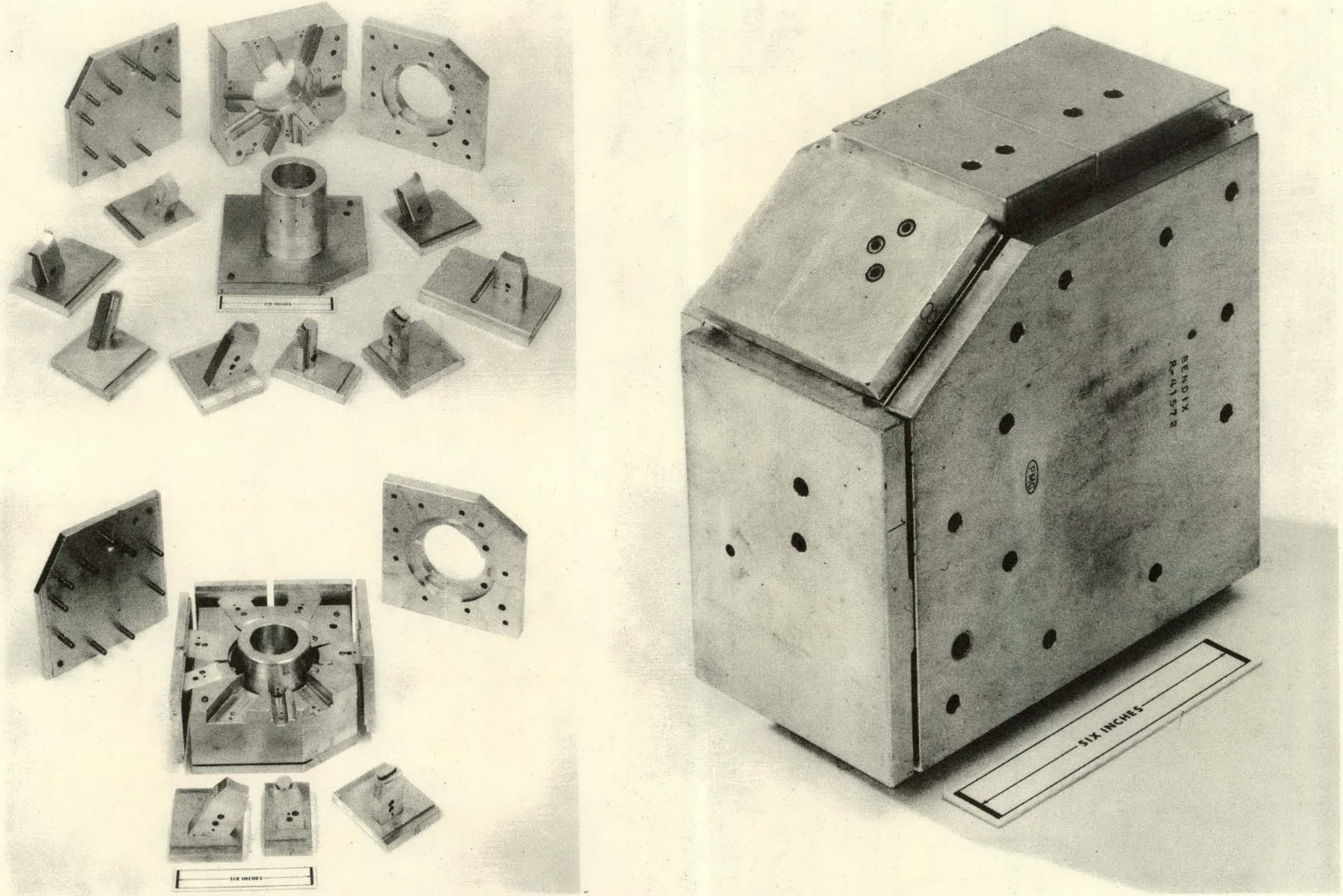

Figure 6. Wax Pattern Mold for Original Design Casting

The new pattern mold was constructed and sample castings produced. The foundry was able to apply some of the knowledge gained in producing the original mold to fabrication of the new mold, thereby eliminating some past problem areas. However, it was still necessary to go through a prove-in and refining cycle in order to assure the needed dimensional repeatability.

When confidence was achieved in the ability of the foundry to produce castings to the current design definition, (Appendix B-2, B-3, and C) procurement of six Foundry Control Samples was authorized. These are units produced by a specific foundry for the purpose of formally verifying that foundry's capability of consistently mass producing castings to the current design definition. When the foundry had been granted Foundry Control Approval, the Bendix Purchasing Department was released to proceed with procurement of quality castings as required.

To date, more than 1000 castings have been received at BKC, and have been, or are being, successfully machined (Figure 7) and incorporated into final assemblies.

The evolution from sheet metal welded assembly to finished machined casting is illustrated by Figure 8.

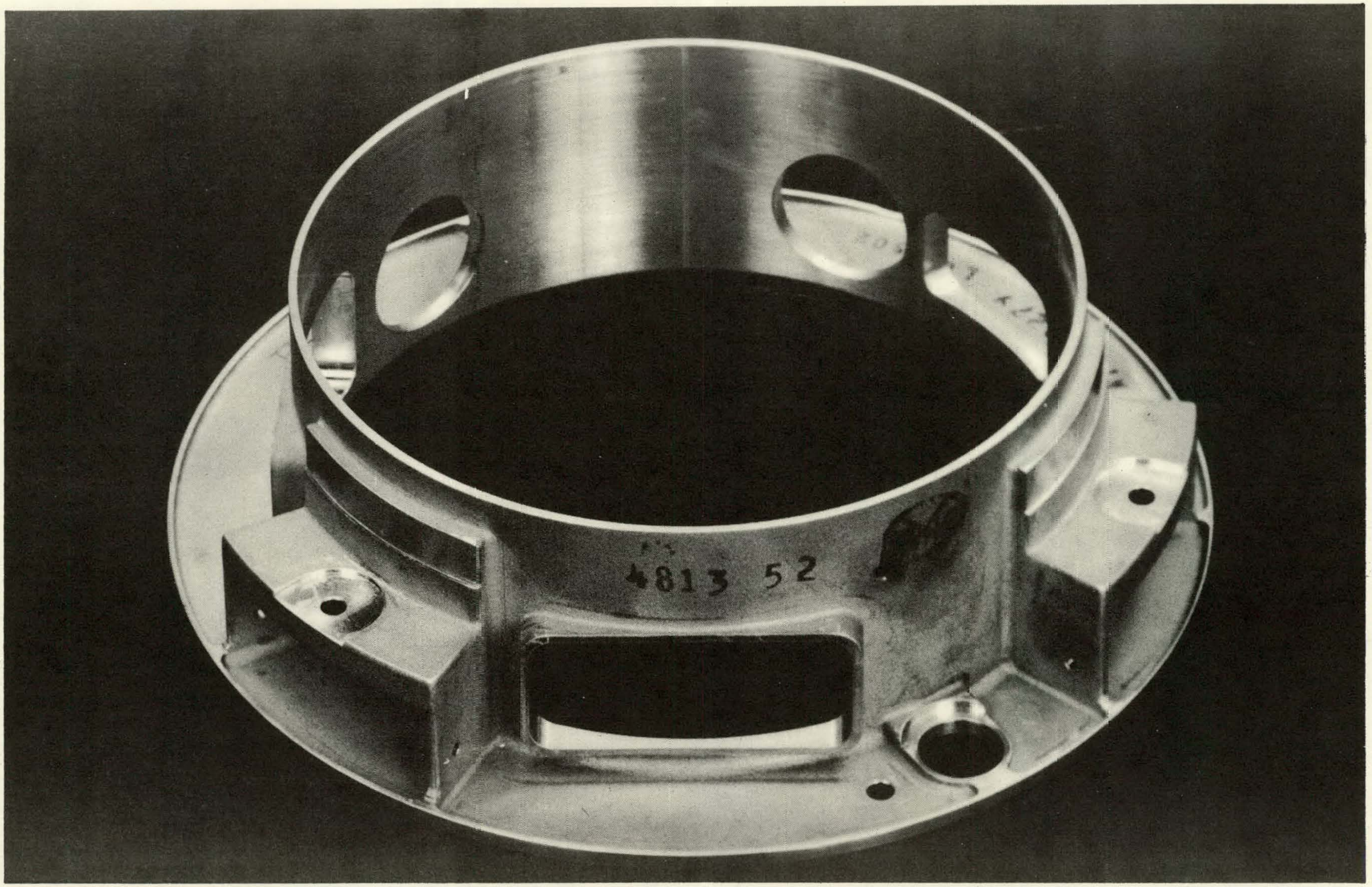

Figure 7. Casting After Final Machining

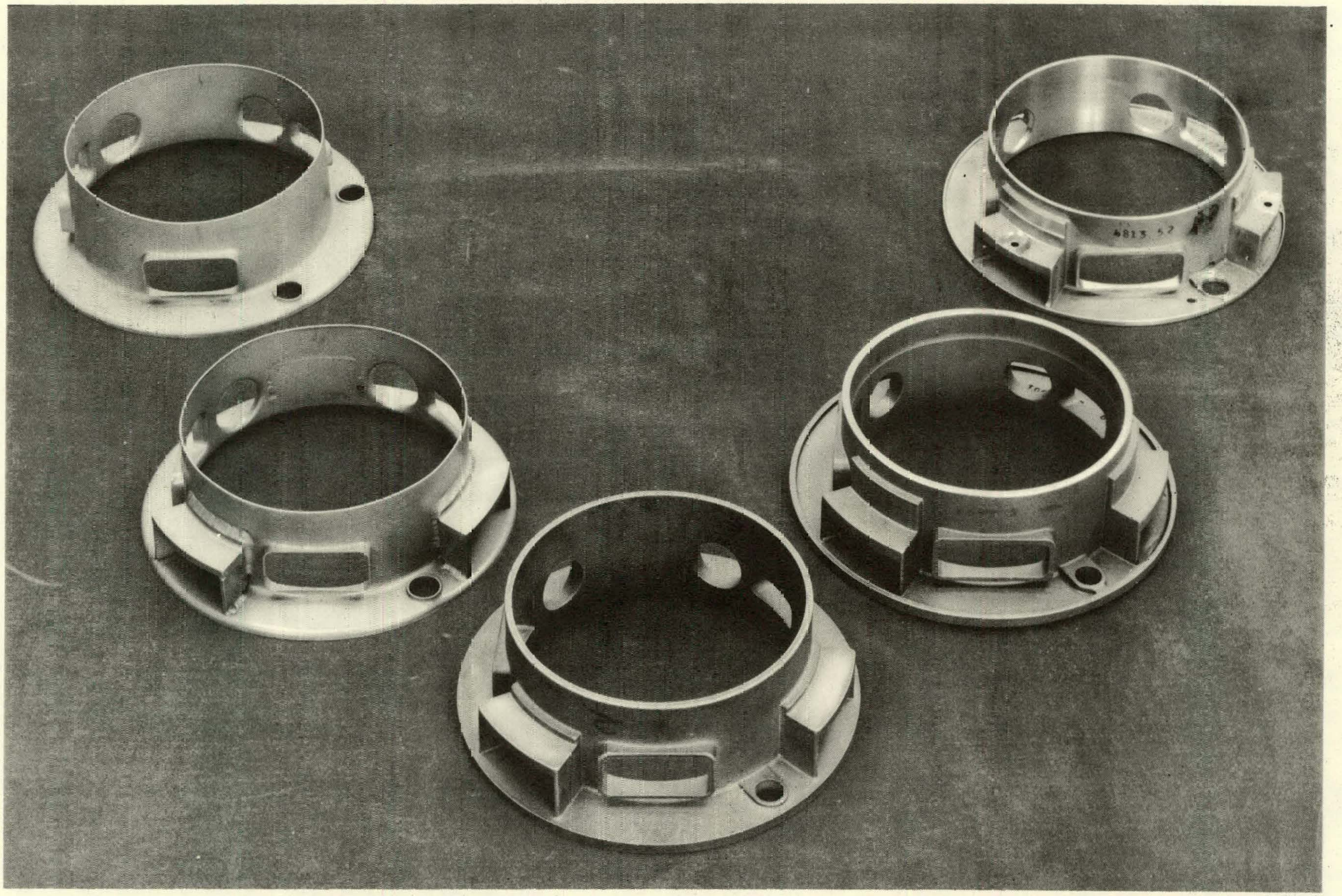

Figure 8. Evolution of Case from Formed Sheet Metal to Machined Casting

REFERENCES

1. Casting, Graded Quality, Specification No. 9921013
2. BKC Management Procedure No. 865
3. Steel, Corrosion Resistant (17-4 PH) Investment Castings, Specification No. 7372174
4. Casting Feasibility Study Plan, (Rev. 3) Nov. 1969.

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APPENDIX A

INVESTMENT CASTING FLOW CHARTS

A-1. Investment Casting Production Techniques
A-2. Casting Flow Time

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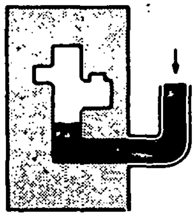
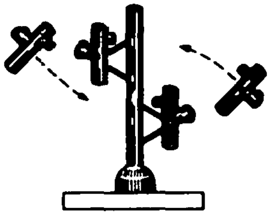
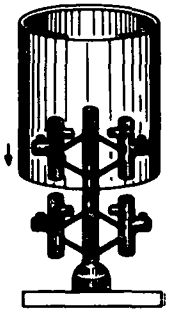
basic production techniques for investment casting



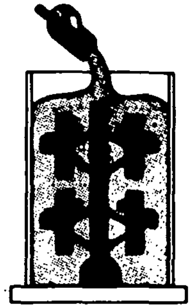
① WAX OF PLASTIC IS INJECTED INTO DIE TO MAKE A PATTERN



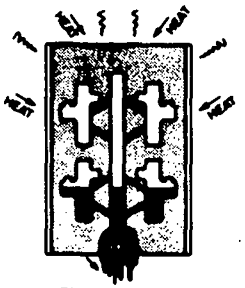
② PATTERNS ARE GATED TO A CENTRAL SPRUE



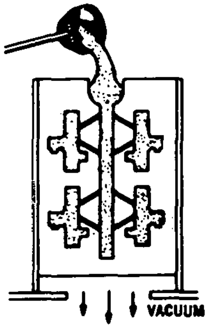
③ A METAL FLASK IS PLACED AROUND THE PATTERN CLUSTER



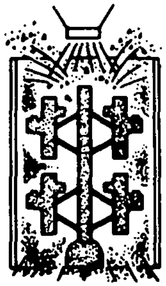
④ FLASK IS FILLED WITH INVESTMENT MOLD SLURRY



⑤ AFTER MOLD MATERIAL HAS SET AND DRIED, PATTERNS ARE MELTED OUT OF MOLD

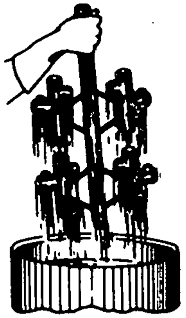


⑥ HOT MOLDS ARE FILLED WITH METAL BY GRAVITY, PRESSURE VACUUM, OR CENTRIFUGAL FORCE



⑦ MOLD MATERIAL IS BROKEN AWAY FROM CASTINGS

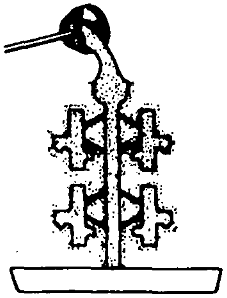
INVESTMENT FLASK CASTING



③ PATTERN CLUSTERS ARE DIPPED IN CERAMIC SLURRY

④ REFRACTORY GRAIN IS SIFTED ONTO COATED PATTERNS. STEPS 3 AND 4 ARE REPEATED SEVERAL TIMES TO OBTAIN DESIRED SHELL THICKNESS

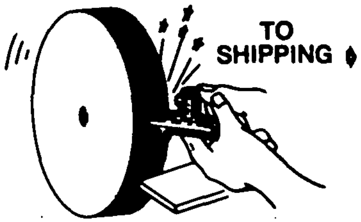
⑤ AFTER MOLD MATERIAL HAS SET AND DRIED PATTERNS ARE MELTED OUT OF MOLD



⑥ HOT MOLDS ARE FILLED WITH METAL BY GRAVITY. PRESSURE. VACUUM UUM, OR CENTRIFUGAL FORCE

⑦ MOLD MATERIAL IS BROKEN AWAY FROM CASTINGS

INVESTMENT SHELL CASTING

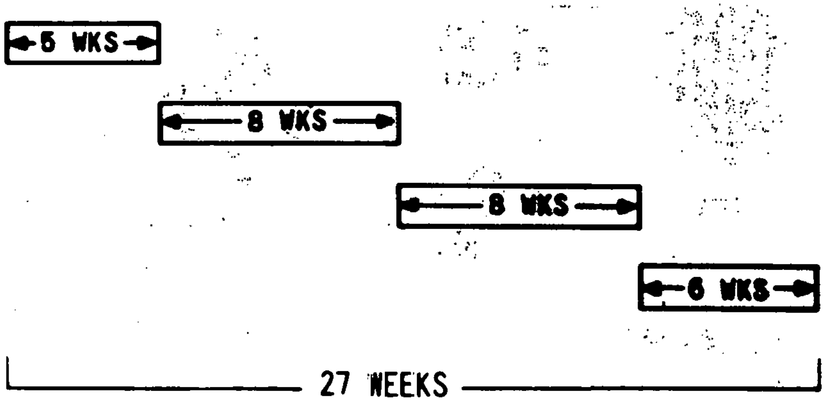


⑧ CASTINGS ARE REMOVED FROM SPRUE, AND GATE STUBS GROUND OFF

CASTING FLOW TIME

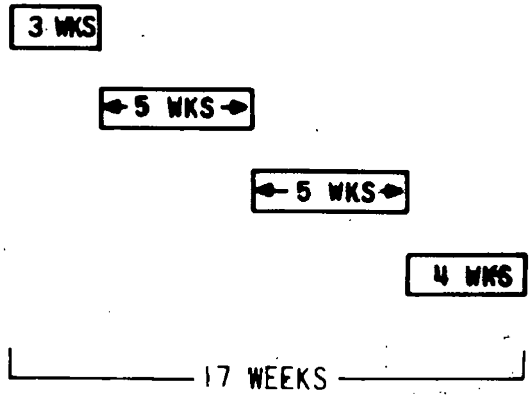
AVERAGE FLOW TIME FOR CASTING INCORP. — NORMAL

PHASE		FUNCTION
I	-	DESIGN DEVELOPMENT
II	-	FABRICATION DEVELOPMENT
III	-	FABRICATION FOUNDRY CONTROL UNITS
IV	-	WR PROCUREMENT



AVERAGE FLOW TIME FOR CASTING INCORP — ACCELERATED

PHASE		FUNCTION
I	-	DESIGN DEVELOPMENT
II	-	FABRICATION DEVELOPMENT
III	-	FABRICATION FOUNDRY CONTROL UNITS
IV	-	WR PROCUREMENT



APPENDIX B

CASE SECTION CASTING DRAWINGS

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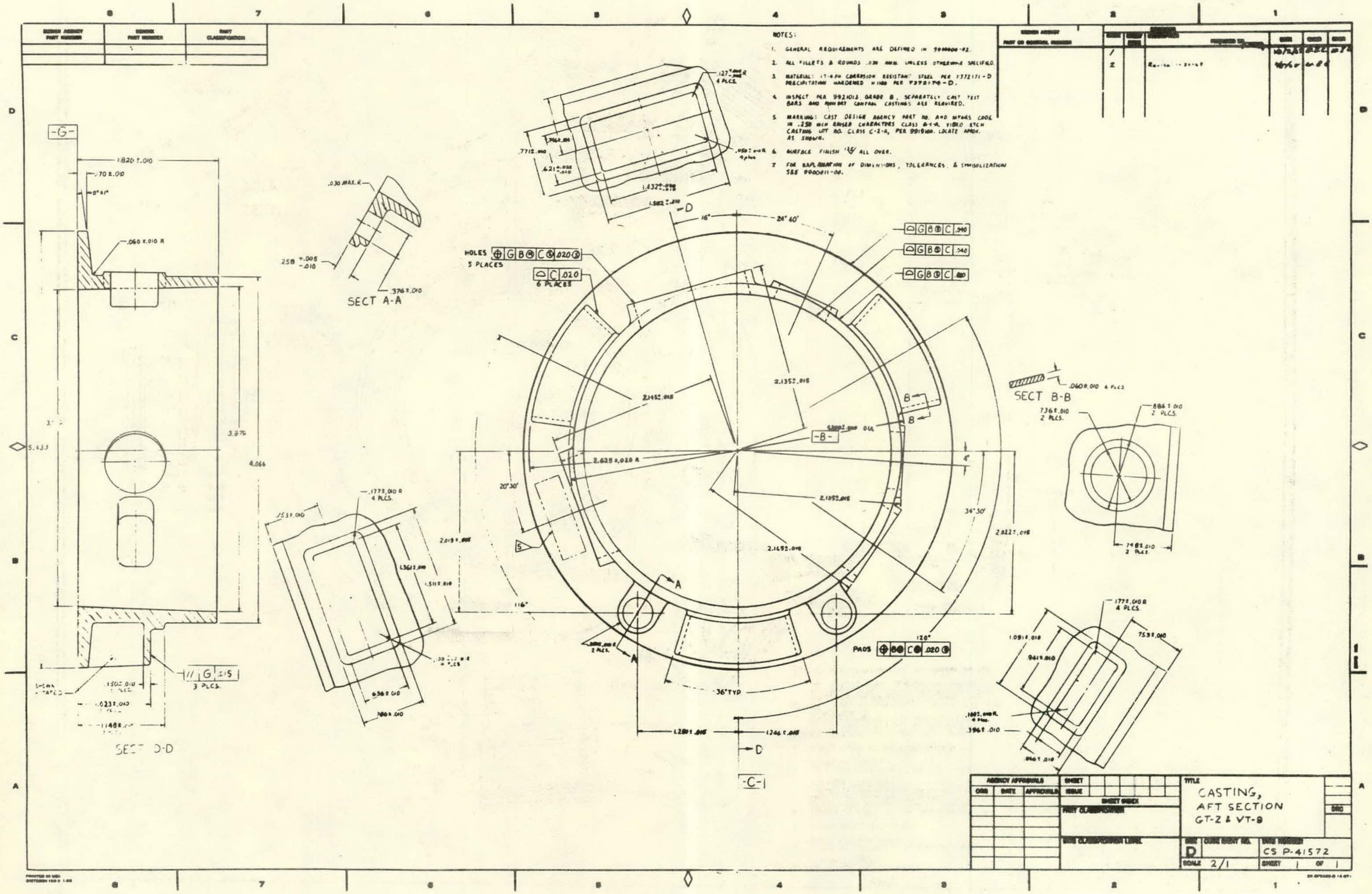


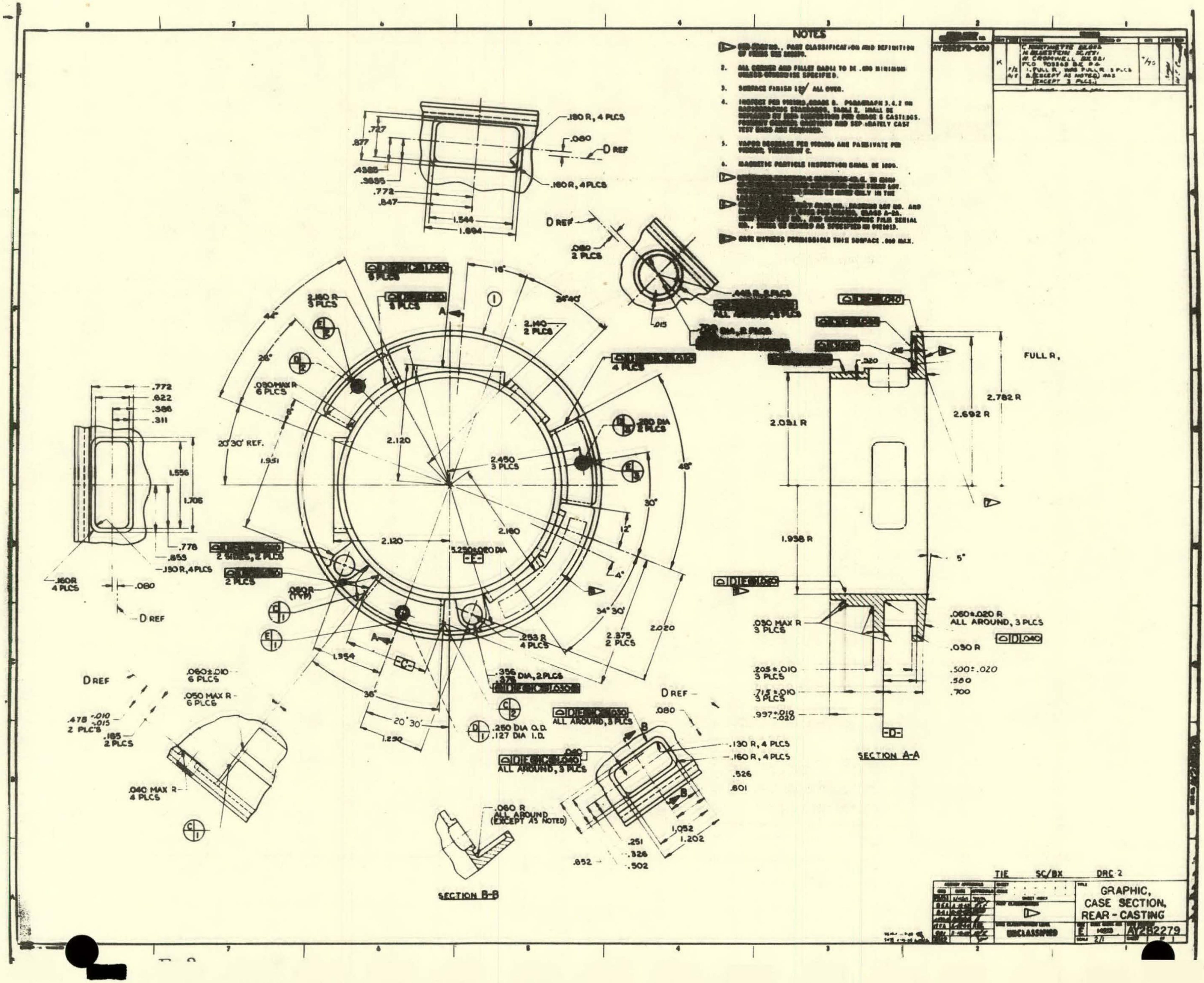
NOTES:

1. GENERAL REQUIREMENTS ARE DEFINED IN 9900000-02.
2. ALL FILLETS & ROUNDS .030 MIN. UNLESS OTHERWISE SPECIFIED.
3. MATERIAL: 17-4PH CORROSION RESISTANT STEEL PER 7372171-D PRECIPITATION HARDENED H1100 PER 7373174-D.
4. INSPECT PER 9921013, GRADE B, SEPARATELY CAST TEST BARS AND FOUNDRY CONTROL CASTINGS ARE REQUIRED.
5. MARKING: CAST DESIGN AGENCY PART NO. AND MFGRS CODE IN .250 INCH RAISED CHARACTERS CLASS 6-1-A. VIBRO ETCH CASTING LOT NO. CLASS C-2-A, PER 9919100. LOCATE APPROX. AS SHOWN.
6. SURFACE FINISH 125√ ALL OVER.
7. FOR EXPLANATION OF DIMENSIONS, TOLERANCES, & SYMBOLIZATION SEE 9900011-00.

1
2 Revision [illegible]

TITLE
CASTING,
AFT SECTION
GT-2 & VT-8

SIZE D
SCALE 2/1
DWG NUMBER CS P-41572
SHEET 1 OF 1



NOTES

1. [illegible] NO., PART CLASSIFICATION AND DEFINITION OF [illegible] SEE [illegible].
2. ALL CORNER AND FILLET RADII TO BE .0[illegible]0 MINIMUM UNLESS OTHERWISE SPECIFIED.
3. SURFACE FINISH 125 ALL OVER.
4. INSPECT PER [illegible], GRADE B. PARAGRAPH 3.4.2 OF RADIOGRAPHIC STANDARDS, TABLE 2, SHALL BE REPLACED BY [illegible] INSPECTION FOR GRADE B CASTINGS. [illegible] CASTINGS AND SEPARATELY CAST TEST BARS ARE REQUIRED.
5. VAPOR DEGREASE PER [illegible] AND PASSIVATE PER [illegible], TREATMENT C.
6. MAGNETIC PARTICLE INSPECTION SHALL BE 100%.
7. [illegible] ONLY IN THE [illegible]
8. [illegible] NO., [illegible] LOT NO. AND [illegible] CLASS A-2A. [illegible] NO., AND RADIOGRAPHIC FILM SERIAL NO., SHALL BE MARKED AS SPECIFIED IN [illegible].
9. GATE WITNESS PERMISSIBLE THIS SURFACE .0[illegible]0 MAX.

AY2B2279-001

K

C. CROMWELL

1. FULL R, WAS FULL R, 2 PLCS

2. (EXCEPT AS NOTED) WAS (EXCEPT 3 PLCS)

TIE SC/BX DRC 2

GRAPHIC,
CASE SECTION,
REAR - CASTING

UNCLASSIFIED

E

AY2B2279

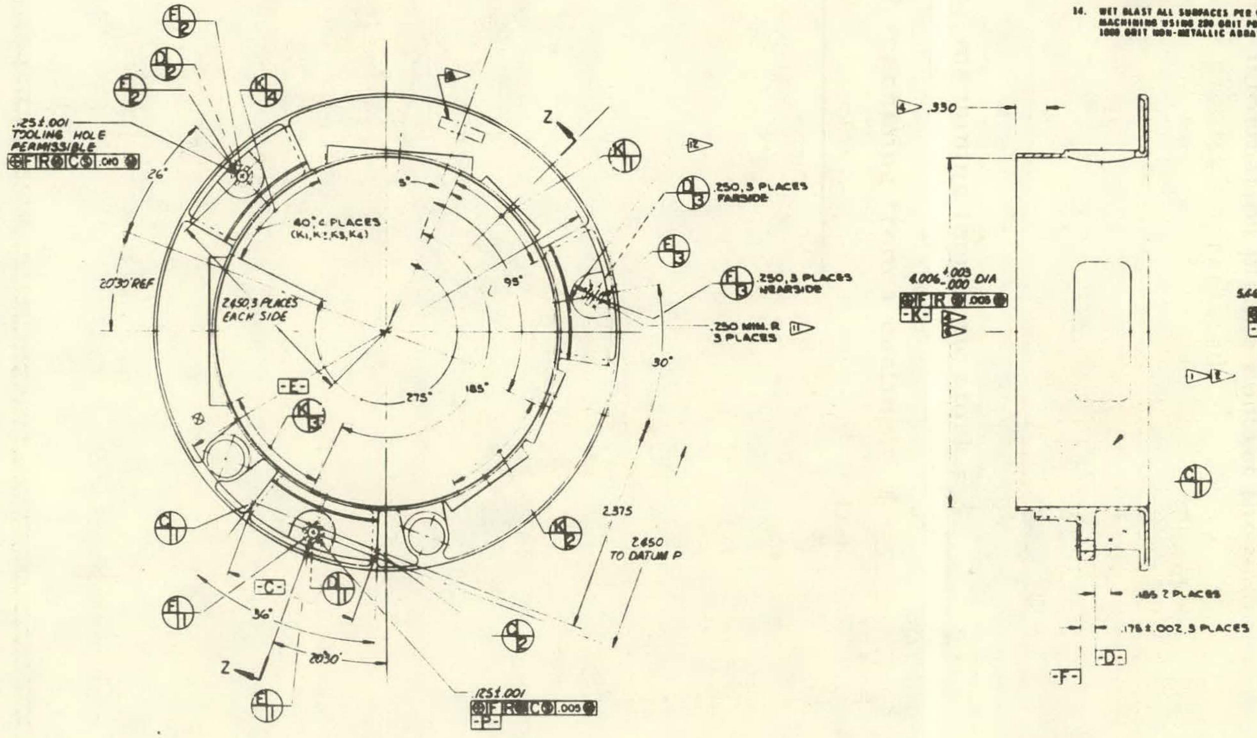
2/1

NOTES

1. FOR PART NUMBER, PART CLASSIFICATION AND DEFINITION OF ITEMS SEE 262264
2. MARK DESIGN AGENCY PART NUMBER PER PART NUMBER TABLE PER 9919100, CLASS A 2, SIZE AND METHOD OPTIONAL. LOCATE APPROXIMATELY AS SHOWN
3. POSITIONAL TOLERANCE SPECIFIED SHALL BE INTERPRETED AS A WIDTH
4. 4.006 $^{+.003}_{-.000}$ DIA APPLIES ONLY IN AREA INDICATED. REMAINING CYLINDER MAY BE 4.010 ± .005 DIA
5. VAPOR DEGREASE PER 9906006 AND PASSIVATE PER 9904301, TREATMENT C
6. DIMENSIONS INDICATED MAY BE INSPECTED IN A RESTRAINED CONDITION
7. INDEPENDENT FEATURE.
8. CONTROL NUMBER MAY BE USE AT THE MANUFACTURER'S OPTION. MARK PER 9919100, CLASS F-1-A, .120 INCH CHARACTERS. LOCATE APPROX. AS SHOWN.
9. PERMISSIBLE CUT .020 MAX DEEP THIS AREA TWO PLACES
11. MAX SIZE AND SHAPE OF DATUM F SURFACE IS OPTIONAL WITHIN SPECIFIED CONTOUR LIMITS
12. MACHINE STEP PERMISSIBLE 3 PLACES.
13. INDICATED WIDTH APPLIES WITHIN .250 MIN. OF ADJACENT SIDES. REMAINDER OF DIMENSION MAY HAVE A TOLERANCE OF +.004/-.000
14. WET BLAST ALL SURFACES PER 9906002 AFTER MACHINING USING 220 GRIT FOLLOWED BY 1000 GRIT NON-METALLIC ABRASIVE

AY282280 005

REV	DESCRIPTION	DATE
H	R WOODLING 007 BX MIDDLETON 1001 R LARISON 00 BX FCO 700835 BX P6 1 DIA CONTROL NO WAS AY282280-004 2 REDEFINED DATUM DIA K AS FOUR SEGMENTS 40° 4 PLCS (K1, K2, K3, K4) LOCATED AT 5°, 95°, 185° & 275° CLOCKWISE RESPECTIVELY FROM ℄ OF DATUM P & ADDED INDICATORS K1, K2, K3 & K4 3 ADDED NEW SHT 2 CONTAINING ALL EXISTING MACHINING DIMS EXCEPT THOSE REQUIRED FOR DATUMS. 4 DELETED ALL NON DATUM DIMS FROM SHEET 1. 5 SHT 1, ADDED NOTE ABOVE TITLE BLOCK. SHT 1 DATUM DIMS SHT 2, GENERAL DIMS FCO 700870 BX P6 B/1 1. 5.462 +.000/-.006 WAS 5.462 +.000/-.008 C/2 2. .175±.002, 3 PLACES WAS .175 3 PLACES 3. .330 WAS .315 4. DELETED CONTOUR DATUM [illegible] FOR SURFACE P 5. DELETED [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] FROM BOTTOM OF FLANGE WAS [illegible] [illegible] .250 ALL AROUND [illegible] 2 PLACES FROM BOTTOM OF FLANGE WAS [illegible] 2 PLACES FROM DATUM P [illegible]	9/70
J	LOSCHER [illegible] H BLUESTEIN [illegible] J LARISON [illegible] FCO [illegible] BX P4 1. ADDED [illegible] 13 2. ADDED [illegible] 13 CALLOUT [illegible] 3. ADDED [illegible] REF [illegible] IN ZONE [illegible]	[illegible]
K	MARTINETTE [illegible] BX H. BLUESTEIN BX [illegible] J R LARISON BX [illegible] FCO 70035[illegible] BX P6 SHT 2 1. INCREASED WIDTH & LENGTH OF RECTANGULAR CUTOUTS BY .001 [illegible] 2. .27 1.000, -.007 [illegible]	9/70
L	H. LOSCHER [illegible] BX/ H BLUESTEIN [illegible] SC/ J. LARISON [illegible] BX FCO 705109 BX P4 C/4 1. MOVED MARKING LOCATION 90° COUNTERCLOCKWISE	10 [illegible]



SHEET 1 DATUM DIMENSIONS
SHEET 2 GENERAL DIMENSIONS

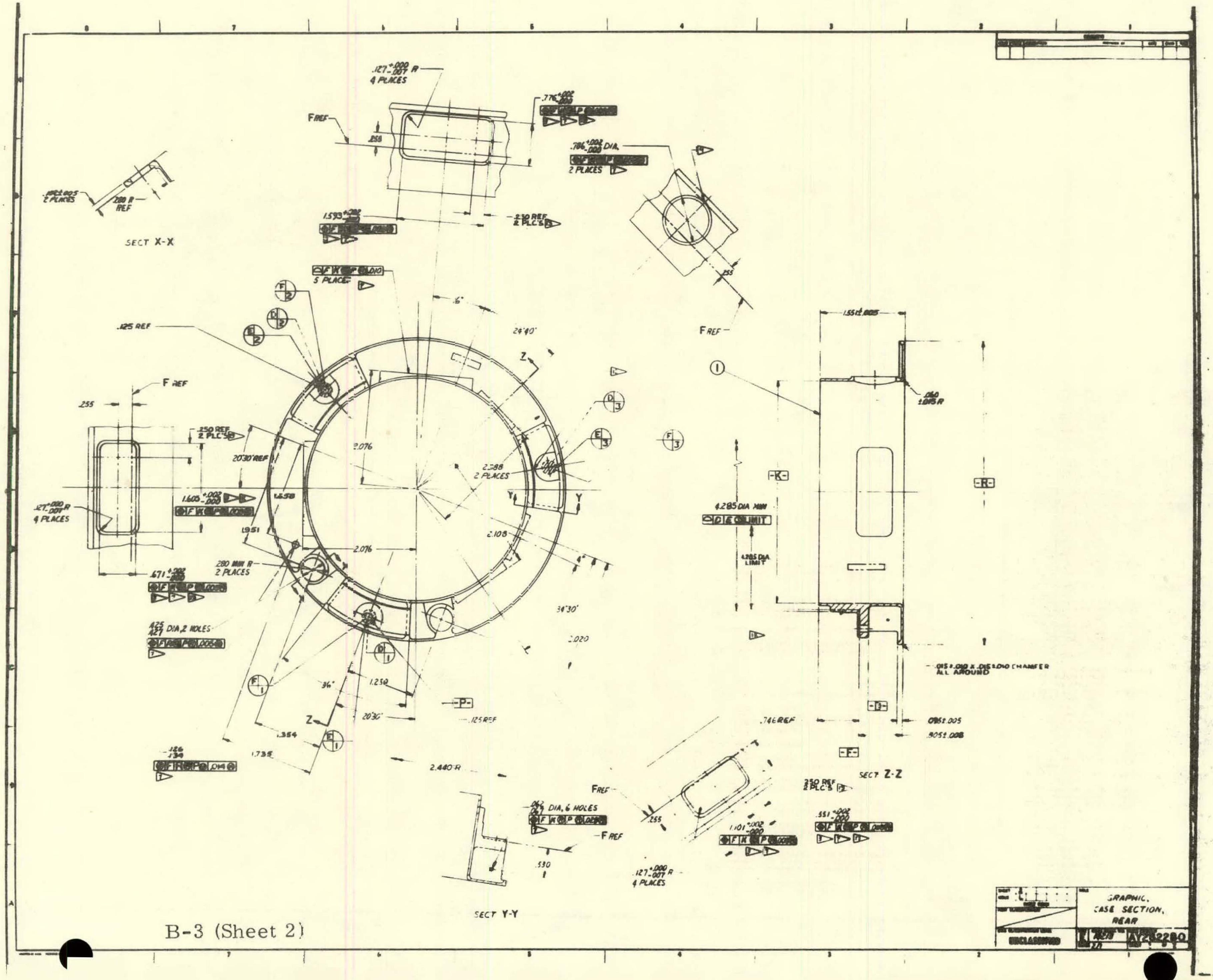
TIE SC/BX DRC 2

GRAPHIC,
CASE SECTION,
REAR

UNCLASSIFIED

AY282280

B-3 (Sheet 1)


SECT X-X
SECT Y-Y
SECT Z-Z
F REF
.127 +.000 -.007 R 4 PLACES
.776 +.002 -.000
.784 +.002 -.000 DIA. 2 PLACES
1.593 +.002 -.000
.250 REF 2 PLC'S
.255
.125 REF
24°40'
2.076
2.388 2 PLACES
2.108
20°30' REF
1.600 +.002 -.000
1.658
1.951
.671 +.002 -.000
.280 MIN R 2 PLACES
.425 .427 DIA 2 HOLES
34°30'
2.020
36°
1.250
20°30'
.354
1.735
2.440 R
.126 .134
.062 .064 DIA, 6 HOLES
.530
1.101 +.002 -.000
.551 +.002 -.000
1.551±.005
.060 ±.015 R
4.285 DIA MIN
4.285 DIA LIMIT
.015±.010 X .015±.010 CHAMFER ALL AROUND
.746 REF
.095±.005
.905±.008
-K-
-R-
-P-
-F-
GRAPHIC, CASE SECTION, REAR
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B-3 (Sheet 2)

APPENDIX C

MATERIAL REQUIREMENTS AND TEST RESULTS

282279 Case Section, Rear

Material Requirements (Per 7372174) - (17-4 PH)

Mechanical Properties

Ultimate Tensile Strength, psi	130,000 Min.
Yield Strength, psi, at 0.2% offset	120,000 Min.
Elongation, Percent in 4 D	6.0 Min.
Hardness	Rockwell C33 Min.

Chemical Composition	Percent by Weight Min.	Max.
Carbon	- - -	0.06
Manganese	- - -	0.70
Silicon	0.50	1.00
Phosphorus	- - -	0.04
Sulphur	- - -	0.03
Chromium	15.50	16.70
Nickel	3.60	4.60
Copper	2.80	3.50
Columbium plus Tantalum	0.15	0.40
Nitrogen	- - -	0.05

Radiography per 9921013 -- Grade B

Average Test Results (Mech. Prop.) obtained from 19 consecutive lots of WR Production Castings.

Ultimate Tensile Strength, psi	151,600
Yield Strength, psi, at 0.2% offset	147,100
Elongation, Percent in 4 D	13.4
Hardness, Rockwell C	34

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APPENDIX D

BENDIX
(Kansas City, Div.)
CASTING FEASIBILITY STUDY PLAN

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CASTING FEASIBILITY STUDY

WHAT IS IT?

A formal Bendix (Kansas City) analysis of the potential value in applying the casting process as a means of producing a finished or semi-finished metal product.

WHY USE IT?

1. To establish formal data which may be used to determine the potential advantages or disadvantages of casting specific products.
2. To present a formal analysis, comparing estimated cost of raw stock fabricating vs. casting.

WHEN SHOULD IT BE REQUESTED?

When it appears that fabricating the required product from raw stock would --

a. be extremely time consuming.

b. require elaborate or expensive tooling.

c. necessitate secondary assy. operations (welding, brazing, etc.).

d. be difficult or impossible due to geometric shape.

HOW IS IT INITIATED?

The Product Engineer submits a memo, plus two product drawings to Dept. 831-1 requesting the study be performed.

Dept. 831-1 will perform the study in accordance with the Casting Feasibility Study plan, and publish a formal report to the requesting Product Engineer.

July, 1967
Rev. 2 October 23, 1969
Rev. 3 November 24, 1969

CASTING FEASIBILITY STUDY PLAN

OBJECTIVES OF STUDY

A. To determine if metal products, initially or currently, defined in the product design system as completely fabricated from raw stock, can be produced as a casting, and finished machined (or used as cast) to arrive at the final design definition.

B. To analyze the cost that might be incurred by both methods of manufacturing (fabricated from raw stock or produced from a casting).

C. To analyze the effect on the function and reliability by the use of a casting approach.

D. To formulate a potential program cost savings that could be realized by redesign of the part under study using the casting approach.

E. To help insure the availability of the finished part definition in the shortest time period after scheduled release.

F. To submit recommendations, based on the study findings, to the responsible Product Engineer for evaluation, and his decision (negative or positive) as to the feasibility of using a casting approach.

METHODS FOR PERFORMING STUDY

A. Obtain copies of the finished part drawing, and/or sketched definitions of the part, to be studied.

B. Discuss casting feasibility with responsible finished part Product Engineer and Purchasing.

C. Submit request to Process Engineering for estimated cost of tooling needed to produce:

   (1) a finished part completely fabricated, from raw stock, to current design definition.

(2) a finished part produced from a casting, needing only secondary or finish machining (per marked machine drawing or casting sketch).

D. Submit request to Methods Engineering for an estimate of total manufacturing time (in standard hours) required to:

(1) completely machine a part from raw stock to current design definition.

(2) perform secondary or finish machining on a casting (per marked machined drawing or casting sketch) to arrive at the finished part design definition.

E. When estimates are returned from Methods and Process Engineering:

(1) Compute the total estimated cost to produce part in question by machining completely from raw stock.

NOTES: A. Base computations on current labor and material cost factors as furnished by Accounting and/or Purchasing.

B. Reflect --

Estimated raw material cost (per unit and program)

Estimated tooling cost (per unit and program)

Estimated labor time converted into dollars (per unit and program).

(2) Compute total estimated cost to produce part in question, from a casting that requires secondary machining (or no machining), to conform to the finished part definition.

NOTES: A. Base computations on current labor and material cost factors as furnished by Accounting and/or Purchasing.

B. Reflect --

Estimated casting cost (per unit and program)

Estimated finished machine tooling cost, if any, (per unit and program)

Estimated labor time, if any, converted into dollars (per unit and program).

(3) From figures arrived at in E. 1 and E. 2 above:

a. Compute potential cost savings (per unit and program) if the casting approach is acceptable.

F. When study is completed, publish a detailed report of findings addressed to the responsible Product Engineer and request that he review and advise (by memo) of his opinion and/or decision on this subject.

Copies of this report will be distributed to:

	Copies
Responsible Product Engineer	2
Responsible Product Group Supervisor	1
Production Management Administration Attention: V. H. Clabaugh, Jr., D/200	1
R. C. Ufford, D/831	1
F. J. Boyle, D/831	1
C. W. Gallup, D/640	1
File	1

G. If Product Engineer's response is negative, close the D/831 "Casting Feasibility Study" file, and mark "casting use <u>not</u> feasible".

H. If Product Engineer's response is positive, proceed with:

(1) Initiating request to Drafting for detailed casting drawing identified as a "preliminary" design, or reproduce Product Engineer's design sketch.

(2) Obtain copies of preliminary casting drawings or design sketch (supply three copies to Purchasing, and one copy to Product Engineer).

(3) Arrange to visit potential casting suppliers for the purpose of:

a. Determining their ability to fabricate the proposed castings in a manner that will insure the least amount of difficulty when WR procurement is initiated.

b. Discussing their ability to economically produce the subject casting to the proposed preliminary design.

c. Negotiate any exceptions they might have to specified design requirements that could affect their ability to consistently produce (discuss proposed casting designs in detail).

d. Discussing areas where consideration of design changes could reduce the cost of castings and/or tooling without affecting intended function and/or reliability of the end product.

(4) Coordinate design requirements with responsible Product Engineer (after obtaining comments and suggestions from suppliers).

(5) Initiate request to Drafting for a firm casting design (as will be proposed to the Design Agency).

(6) Supply three copies of the final casting design proposal to the responsible Product Engineer. Request that D/831-1 be notified when a final decision on the casting concept is reached. (Will BKC start development and/or WR fabrication with the casting, or fabricating concept?)

(7) When notified that the casting approach will be used for WR fabrication, initiate KCD-1907, "Cost Improvement Action" sheet.

(8) When notified that the casting approach will not be used, close out study file.

See attached sample:
Casting Feasibility Study "work sheets"

REQUEST FOR MFGR. TIME ESTIMATE

TO:____________________ DEPT. ________ DATE REQUESTED__________

PART NO. ________________ PART NAME ______________________________

EST. TOTAL PROD. ________________ EST. NEEDED BY ____________________

Request for Est. Tooling Cost to ______________ (Processing) on ______________

Please review the attached drawings and supply the undersigned with your estimate of the total time (in std. hours) that would be required to; (a) completely machined from raw stock, (b) finish machine from a casting (per marked drawing). Enter the information below and return this form to W. E. Cromwell, D/831. This information will be used for the purpose of design evaluation. For additional information please contact the undersigned. Your cooperation in this request will be greatly appreciated.

Thank you.

W. E. Cromwell, D/831
Ext. 3221

Estimated std. hours per unit for comp. machining from raw stock = ____________

Estimated std. hours per unit for finish machining from a casting = ____________

By ____________________________________ Date Comp. ______________

REQUEST FOR MFGR. TOOLING ESTIMATE

TO: ______________ DEPT. __________ DATE REQUESTED __________

PART NO. ____________ PART NAME ______________________

EST. TOTAL PROD. ______________ EST. NEEDED BY ______________

REQUEST FOR EST. MFGR. TIME TO ____________ (Methods) ON ____________

Please review the attached drawings and supply the undersigned with your estimate of the total cost for tooling required to produce this part to the drawing; (a) from raw stock, (b) from a casting (per marked drawing). Enter the information below and return this form to W. E. Cromwell, D/831. This information is required for purpose of design evaluation. For additional information please contact the undersigned. Your cooperation in this request will be greatly appreciated.

Thank you.

W. E. Cromwell, D/831
Ext. 3221

Estimated tooling cost for comp. machining from raw stock = $ ____________

Estimated tooling cost for finish machining from a casting = $ ____________

By ______________________________ Date Comp. ____________

CASTING FEASIBILITY STUDY - ESTIMATE

Start Date ____________ Finished Part No. ____________

Comp. Date ____________ Part Name ____________

Est. Program Qty. ____________ Product Engineer ____________ Dept. ______ Ext. ______

Function ____________

A Fabricated Approach	Unit Cost	Program Cost
Estimated Raw Material Cost		
Estimated Tooling Cost		
Estimated Labor Cost		
(A) Totals		

B Casting Approach	Unit Cost	Program Cost
Estimated Raw Casting Cost		
Estimated Finish Mach. Tooling Cost		
Estimated Finish Manufacturing Cost		
(B) Totals		
POTENTIAL COST SAVINGS Per Unit/Program (A - B)		

Remarks: ____________

DEEP DRAWN STAINLESS STEEL CONTAINER

Project Leader

H. J. Seese, Jr.

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SUMMARY

The fabrication of a one piece deep-drawn, stainless steel container with the contour and wall thickness dimensions in the range approaching machined component requirements, necessitated application of tooling and manufacturing operations not normally experienced in sheet metal forming.

The Hydroform process was selected instead of conventional steel draw dies because of the inherent work hardening factors in stainless steel and the depth of draw required from flat blank stock.

The container was successfully produced by the Hydroform process after development of a blank diameter to compensate for the sixty percent blank size reduction factor, the development of a pressure cycle that eliminated wrinkles and controlled wall thickness thin-out, a special material study conducted for optimum drawing qualities with minimum intergranular stretch ("orange peel") and the development of a special cup-shaped Hydroform diaphragm unique to the metal forming process.

The shaped diaphragm, with its potential for cost savings and increasing the capability of the Hydroform process, has not, until this time been used in the industry.

The process as finally developed yields approximately 90 percent acceptable parts.

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DISCUSSION

SCOPE AND PURPOSE

The fabrication of a one piece deep drawn stainless steel container with a conical section blending into a larger diameter cylindrical section presented difficulties not normally encountered in sheet metal forming. The maximum possible wall thickness consistent with design requirements, held to a close tolerance had to be obtained throughout the container, including the area of transition between the conical and cylindrical sections (Figure 1).

Because of the depth of draw required from flat blank stock and the work hardening factors in stainless steel, the Hydroform process was selected instead of conventional steel draw dies.

The transition from process concept to a proven reliable production process required:

- Extensive development of multiple drawing operations,
- The development of a new concept of Hydroform machine diaphragm configuration to improve the yield of parts,

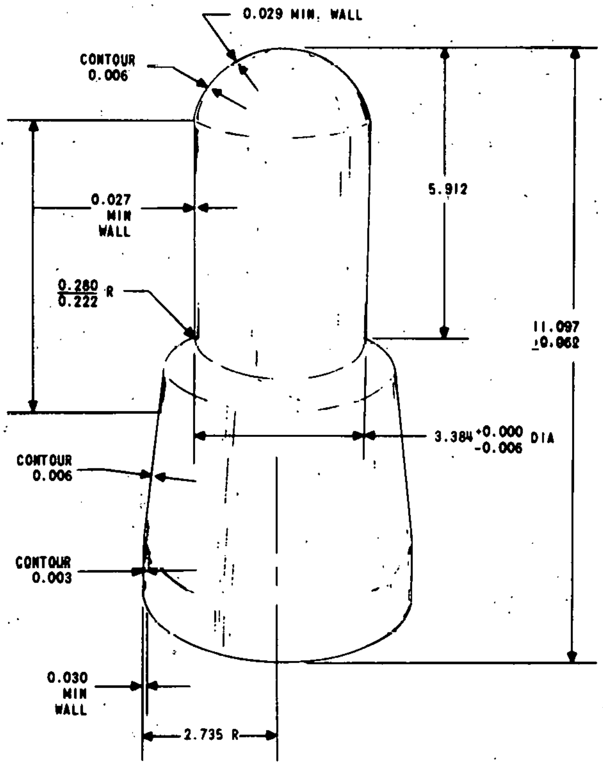

Figure 1. Dimensional Sketch of Container

- Optimizing of the time and temperature for the annealing operation required between each draw operation, and

- The creation of a new material standard for the raw material.

ACTIVITY

Immediately following is a detailed description of the complex process as it finally evolved. This is followed by a description of specific development activities that were necessary before the final process could be specified.

Blank Preparation

An 18 by 18 inch blank is square sheared from sheet stock then circle sheared to 14-1/2 inch diameter. The circle sheared edge is deburred and the blank is vapor degreased to remove foreign material accumulated during shearing and deburring. Cimflow 10 lubricant is evenly applied to both surfaces of the blank in preparation for Hydroforming.

First Draw Tooling and Preform Shape

The first draw tooling consists of a punch with the shape identical to the conical end of the final formed part. This conical shape is used on all of the draw dies for this part to establish a preform shape compatible to the final part shape and to enhance the metal flow in the next two draw operations. The punch contains an air valve to permit stripping of the part from the punch without distortion. The draw ring is a standard ring with an inside diameter sized to fit the form punch (Figure 2). The flat blank is positioned, using a centering ring, on top of the draw ring (Figure 3).

The forming cycle consists of lowering the top ram of the press, applying hydraulic pressure to the diaphragm to clamp the blank in position and raising the form punch to a preset height. The displacement of the punch into the rubber diaphragm increases the hydraulic pressure, but not enough to prevent wrinkles from forming in the finished part. Wrinkles are prevented by energizing the pumps to provide additional pressure to a predetermined level arrived at during the development of the forming cycle process. At the completion of the punch travel the hydraulic pressure is released and the ram raised. The punch is lowered and the part is removed from the press (Figure 4).

Second Draw Tooling and Intermediate Formed Shape

The second draw tooling is an extension of the first draw to provide sufficient material in the intermediate form for the redraw operation. The punch has the conical shape and spherical radius of the final formed shape. The punch length is increased to provide a skirt with sufficient material to extend the cylindrical area to the finished size (Figure 5). The flange is removed in a lathe operation in preparation for final redraw operation (Figure 6).

Figure 2. First Draw Tooling

Figure 3. Blank Positioned for First Draw

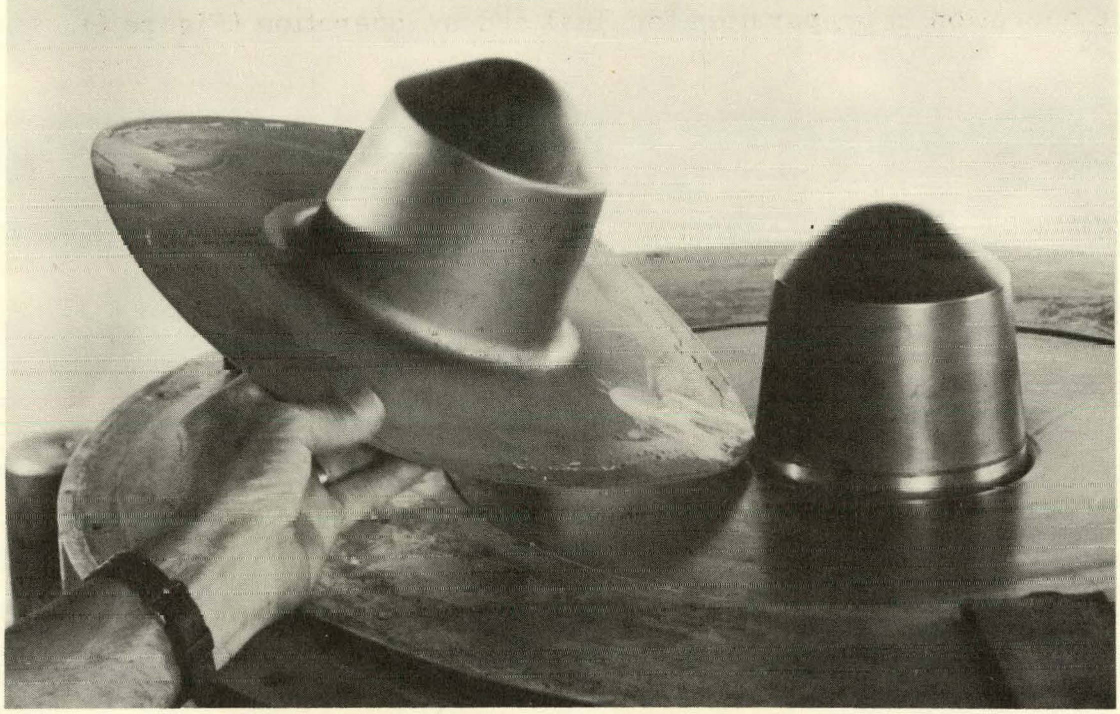
Figure 4. Part After First Draw

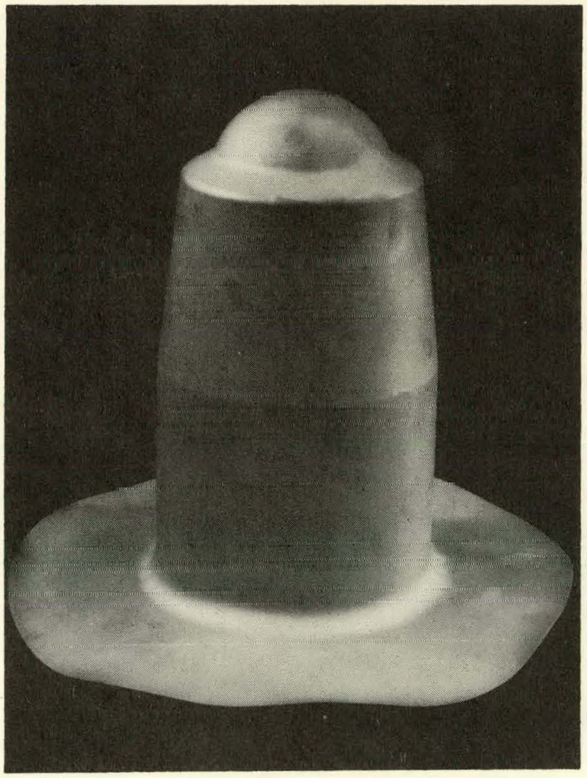
Figure 5. Part After Second Draw

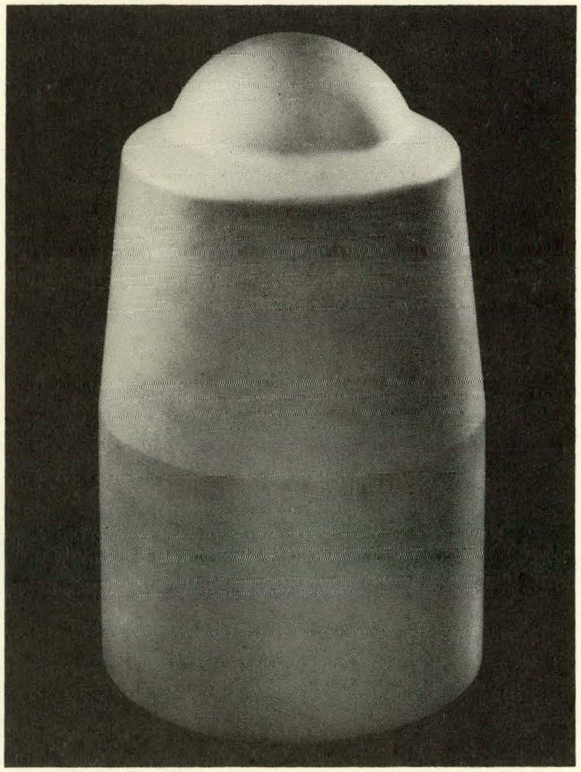
Figure 6. Flange Removed

Third Draw Tooling and Final Formed Shape

The tooling for the third and final draw operation departs from conventional Hydroform procedure in design and operation. The normal drawing operation requires a flanged area for the application of hold down or drawing pressure. The redraw operation as finally developed acquires the holddown pressure from a portion of the exposed intermediate formed shape which extends above the draw ring. The balance of the intermediate form extends below the draw ring surface and is pulled through the draw ring as the cylindrical center punch moves up. The hydraulic drawing pressure is automatically adjusted by a cam as the formed shape increases in length to force the material to conform to the punch (Figure 7).

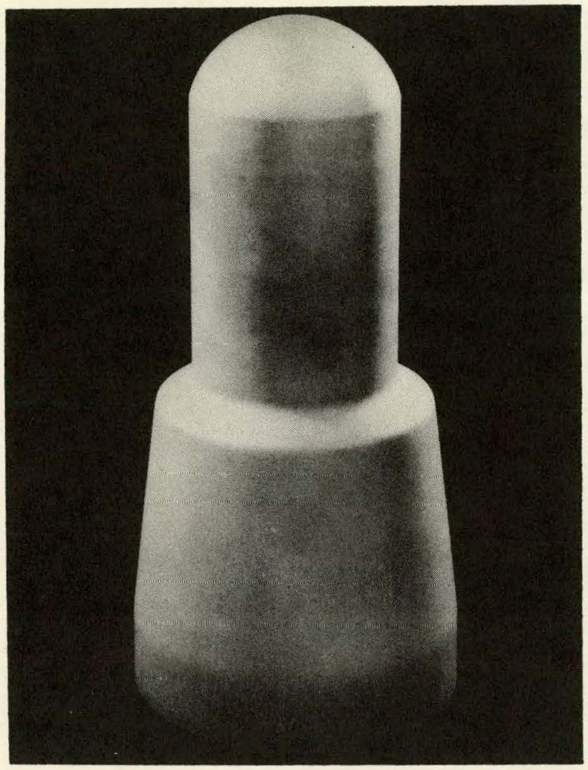

Figure 7. Part After Third Draw

Sizing Operations

A final sizing operation is required to reduce one of the corner radii in the transition area and to round the part. This operation is performed using matched steel dies in a 300-ton hydraulic press. Since the as-drawn part wall thickness varies approximately 0.008 inch in a predictable manner, the punch and die cavity were designed and fabricated to compensate for this variation.

This operation is necessary because the inside corner radius in the transition area cannot be Hydroformed to the finish part specification. Pressure on the Hydroform machine diaphragm of a sufficient magnitude to force the part material to conform to the small inside radius would be too great to permit the necessary movement of material required to form the small cylindrical section of the part during the third draw.

Development of Pressure Cycle for Final Formed Shape.

Since the thickest and most uniform wall possible was necessary to assure part function in use, the first parts through the final form operation were reviewed. This review revealed a variation in wall thickness that was not acceptable in the completed part. The wall thickness in the conical section and the transition section between the conical and cylindrical section was under acceptable limits. The final Hydroform draw operation was investigated to determine the intent and nature of this problem. Twelve units that had been completed through the second draw and were ready for final draw were measured in the critical areas and measurements recorded for comparison after the final draw. The pressure cycle was then varied from the minimum pressure that produced a wrinkled part, to the maximum pressure that thinned the cylindrical section to the breaking point. Working between these maximum and minimum pressure levels an optimum pressure was reached that consistently produced wrinkle free parts with the thickest wall.

Development of Special Shape Diaphragm

While developing the third form operation it became obvious that the flat type diaphragm, which is the standard for Hydroforming, would not economically perform its function. The stresses that developed in the diaphragm during the extremely deep third draw cycle stressed the rubber beyond its elastic limits, leading to rupture after approximately six parts. After analysis of the position of the tooling and the shape of the preformed part prior to this operation, it was determined that additional rubber was required in the center of the diaphragm to compensate for the displacement caused by the tooling and preformed shape. A diaphragm was designed and made with a cup-shaped center to fit over the preformed shape before any hydraulic forming pressure was applied to the diaphragm. Use of this special cup-shaped diaphragm, unique to the forming industry, has increased the yield per diaphragm from; 6 parts to 160 parts (Figures 8 and 9).

An additional benefit derived from this development was the enhancement of the degree of control of wall thickness that could be achieved. This was possible because less pressure was required to force the diaphragm to conform to the shape of the part as determined by the shape of the punch. This reduction of required pressure provided a wider range of available force for controlling the amount of metal slip which occurs while the punch is moving into the diaphragm.

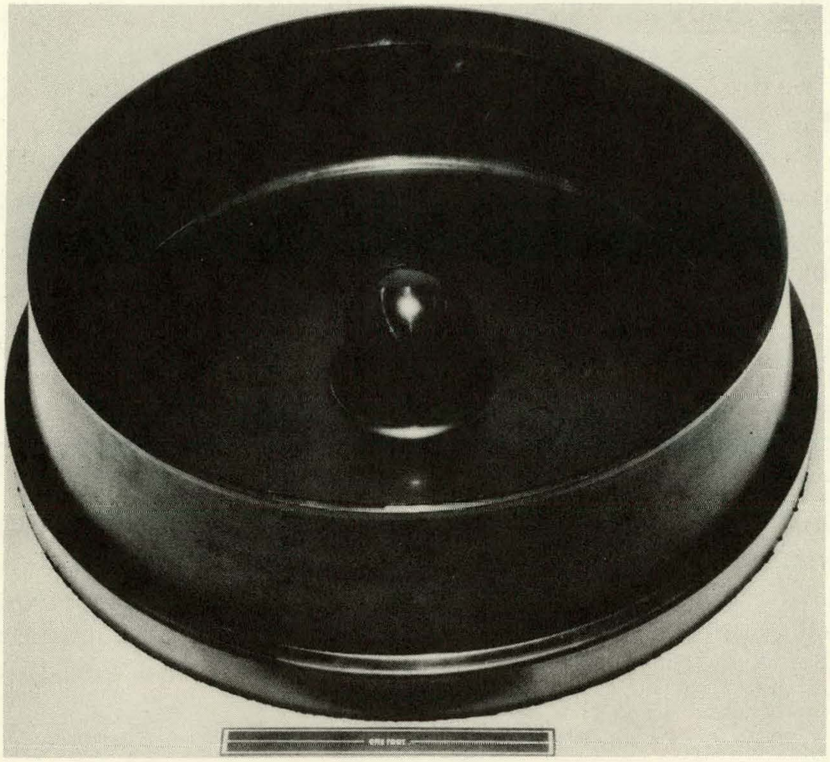

Figure 8. Special Diaphragm, Top

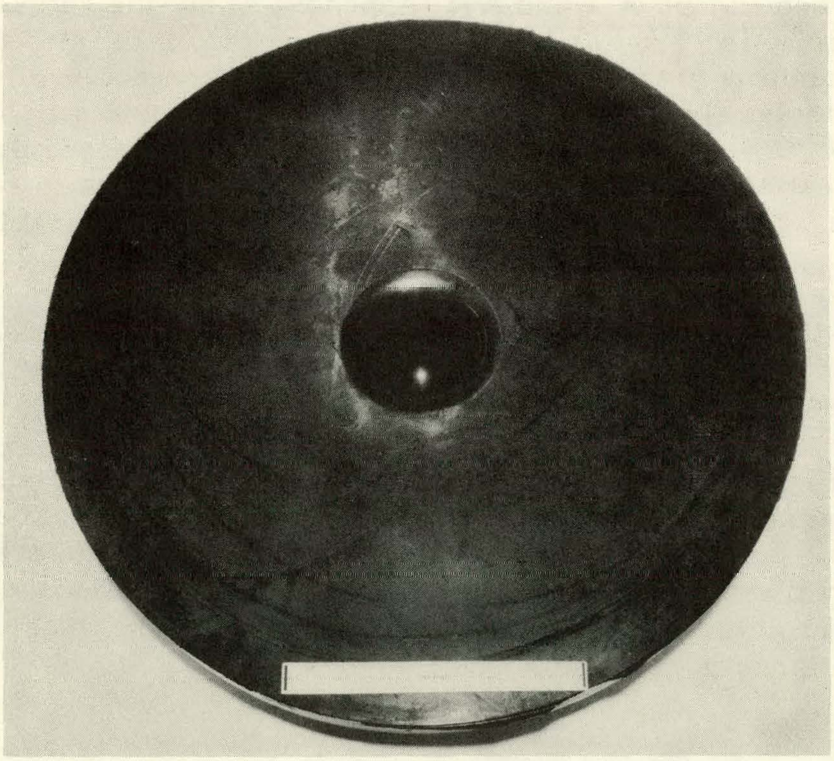

Figure 9. Special Diaphragm, Bottom

Special Material Study

The severity of the third forming operation initially produced a rough surface condition in the cylindrical area. This condition is commonly referred to as "orange peel" and is the result of intergrannular stretching of the material. Parts formed with this condition were below the minimum part wall thickness specification after polishing to meet the 16 AA external surface finish required in the next assembly configuration.

A material study was initiated to eliminate the orange peel condition. Metallurgical evaluation of rough parts indicated that the causes were associated with the annealing operations, which were performed between each forming operation, and with grain size in the raw sheet stock.

Six parts of known blank thickness were processed through the first draw and in-process anneal operation. Two of the six parts, B-10 and A-1, were sectioned and the wall thickness measured. See Table A-1 in Appendix A. The balance of four parts were processed through the second draw and in process anneal. One part, A-3, was sectioned and the wall thickness measured. See Table A-2 in Appendix A.

The final three parts, A-6, A-9 and B-3, were formed to the third and final shape and annealed with three different heat treat cycles to study the effect on the wall thickness and grain size. The wall thickness variation was not significant, see Figure A-1 and A-3 (Appendix A) but the surface condition or orange peel effect, showed marked differences. A decided improvement in surface condition was indicated on part B-3 which received the lower temperature, shorter time heat treat cycle. Parts are presently being produced using the 1600°F - 20 minutes cycle, for the first and second draws and a final heat treat after the third draw of 1850°F - 10 minutes to remove all forming stresses. Surface condition and wall thickness is acceptable with this process.

As a part of this investigation the blank material was also evaluated metallurgically. It was determined the blank material consisting of ASTM grain size 7 or less was also necessary to eliminate "orange peel."

The original specification called for 304L stainless steel, of a standard mill run thickness and tolerance of .037 ± .003 inch, with no grain size specified. As a result of the material study and the development of the drawing process a new material standard was established and specified. This new standard specified the thickness to be .037 ± .001 inch, to assure thicker parts, and specified the grain size to be ASTM No. 7 or less.

ACCOMPLISHMENTS

The successful development of the process for this part has enhanced Bendix capability in the field of Hydroforming die drawn, thin walled containers. Techniques and background knowledge required to achieve tight tolerances on this type of product have also been obtained. Experience in multiple drawing operations was acquired.

Of particular significance is the development of the shaped Hydroform diaphragm. This achievement provides a true advance in metal forming, from not only a cost saving standpoint, but also in extending the capability of the Hydroform process in that it permits the utilization of this process for deeper draws and for parts of more complex geometry.

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APPENDIX A

THICKNESS PROFILE TABLES

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Table 1. Thickness Profile, First Stage of Three-Stage Draw

B-10 (25 Minutes, 1850°F)

Pole 0.0334			
1	0.0310	2	0.0312
3	0.0303	4	0.0306
5	0.0287	6	0.0298
7	0.0297	8	0.0304
9	0.0306	10	0.0315
11	0.0300	12	0.0315
13	0.0293	14	0.0302
15	0.0295	16	0.0309
17	0.0298	18	0.0312
19	0.0296	20	0.0312
21	0.0319	22	0.0318
23	0.0325	24	0.0340
25	0.0343	26	0.0343
27	0.0343	28	0.0345
29	0.0348	30	0.0362
31	0.0353	32	0.0363
33	0.0360	34	0.0368
35	0.0363	36	0.0373
37	0.0362	38	0.0380
39	0.0368	40	0.0381
41	0.0372		

A-1 (25 Minutes, 1850°F)

Pole 0.0330			
1	0.0326	2	0.0319
3	0.0301	4	0.0294
5	0.0291	6	0.0300
7	0.0302	8	0.0309
9	0.0309	10	0.0313
11	0.0307	12	0.0306
13	0.0299	14	0.0299
15	0.0307	16	0.0310
17	0.0311	18	0.0306
19	0.0311	20	0.0307
21	0.0312	22	0.0310
23	0.0336	24	0.0331
25	0.0343	26	0.0340
27	0.0348	28	0.0349
29	0.0353	30	0.0362
31	0.0363	32	0.0372
33	0.0365	34	0.0374
35	0.0369	36	0.0381
37	0.0373	38	0.0382
39	0.0374	40	0.0394
41	0.0380		

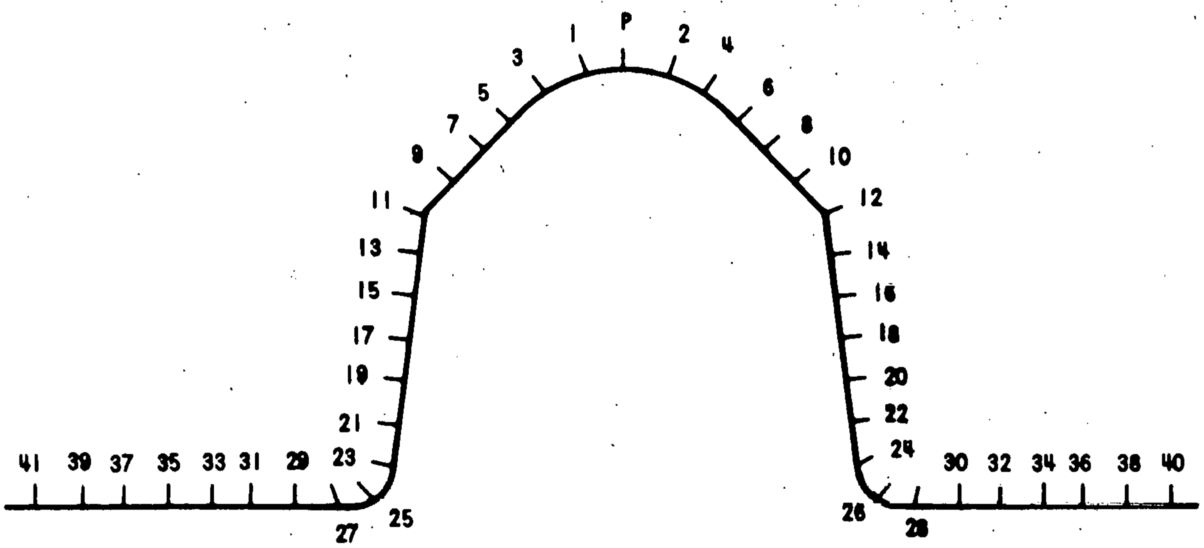
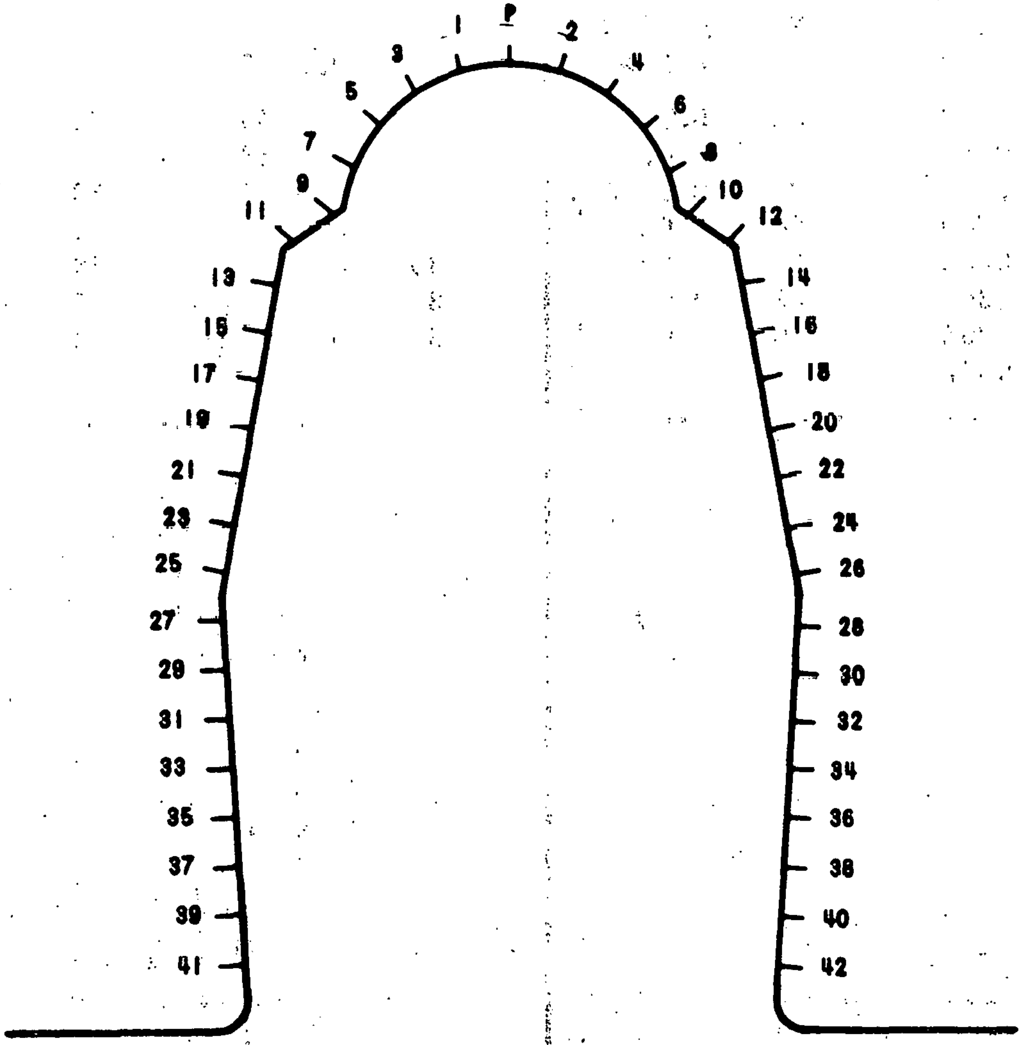


Table 2. Thickness Profile, Second Stage of Three-Stage Draw

A-3 (25 Minutes, 1850°F)

Pole 0.0341

1	0.0335	2	0.0320	23	0.0342	24	0.0320
3	0.0308	4	0.0303	25	0.0349	26	0.0331
5	0.0300	66	0.0307	27	0.0349	28	0.0341
7	0.0321	8	0.0352	29	0.0359	30	0.0348
9	0.0360	10	0.0352	31	0.0364	32	0.0351
11	0.0329	12	0.0316	33	0.0368	34	0.0354
13	0.0338	14	0.0329	35	0.0371	36	0.0352
15	0.0342	16	0.0330	37	0.0376	38	0.0357
17	0.0344	18	0.0336	39	0.0384	40	0.0358
19	0.0344	20	0.0333	41	0.0424	42	0.0366
21	0.0342	22	0.0334				



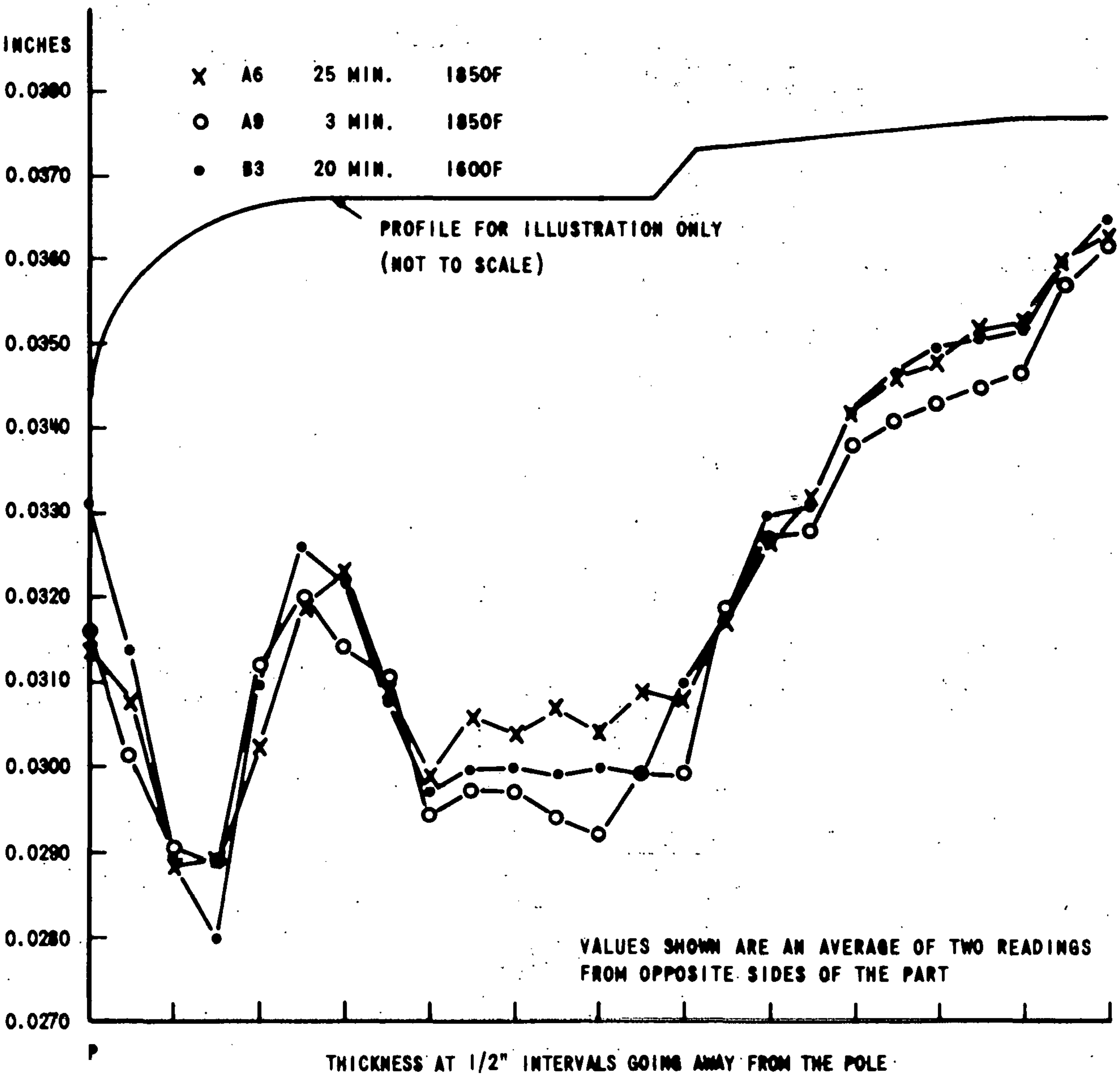


Figure A-1. Comparison of Wall Thickness for Parts A-6, A-9, and B-3

Table 3. Thickness Profile, Third Stage of Three-Stage Draw

A-6 (25 Minutes, 1850°F)

Pole 0.0314

1	0.0308	2	0.0309
3	0.0291	4	0.0288
5	0.0288	6	0.0291
7	0.0300	8	0.0305
9	0.0316	10	0.0323
11	0.0321	12	0.0325
13	0.0309	14	0.0310
15	0.0299	16	0.0300
17	0.0305	18	0.0308
19	0.0304	20	0.0305
21	0.0307	22	0.0307
23	0.0304	24	0.0304
25	0.0306	26	0.0312
27	0.0307	28	0.0309
29	0.0315	30	0.0320
31	0.0325	32	0.0327
33	0.0329	34	0.0335
35	0.0340	36	0.0344
37	0.0344	38	0.0349
39	0.0345	40	0.0352
41	0.0349	42	0.0356
43	0.0346	44	0.0361
45	0.0356	46	0.0365
47	0.0358	48	0.0368

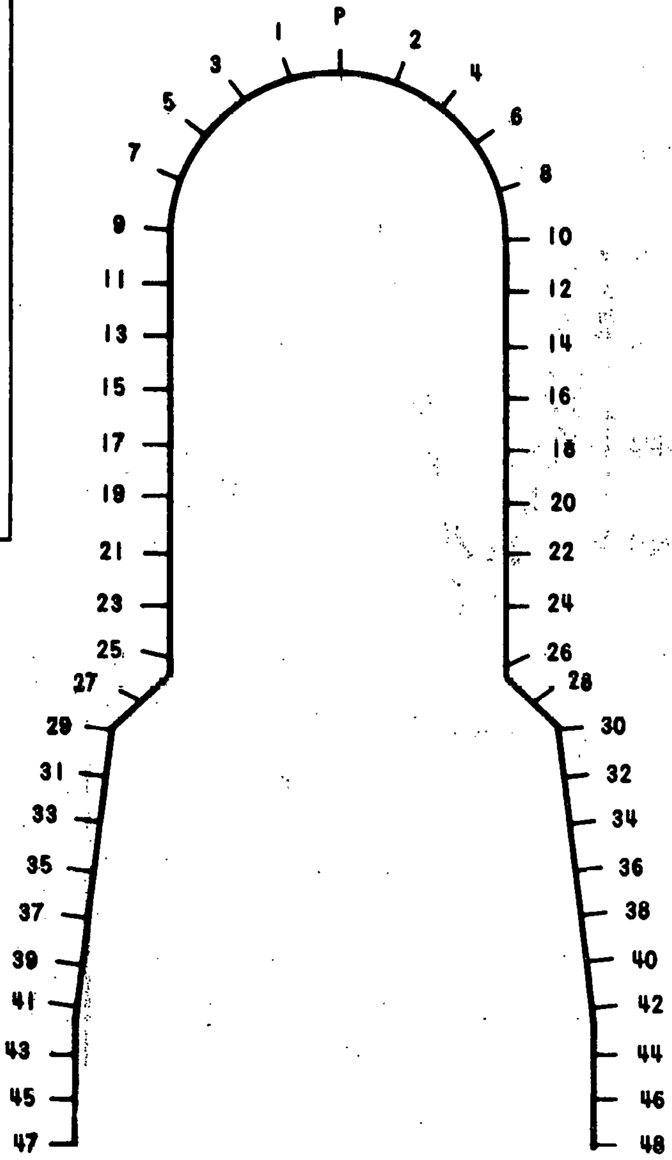


Table 3 Continued. Thickness Profile, Third Stage of Three-Stage Draw

A-9 (3 Minutes, 1850°F)

Pole 0.0316

1	0.0307	2	0.0297
3	0.0293	4	0.0287
5	0.0289	6	0.0290
7	0.0314	8	0.0311
9	0.0322	10	0.0319
11	0.0315	12	0.0313
13	0.0311	14	0.0309
15	0.0296	16	0.0293
17	0.0298	18	0.0296
19	0.0297	20	0.0296
21	0.0294	22	0.0294
23	0.0294	24	0.0291
25	0.0299	26	0.0300
27	0.0299	28	0.0300
29	0.0319	30	0.0320
31	0.0328	32	0.0327
33	0.0328	34	0.0328
35	0.0337	36	0.0339
37	0.0342	38	0.0341
39	0.0344	40	0.0343
41	0.0347	42	0.0344
43	0.0349	44	0.0345
45	0.0359	46	0.0356
47	0.0363	48	0.0361

B-3 (20 Minutes, 1600°F)

Pole 0.0331

1	0.0314	2	0.0315
3	0.0291	4	0.0288
5	0.0281	6	0.0279
7	0.0311	8	0.0310
9	0.0328	10	0.0325
11	0.0324	12	0.0320
13	0.0308	14	0.0308
15	0.0297	16	0.0297
17	0.0301	18	0.0300
19	0.0302	20	0.0298
21	0.0299	22	0.0299
23	0.0301	24	0.0299
25	0.0298	26	0.0300
27	0.0312	28	0.0308
29	0.0318	30	0.0318
31	0.0332	32	0.0328
33	0.0334	34	0.0328
35	0.0346	36	0.0340
37	0.0350	38	0.0344
39	0.0354	40	0.0347
41	0.0355	42	0.0348
43	0.0355	44	0.0350
45	0.0363	46	0.0358
47	0.0369	48	0.0361

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LONGITUDINAL AND SPIRAL MILLING ON A GISHOLT CENTER DRIVE LATHE

Project Leader

H. L. Higbie

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SUMMARY

A method was required to machine three internal cable grooves through a 36-inch-long section of reduced diameter, centered in the inside of a 15-inch-diameter by 79-inch-long tubular aluminum case. Two grooves were straight and the third groove required 18 degrees rotation to obtain the required cable entrance and exit positions. The need for spiral groove milling was determined 60 days before the required delivery of first production parts. Short production lead time for the spiral groove and the low quantity of cases needed necessitated the use of available equipment and low-cost tooling which could be obtained in time to meet production schedules.

A Gisholt center drive lathe could be modified in time to support production for a total cost of $4500. The modification, which is a new application for this machine, consisted of adding an independent carriage feed, a spiral generating attachment, and a spindle index system. A special right angle milling head with counter weight and drive motor mounting was fabricated to mount on the right hand end lathe turret. This head provided the capability for milling grooves through the reduced section to a 58-inch maximum depth from the end of the case. This modification proved successful and parts were produced in time to meet schedules.

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DISCUSSION

SCOPE AND PURPOSE

Three milled grooves for housing cables were required through a 36 inch section in the middle of a 79-inch-long cylinder. Two of the grooves were straight while the third had to spiral and exit from the 36 inch section 18 degrees from its entrance point. The need for the spiral groove was determined and specified 60 days before the scheduled delivery of first production parts.

A view of the internal cable grooves required for this case is shown in Figure 1.

Requirements for machining the 1/2-, 1-1/4-, and 1-1/2-inch-wide grooves through the 36-inch-long center section of this 79-inch-long aluminum case exceeded the capacity of available milling equipment.

The 18-degree rotation of the 1-1/4-inch-wide groove to obtain defined entrance and exit positions required development of spiral milling capability.

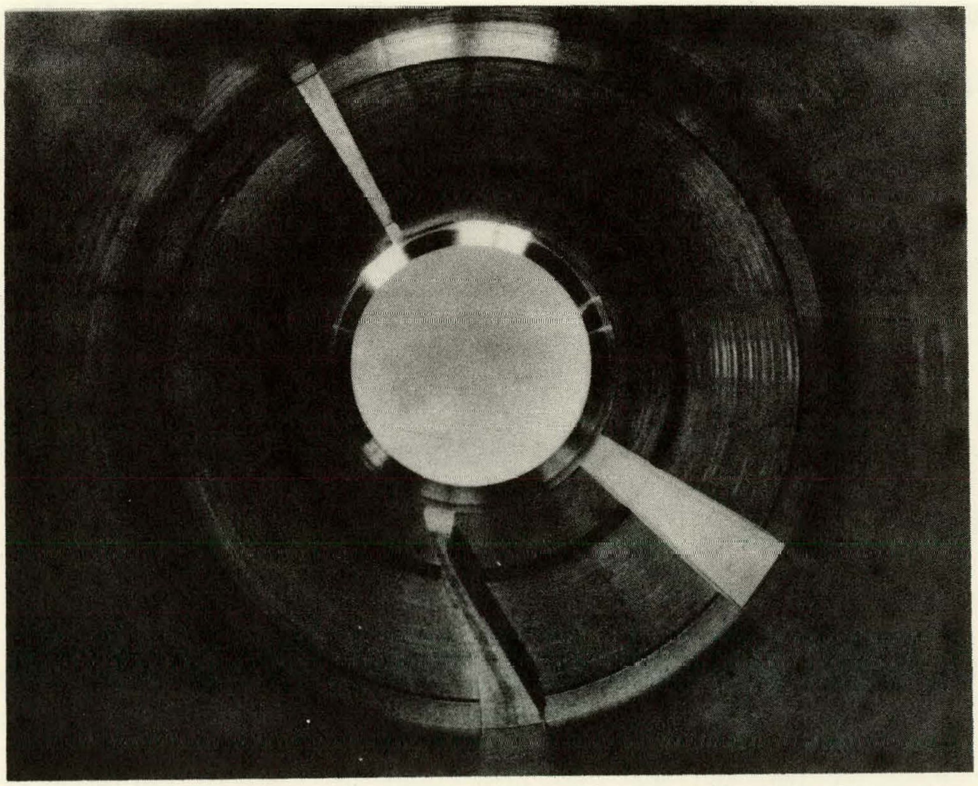

Figure 1. Inside View of Case Showing Cable Grooves

The small quantity of cases required and the short lead time from receipt of the spiral groove requirement to delivery of parts necessitated the use of available equipment with modifications and tooling which could be completed in time to meet production schedules.

PRIOR WORK

Early development and test parts required three longitudinal grooves. Since existing equipment at Bendix was not of sufficient size to accomplish this milling, a modification of a Gisholt center drive lathe was conceived and implemented at a cost of about $1000. A possible alternative to this approach would be to design and fabricate a spiral fixture. This was considered briefly, but discarded because of excessive cost, estimated to be $50,000, and long lead time--approximately 6 months.

The original Gisholt modification, while satisfactory for development hardware, would have been inefficient from the standpoint of equipment utilization in production, and also had a slight potential for damaging the machine. Improvements were then conceived, and parts were ordered to alter the original modification for production; however, shortly after implementation was started, the requirement for the spiral groove was received. Further modification to accomplish the spiral milling was then planned, and the entire machine modification for production longitudinal and spiral groove milling was made as described in the following section.

ACTIVITY

A Gisholt center drive lathe and special right angle milling head were modified as illustrated in Figure 2 to mill the internal cable grooves in the case.

An independent longitudinal carriage feed system for milling was added to the Gisholt center drive lathe. This modification was required to obtain carriage feed for milling without rotating the spindle.

This was accomplished by additions to the lathe rapid traverse system. A gear reduction unit and a 1-1/2 hp electric motor were coupled through an electric clutch to the unused end of the worm gear shaft in the lathe's rapid traverse gear box.

The added feed unit is shown in Figure 3.

An available Varidyne unit was added to control speed of the 1-1/2 hp feed motor and to provide feed rates of from 1 to 5 inches per minute.

The electrical system was revised so that either feed or rapid traverse could be obtained from the control switch. The electric clutch was used to automatically disconnect the feed unit when the rapid traverse motor was started.

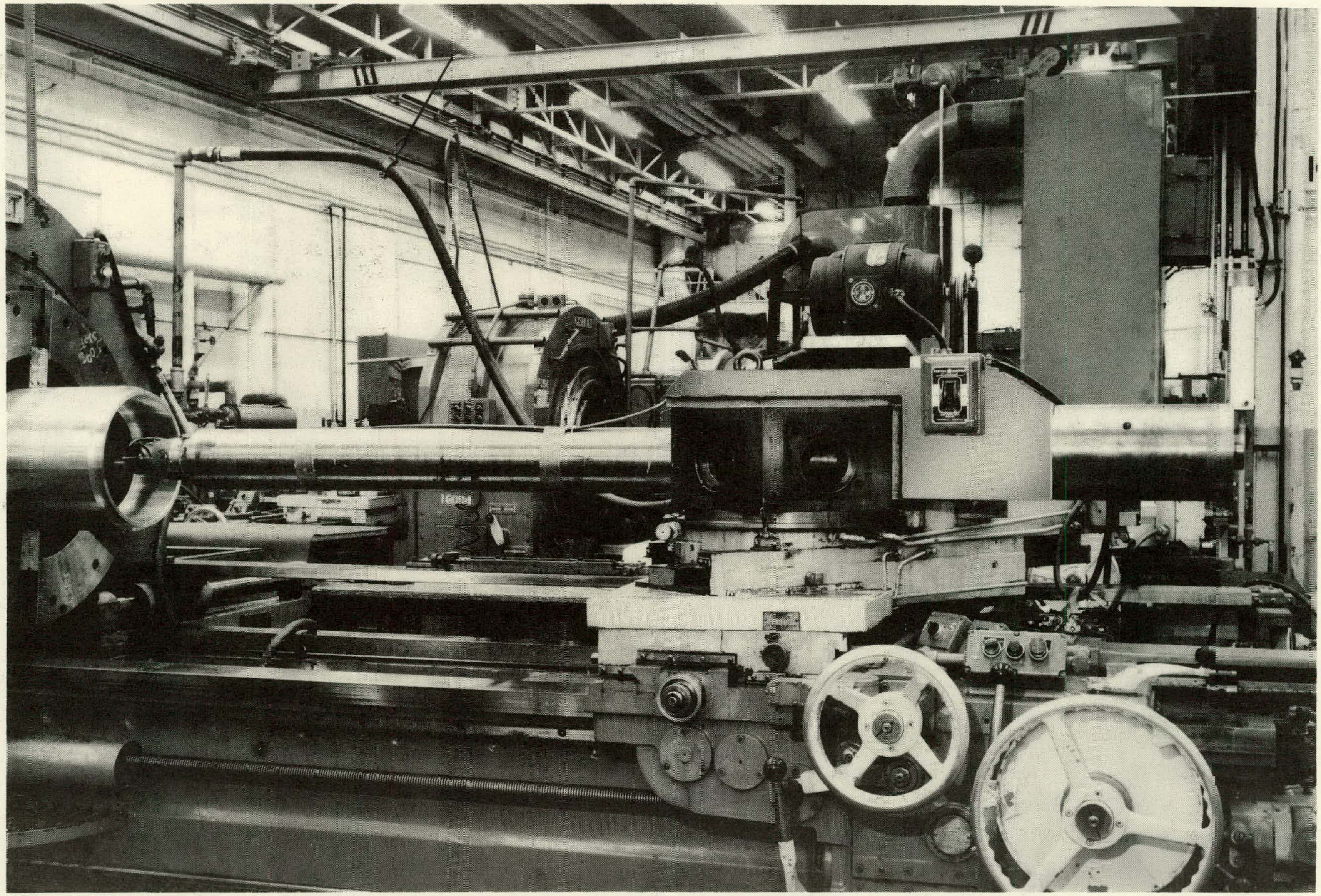

Figure 2. Gisholt Lathe With Special Right-Angle Milling Head

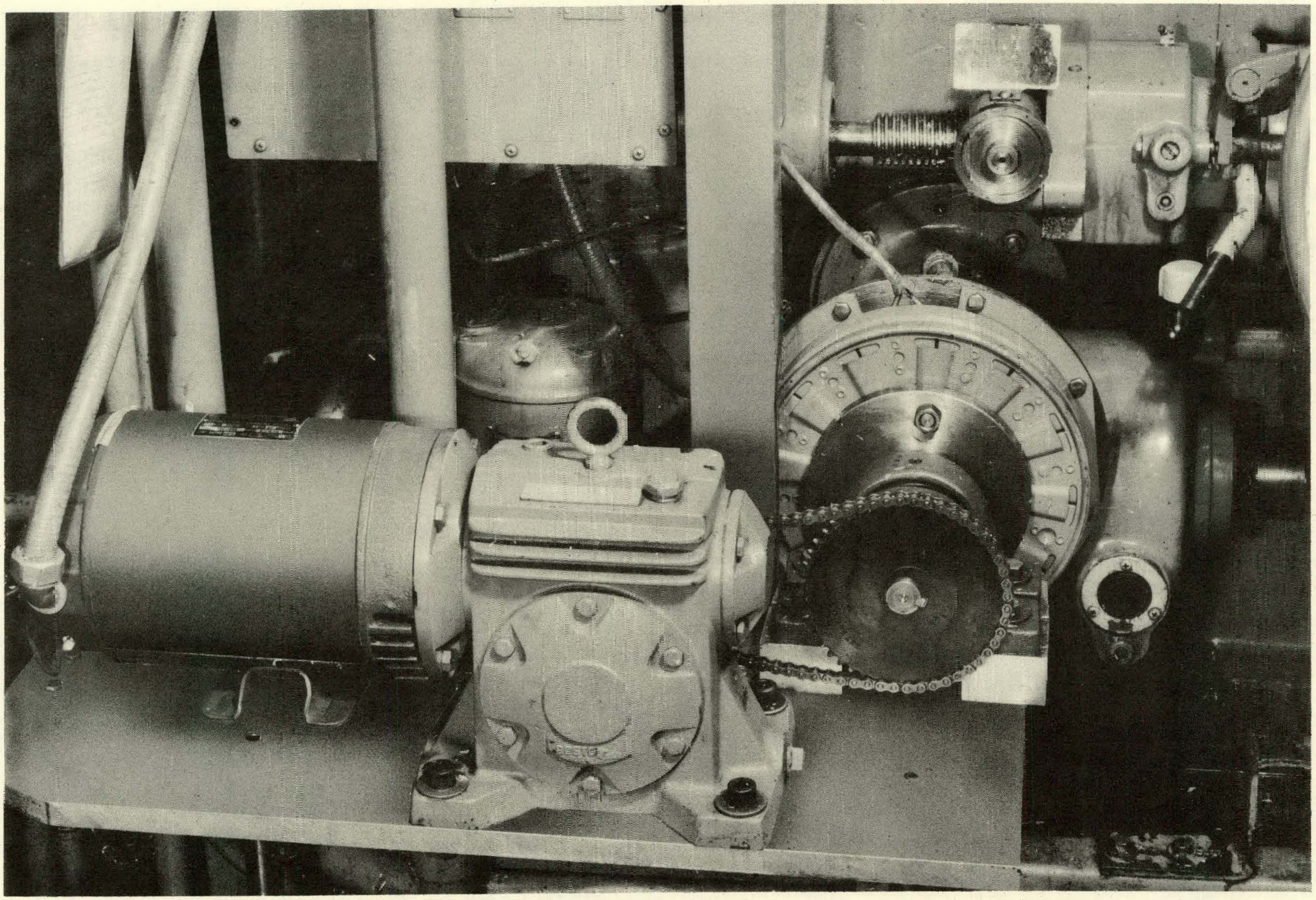

Figure 3. Additions to the Lathe Rapid Traverse System

The attachment to synchronize the spindle rotation with the carriage longitudinal travel for milling the spiral groove was mounted on the back side of the lathe as shown in Figure 4.

A split sleeve with two opposed cam followers was mounted in a bracket on the right hand lathe carriage. Manual clamping of the split sleeve engages the drive for rotating the cylindrical cam to synchronize spindle rotation with the carriage position for milling the spiral groove.

A 2-inch-diameter cam shaft was fabricated in three sections to facilitate milling the dual cam grooves. The spindle drive shaft was removed from the lathe and the cam shaft was coupled to the spindle drive input with a chain and sprockets.

For milling the spiral groove an air cylinder (Figure 5) was coupled to the left hand chuck, to supply power for rotating the spindle the required 18 degrees. This air cylinder also reduced torsion load on the cam shaft, and eliminated backlash in the spindle drive gears.

It was necessary to modify slightly the design of the spiral groove to aid in controlling the entry and exit positions for exact alignment with mating parts of the case assembly. The groove is parallel to the center line of the case for 3 inches from entry into the thick center section, rotates 18 degrees in 30 inches, and exits parallel to the center line for the remaining 3 inches.

A pin and index bushings in the right hand end chuck provide location for radial position of the two straight grooves and locate the entry position for the spiral groove.

The special milling head shown in Figure 2 was fabricated from an available boring bar by adding a drive shaft and a Bridgeport 90° milling attachment. A counterweight and motor mount for a 1 hp motor were mounted on the lathe turret to complete the milling head. In use, although three full width cuts were necessary to mill each of the grooves to the required depths, the 0.030 inch width tolerance was held and there were no steps in the side walls of the grooves.

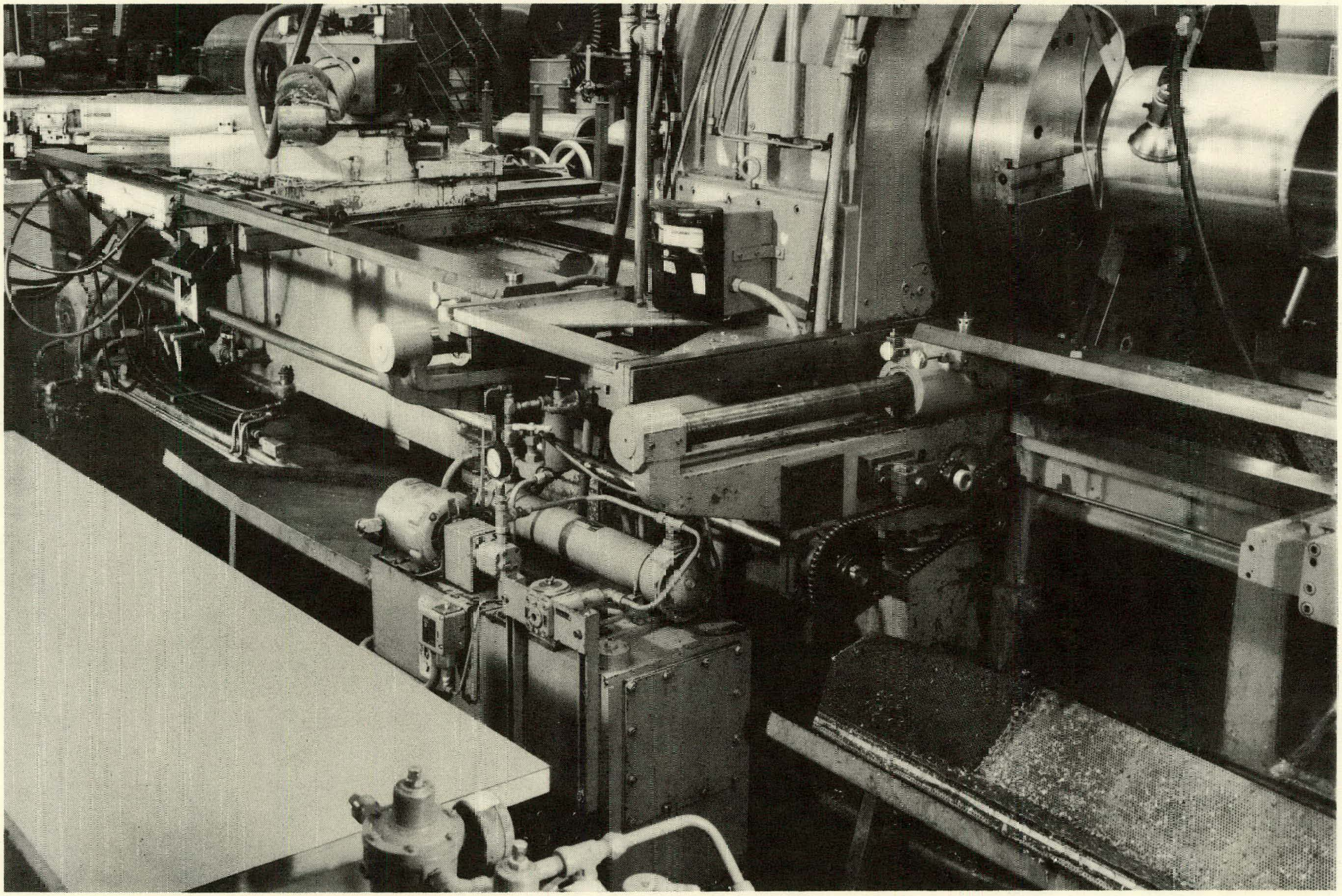

Figure 4. Synchronizing Attachment for Milling the Spiral Groove

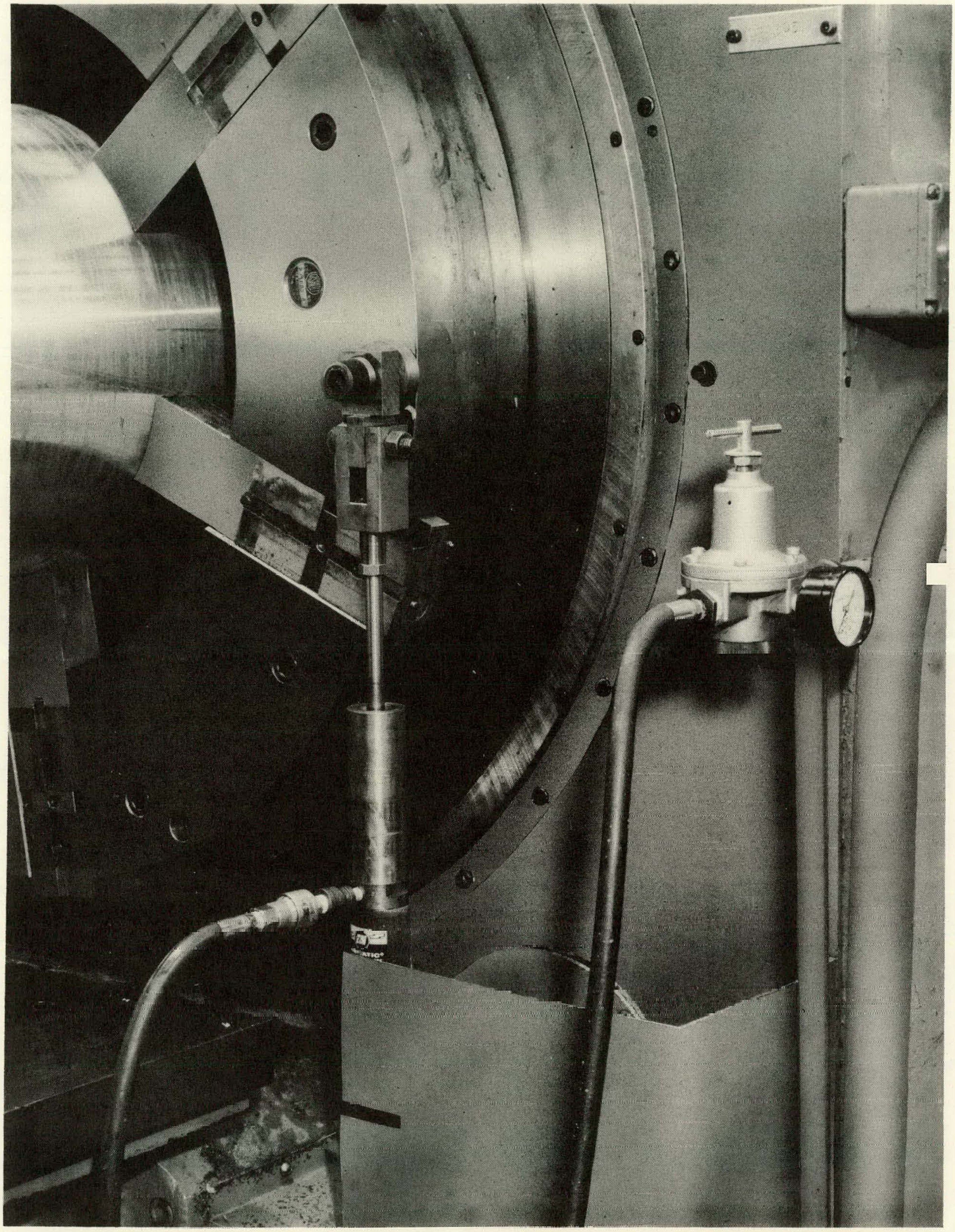

Figure 5. Power Attachment to Rotate the Spindle During Spiral Milling

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ACCOMPLISHMENTS

Although existing equipment could not perform the required milling, a successful, low cost, machine modification was conceived and implemented. This modification was a new application for the center drive lathe.

The total cost of the modification was $4500 for both longitudinal and spiral milling. This figure includes the original $1000 for the early development hardware groove milling.

A major portion of this modification, to add the spiral milling capability, was accomplished with an extremely short lead time.

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DESIGN EVALUATION OF INSULATOR PIN

Project Team

R. D. Lohr, Project Leader
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L. F. Thorne

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SUMMARY

High g-level shock tests were performed to determine the optimum materials and design of a small metal and plastic switching pin, which is subjected to high-g shock in operation. Parts representing ten combinations of materials and shapes were subjected to shocks ranging between 2 and 6 million g's.

The switching pin is used in a battery actuator which fires a percussion cap. There is a safety device, the latch, which prevents premature firing. A monitoring circuit, activated by the switching pin which is part of the latch, indicates whether the latch is secured. This switching pin, named "insulator" because of its design, suffered numerous failures during early testing. The part consists of a steel pin which is over-molded at one end with plastic.

An explosive motor unlatches the device. The effect of the combined impact of the explosive motor plunger on the latch and the impact on the latch as it strikes its housing wall has caused two problems. In one case the nylon breaks apart and in the other case the pin slides partially out of the mounting hole.

High-speed films, taken at Bendix and Sandia, of the latch and insulator during the unlatching sequence captured actual shock failures and provided a means to determine latch velocity. Based on information from these films, a velocity of 300 feet per second provided a starting point for evaluation tests.

A method of testing was devised which used an air gun to propel the insulator bearing projectiles into a steel plug which served as a shock pad. All experimental designs were evaluated this way.

The shock pad, or "target" as it was named for this experiment, was the key to shock level variation. A hole was provided through the center of the target to allow passage of the insulator. The area around the hole formed the braking surface. The shock level could be decreased by decreasing the impact area, thus allowing greater depth of penetration or stopping distance. The type of steel used for the target was also varied to provide an adjustment of shock levels.

The approach to the experiment required reproduction of the failure as a first step. This was necessary since exact shock levels were not known. After failure had been reproduced in the test set up, experimental designs were tested using the failed level as a base line. Approximate g-levels were calculated.

Each of ten designs was tested in a sequence in which the shock level was gradually increased until failure occurred. Polycarbonate plastic was proven

the most shock resistant of the two plastics tested. The design of the pin was an important factor in the shock resistance of both polycarbonate and nylon insulators. Generally, greater resistance to shock loads was achieved by maximizing the volume of capsulated metal.

The effect of thermal shock on the nylon was considered by a special arrangement in this experiment. Although mechanical shock was the ultimate cause of failure, the effect of prior environments could not be overlooked. It was possible, in fact, that failures had only occurred on thermal shocked units, or conversely.

DISCUSSION

INTRODUCTION

The switching pin is a plastic and metal part about 0.160-inch-long and 0.075 inch in diameter. Approximately one half the length of the steel pin is covered by a molded plastic. The part derived its name "insulator" from the covering; functionally the plastic serves as an insulator during the switching action.

The design shown in Figure 1 is the original configuration in which failures occurred. One mode of failure involved cracking the A-2 adhesive which bonded the insulator into the latch. Failure of the bond allowed the insulator to slip forward in the mounting hole. The primary mode of failure, however, was cracking and separation of the molded plastic covering (Figure 2).

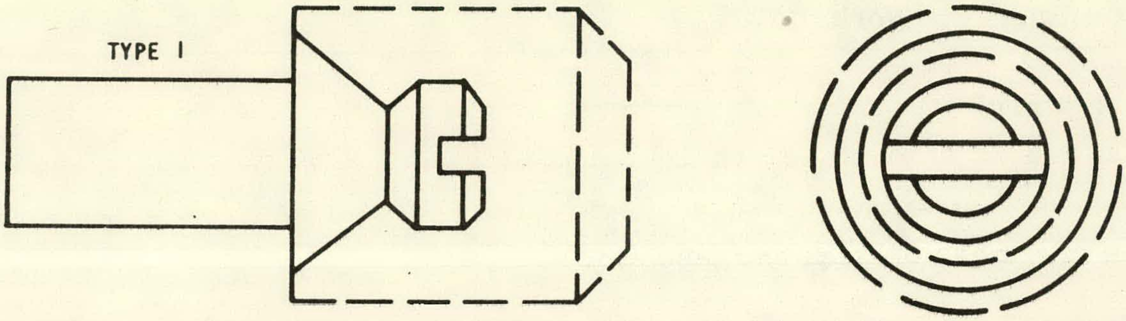


Figure 1. Original Insulator Design

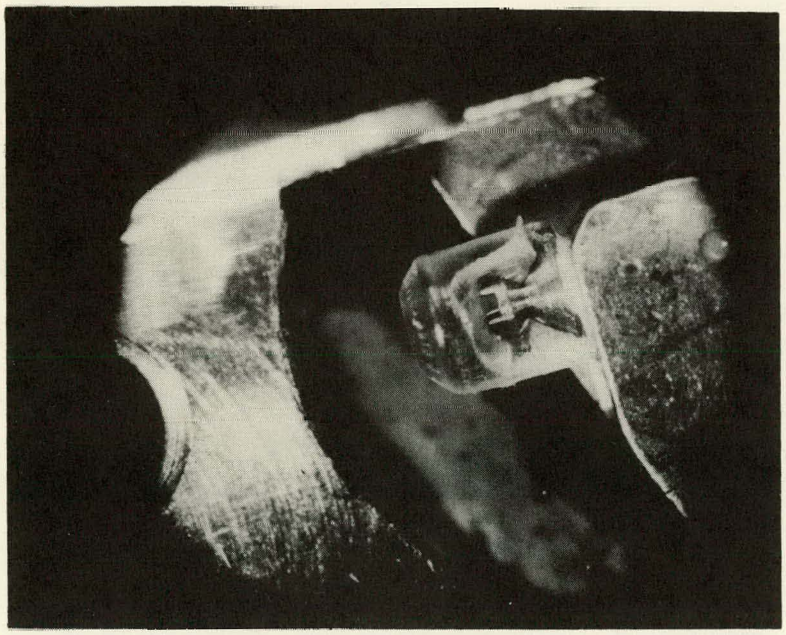


Figure 2. Insulator After Impact

The insulator is subjected to severe shock forces during preparatory unit functions. When the unit is latched, the insulator moves as part of the latch and closes the monitoring circuit switch. Then, as the unit is unlatched to perform its primary function, an explosive motor is fired which thrusts a plunger against the latch on the surface behind the insulator. The latch swivels on a journal (Figure 3) when struck by the explosive motor plunger and is stopped by a steel wall which is part of the foundational structure (base) of the unit. These two actions in sequence shock the latch (and the insulator) at extremely high g-levels. The shock takes place first in one direction as the motor's plunger strikes the latch and then in the opposite direction as the latch strikes the wall of the base. High speed films made at Bendix and Sandia showed the unlatching operation and the resulting insulator failures. The film verified the manner of failure and provided a means to approximate latch-insulator speed, which was 300 feet per second. Knowing the velocity and estimating the stopping distance permitted estimation of shock g-levels. In this case:

Kinetic Energy = Work

$KE = 1/2\, m v^2$

$\text{Work} = F_a d$

where m = mass of latch and insulator

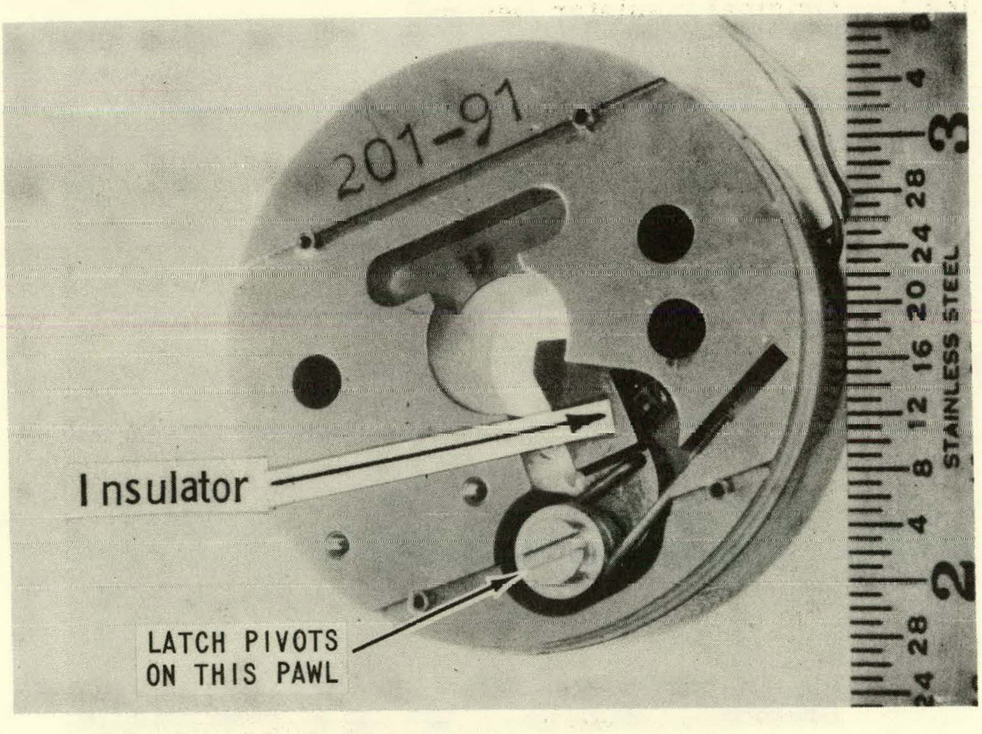


Figure 3. Insulator Shown Mounted in Timer

v = velocity of latch

F_a = average force on braking surface (target)

d = stopping distance; or plastic deflection of impact material (target) in the tests.

$F_a d = 1/2\ mv^2$

$$\frac{F_a}{m} = \frac{v^2}{2d}$$

And $\frac{F_a}{m} = a_a$

where a_a = average deceleration

$$a_a = \frac{v^2}{2d}$$

Assuming Triangular shock pulse:

$F_a t = 1/2\ F_m t$

where F_m = maximum force, and a_m = maximum deceleration

$F_a = ma_a$ and $F_m = ma_m$

then, $ma_a t = 1/2\ ma_m t$

$a_m = 2a_a$

$$\frac{a_m}{2} = \frac{v^2}{2d}$$

$$a_m = \frac{v^2}{d}$$

And $G = \frac{a}{g}$ where G = Number of g's

then, $G = \frac{v^2}{dg}$

if d = 0.030: $G = \dfrac{(300\ \text{ft/sec})^2\ (12\ \frac{\text{in}}{\text{ft}})}{(0.030\ \text{in})\ (32.2\ \text{ft/sec}^2)} = 1,120,000\ \text{g}$

if d = 0.010: G = 3,360,000 g

This analysis first assumed an average force, F_a, was acting throughout the stopping distance. This assumption was not correct but was necessary to provide a way to estimate the maximum force, which is more nearly correct.

ACTIVITY

Test Method

After the vicinity of shock g-level was determined, a test method was devised. Basically, the test equipment consisted of an air gun, target, photocells, and electronic read-out equipment. Block diagrams are included showing the pneumatic system (Figure 4) and the instrumentation system (Figure 5). The insulator was mounted on the flat end of a metal cylinder of 0.280-inch-diameter and 0.463-inch-length (Figure 6). The cylinder (projectile) was placed in the barrel of the air gun, restrained by the trigger, and an air reservoir was installed behind it. Toward the front end of the air gun two photocells were installed on the side of the barrel, and, then, in the end of the barrel, the target was held in place by a back up plate. In addition, an accelerometer was mounted in the back end of the back up plate. Figures 7 and 8 show the equipment ready to fire. Provision was made to allow the projectile to be mounted and shocked in either the forward or backward direction. The backward attitude would simulate the motor firing, while the forward attitude would simulate the latch striking the base wall. After the

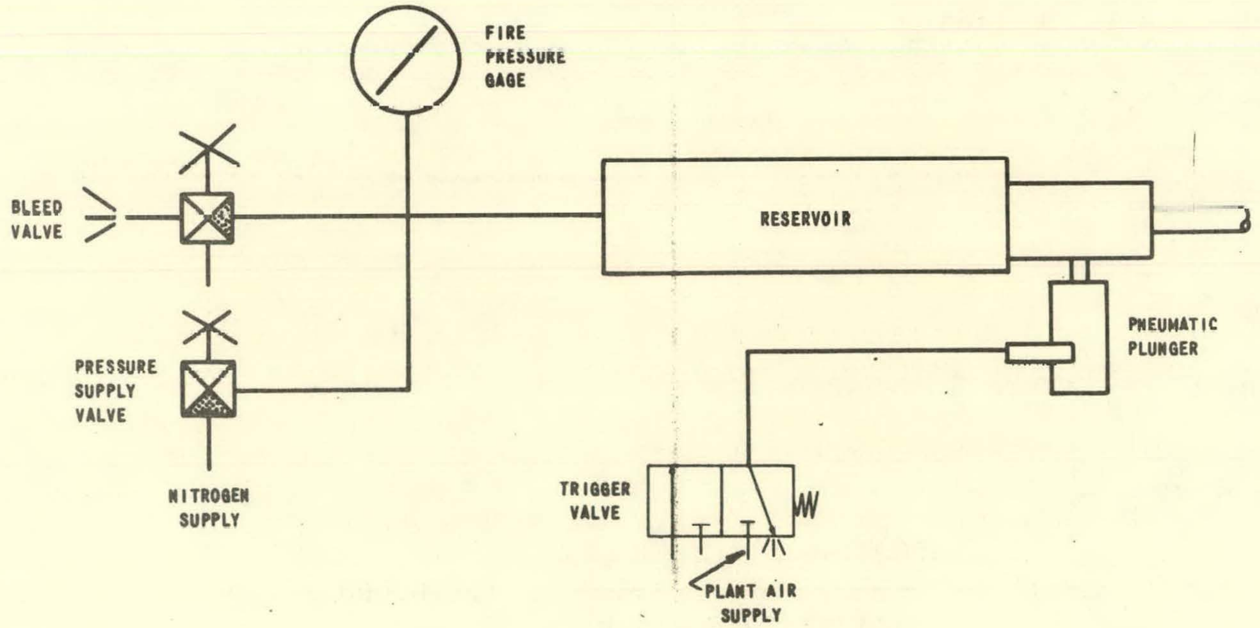


Figure 4. Pneumatic System for Testing Design

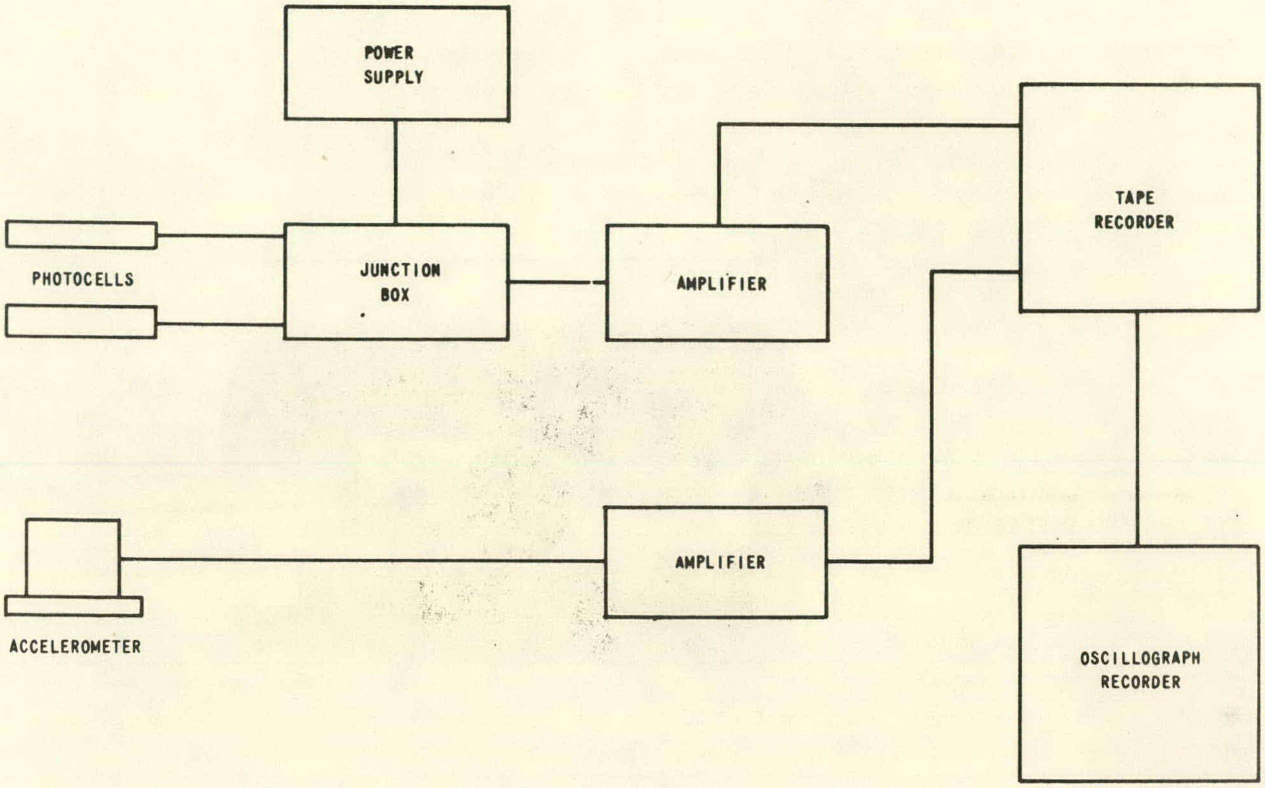


Figure 5. Instrumentation for Testing Design

test specimen was mounted in the test equipment, the procedure below was followed.

1. The electronic equipment was checked to verify readiness of the sensing and recording instruments.
2. The air (nitrogen gas) pressure was fixed at 200 or 220 psig (depending on the direction of test) in the air reservoir and the supply valve was closed.
3. The magnetic recording tape was started.
4. The air-actuated trigger was operated which allowed the projectile to accelerate through the barrel.
5. The tape was stopped.
6. The back up plate was removed and the target ejected.

Following this procedure, the tape information was transferred to an oscillograph chart and read, and the depth of projectile penetration into the target was measured. The condition of the insulator along with identification, velocity, and g-levels were recorded on the data sheet.

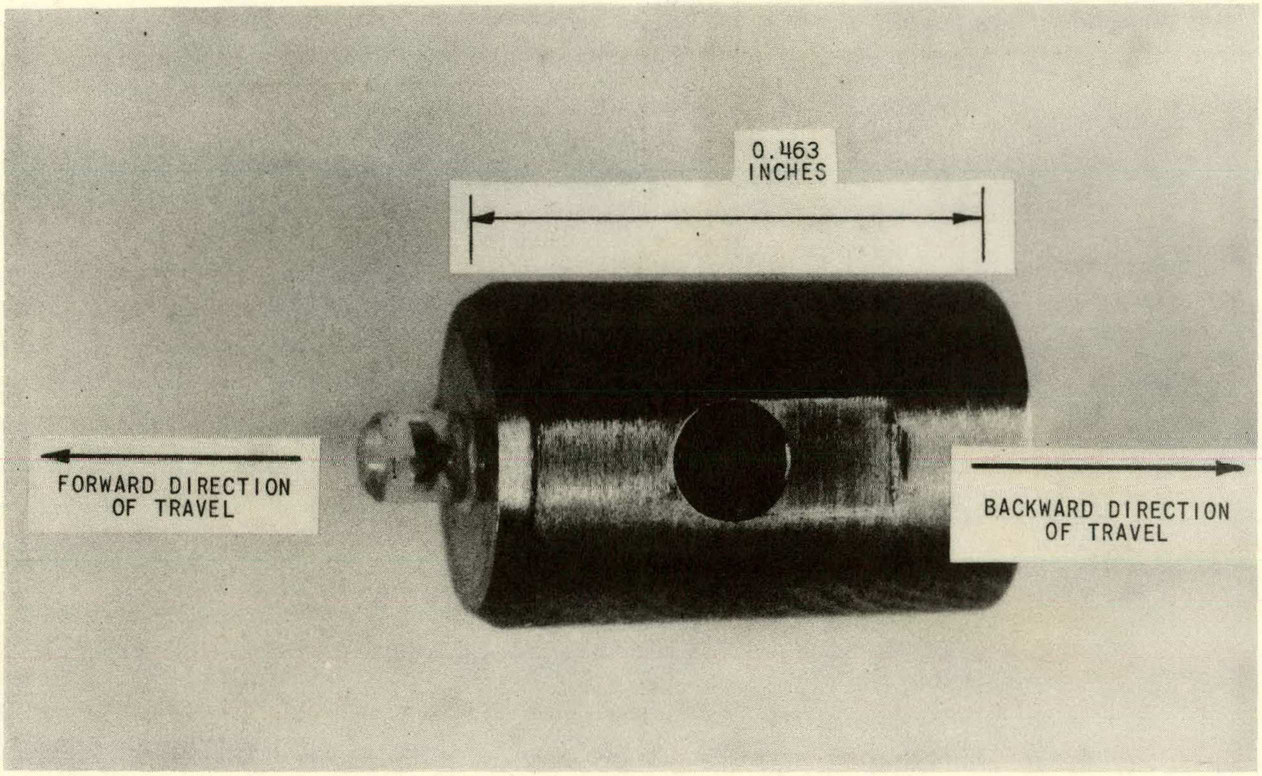


Figure 6. Insulator Mounted on Stainless Steel Projectile

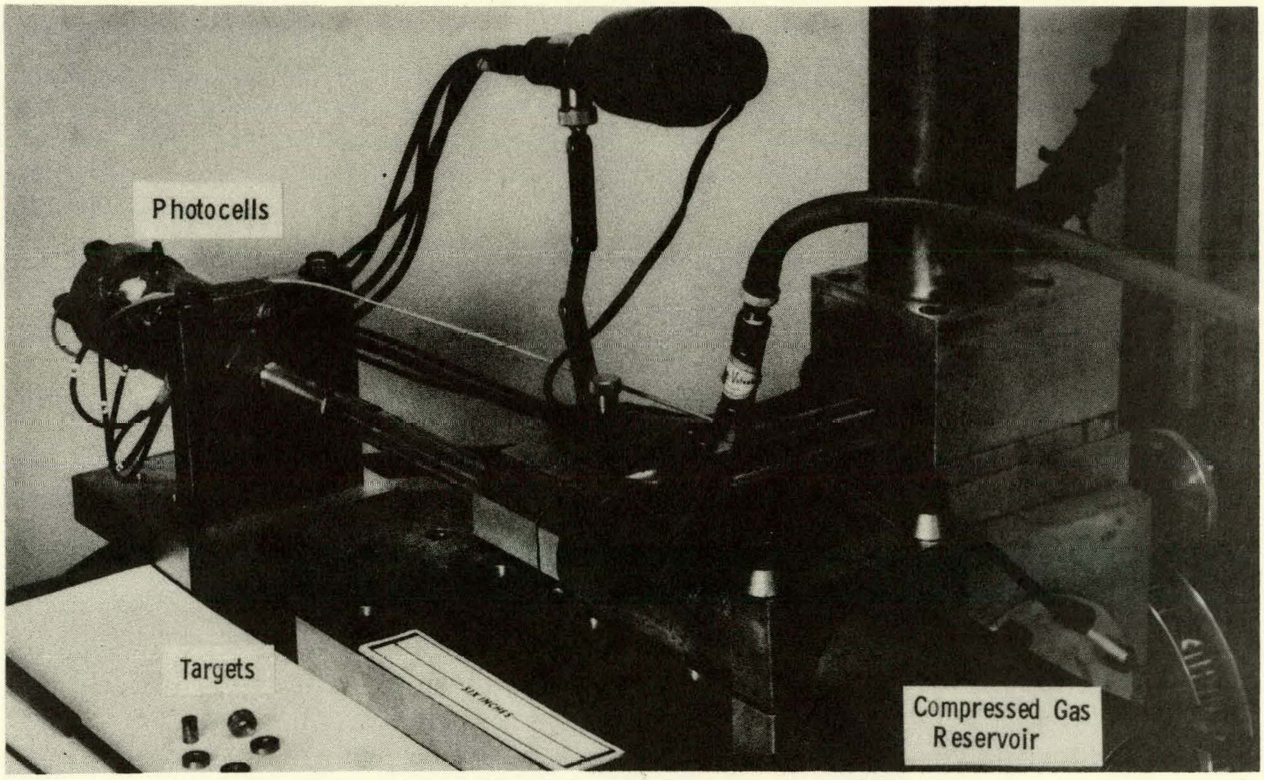


Figure 7. Launch Tube Setup for Measuring Impact Velocity

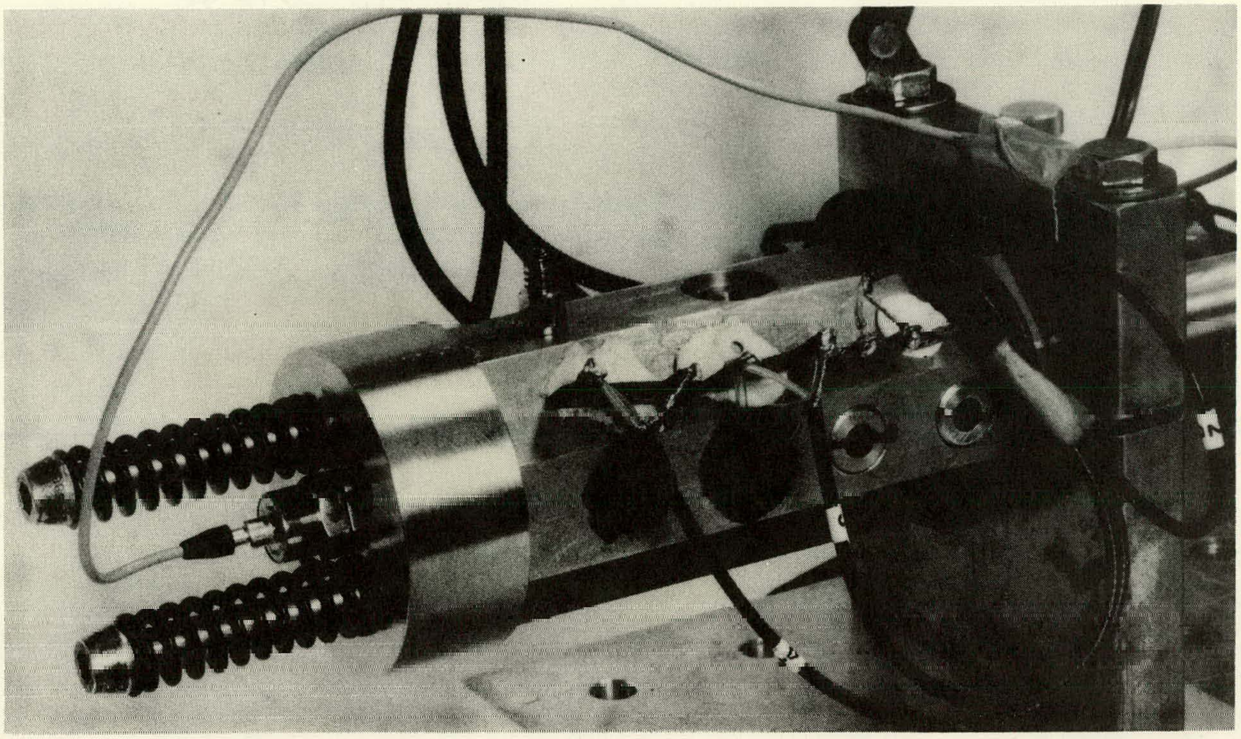
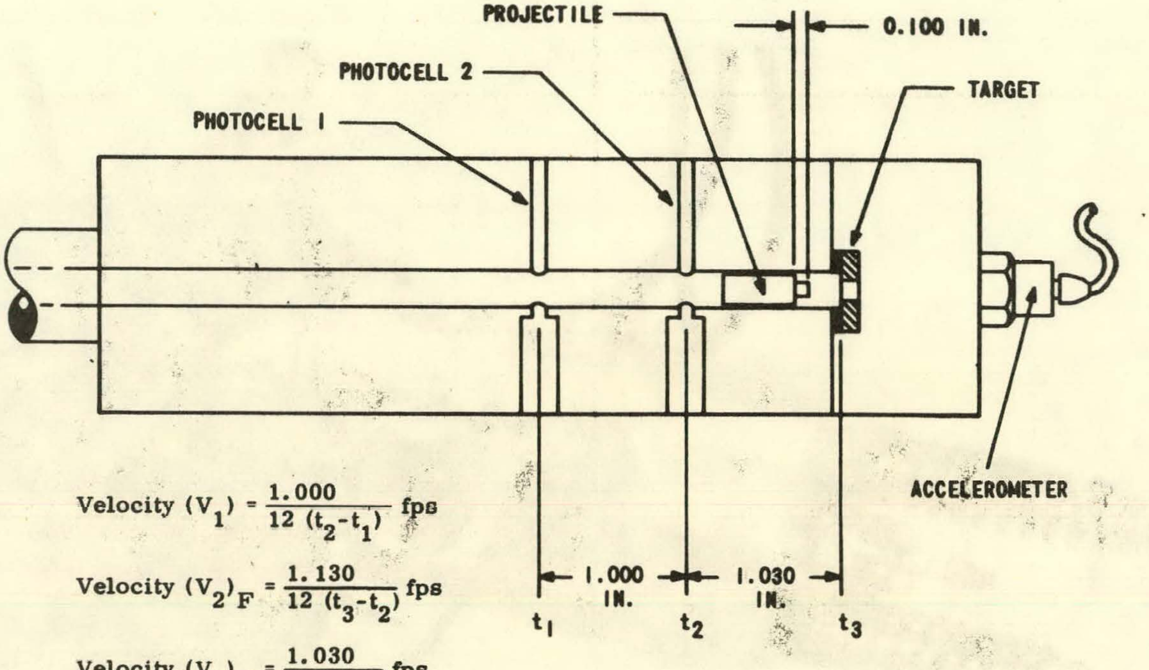


Figure 8. Impact End of Launch Tube

The key to g-level variation was the target, since the volocity of impact was known and it was desirable to maintain as close to 300 feet per second as practical. Three materials: copper, mild steel (hot rolled, low carbon), and 303 stainless steel were selected to achieve g-level changes. Further g-level adjustments were achieved by drilling three different sizes of holes, 5/32, 3/16, and 7/32 inch, in the target according to indications as the experiment progressed. The target was also left without a center hole to attain higher g-levels, but this could be done only when a backward direction of test was performed.

A basis of evaluation was needed which would relate the experimental results to the actual failure. The definition commonly used in shock testing is given in number of g's. But, because of the high level of g's in this situation, it was not possible to use conventional instrumentation to measure g's in the unit. The approach taken was to use the test system to locate the vicinity of failure for the existing design and to test and evaluate results of new designs in the same manner. Figure 9 diagrams the photocells, projectile, and target portion of the test system. Also included are the equations which were used to determine velocity on each test and eventually the g-level by use of equation $G = v^2/dg$. Figure 10 provides a sample calculation of an actual shock test and a reproduction of the corresponding oscillograph chart. All calculations were performed by computer and those tables are included in Appendix A. Location of the vicinity of failure was accomplished by testing 19 insulators of the original design. Five sample insulators were shocked in the forward direction on copper targets, and four samples in the backward



Velocity $(V_1) = \frac{1.000}{12\,(t_2-t_1)}$ fps

Velocity $(V_2)_F = \frac{1.130}{12\,(t_3-t_2)}$ fps

Velocity $(V_2)_B = \frac{1.030}{12(t_3-t_2)}$ fps

$(V_2)_F$ denotes forward direction of projectile travel (shown above).

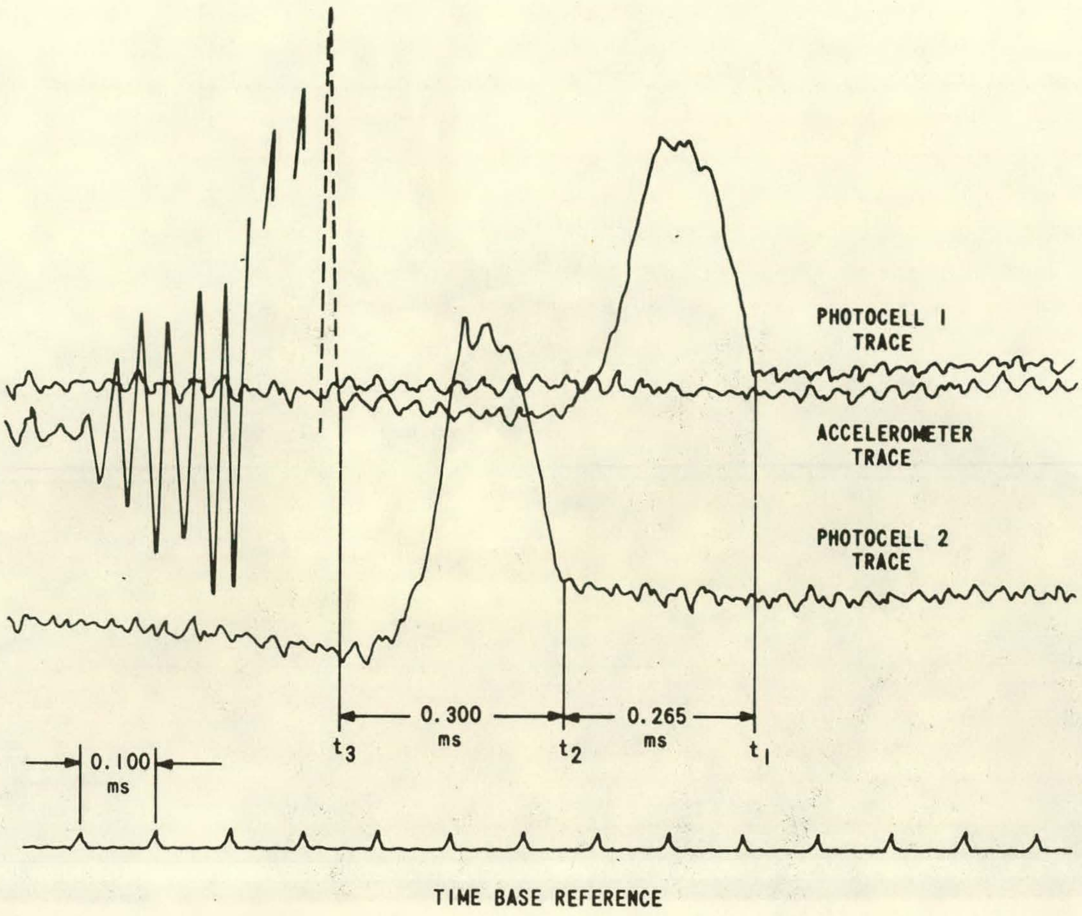
$(V_2)_B$ denotes backward direction of projectile travel.

Figure 9. Velocity Equations

direction on 303 stainless steel targets. Ten sample insulators (Model A) were shocked in the backward direction on mild steel targets with 5/32-inch-diameter center holes. Of these ten, one sample did not crack, four samples cracked slightly, and five samples cracked severely (Figure 11). The latter group of ten test results was accepted as the basis of evaluation, or the vicinity of failure.

A method of fastening the insulator to prevent slippage from the latch and from the projectile was investigated. It was expected that a threaded shaft would be necessary to solve the problem. As a temporary measure, however, insulators were pinned to the projectile to expedite testing. Previous tests were performed on specimens not utilizing the pinned feature, as it was necessary to maintain consistency with production models and failures to establish the basis. But, it was also necessary to determine the strength of a new design when rigidly mounted, since the forthcoming design would incorporate such a feature. Pinned and threaded shafts, however, were both under consideration for the mounting task.

The placement of the molding gate was a possible contributing factor in the failure of the insulator. A new mold had been ordered to reposition the gate,



$$V_1 = \frac{1.000(10)^3}{12(0.265\text{ms})} = 314 \text{ fps} \qquad V_{2F} = \frac{1.130(10)^3}{12(0.300\text{ms})} = 314 \text{ fps}$$

Figure 10. Typical Recorded Data and Velocity Calculations

but for an entirely different reason at the time it was ordered. The arrival of the new mold was very timely for the purpose of this experiment. The gate had been moved from the side wall to the end of the insulator. The irregular surface on the side of the insulator characteristic of the original, side gated, mold could have been an area of stress concentration. In consideration of the original reason for changing the mold and for the reason just stated, all further test specimens were manufactured by the end-gated mold. The notations "Side Gated" and "End Gated" in the data refer to this variable.

Nine additional design variables were tested by this experiment. Three pin designs (Drawings of all pin designs are included in Appendix B.), two materials (nylon and polycarbonate), and the extent of a dimensional control were all considered. A tabulation of the ten designs tested is included in Table 1 which identifies and defines the samples tested. The pin designs are included in Figure 12. The position of the pin within the encapsulation of plastic was the dimensional characteristic under consideration. This feature

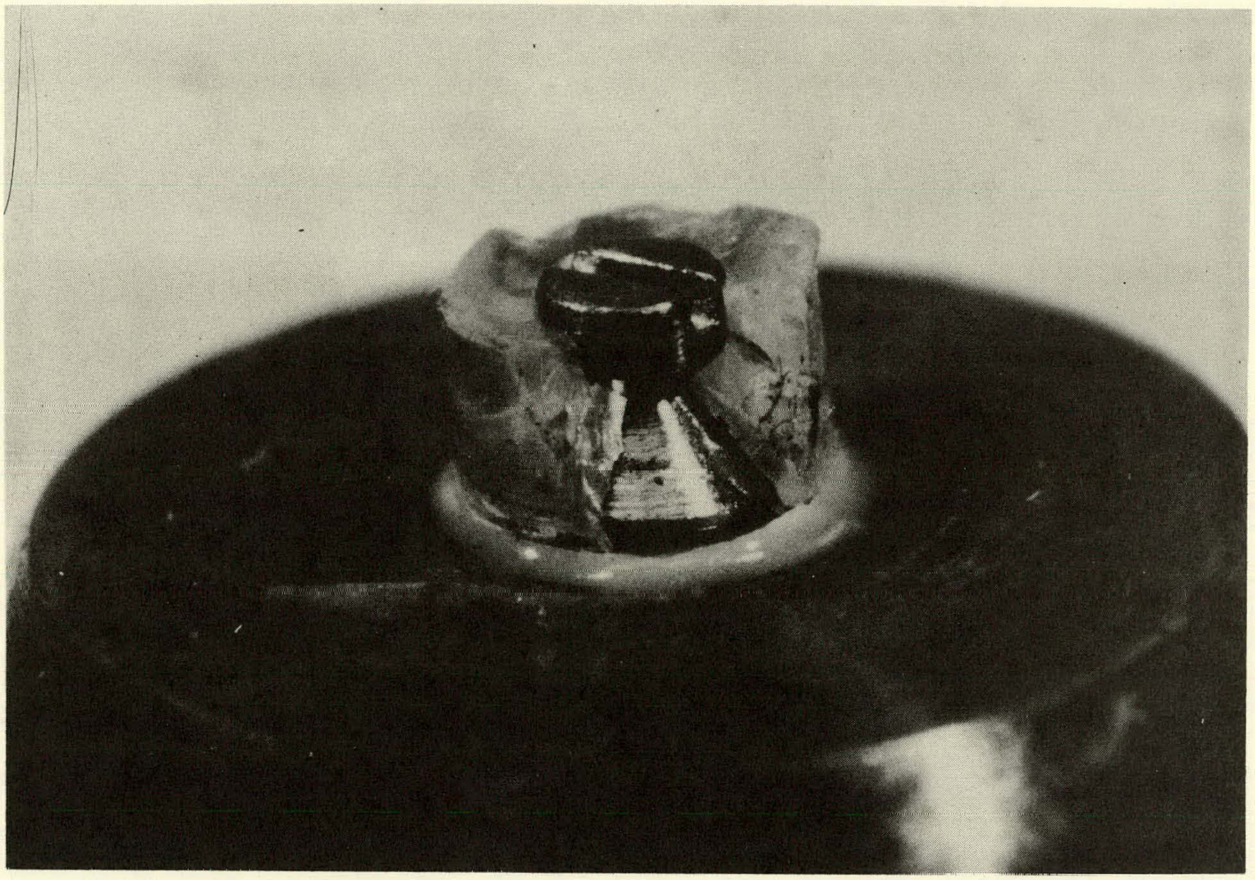


Figure 11. Original-Design Pin After One Mechanical Shock

is noted by the term eccentricity. Three zones of control were tested: up to 0.014-inch eccentricity; up to 0.0035-inch eccentricity; and up to 0.0025-inch eccentricity.

A test sequence was followed throughout the experiment and was modified as experience was gained. Consistent throughout the experiment, however, was the alteration of the direction of shock. All samples except in special tests as noted, were shocked first in the backward attitude and then in the forward attitude. The sequence was repeated until severe cracking of the plastic occurred. Beginning with sample models E through H, a uniform sequence of targets was also implemented into the test. This sequence is included in Table 2. A majority of the tests performed on sample models A through D used mild steel targets having a 5/32-inch center hole. In order to provide a common basis of comparison the first four shocks on each sample (Table 2) were performed using mild steel targets with a 5/32-inch center hole. Since most samples of models A through D failed by the second shock, this approach would indicate whether a new design could sustain more shocks of the same level. The remaining eight shocks provided by the uniform sequence of targets were designed to gradually increase the shock level.

Attention was directed to the possibility of material degradation during environmental exposure. It was considered valuable to investigate the effect of temperature shock on the nylon parts of the original configuration. Five projectiles were specially manufactured for this test. Four mounting holes were provided on the back end of each projectile. Two insulators from stock and two insulators which had been subjected to temperature shock tests were installed on each projectile. This multiple mounting provision provided a

Table 1. Description of Test Samples

Sample Model	Samples Tested	Pin Design	Insulator Material	Design Details
A	10	Type 1	Nylon	Insulator side gated Eccentricity to 0.014 inch
A'	5	Type 1	Nylon	Insulator end gated Eccentricity to 0.014 inch
B	7	Type 2	Nylon	Insulator end gated Eccentricity to 0.014 inch
B'	11	Type 2	Nylon	Insulator end gated Eccentricity to 0.0025 inch
C	3	Type 1	Nylon	Insulator end gated Eccentricity to 0.0035 inch
D	9	Type 2	Polycarbonate	Insulator end gated Eccentricity to 0.0035 inch
E	5	Type 3	Nylon	Insulator end gated Eccentricity to 0.0035 inch
F	5	Type 4	Nylon	Insulator end gated Eccentricity to 0.0035 inch
G	5	Type 3	Polycarbonate	Insulator end gated Eccentricity to 0.0035 inch
H	5	Type 4	Polycarbonate	Insulator end gated Eccentricity to 0.0035 inch
I	10	Type 1	Nylon	Insulator end gated Eccentricity to 0.0035 inch (from stock supply)
I'	10	Type 1	Nylon	Insulator end gated Eccentricity to 0.0035 inch (temperature shocked prior to testing)

means of direct comparison and elimina the question of shock level differences, as would occur in single insulator tests. Each set of four insulators would undergo the same shock wave. Table 3 indicates the test sequence followed for these tests.

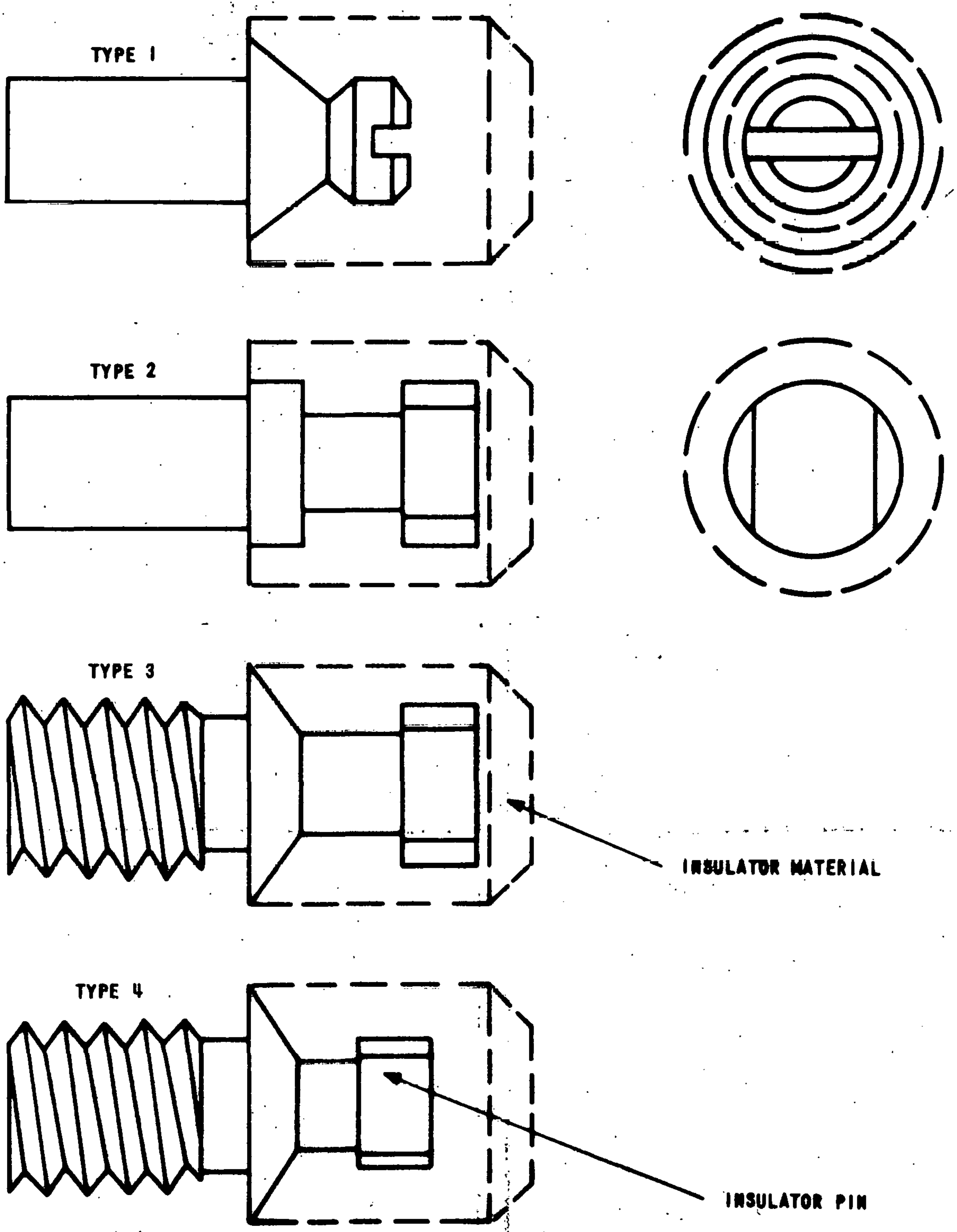


Figure 12. The Four Insulator Pin Designs

Table 2. Test Sequence I

Shot Number	Direction of Travel	Target Material	Hole Size (in.)
1	Backward	Hot-rolled steel	5/32
2	Forward	Hot-rolled steel	5/32
3	Backward	Hot-rolled steel	5/32
4	Forward	Hot-rolled steel	5/32
5	Backward	Hot-rolled steel	Solid
6	Forward	Hot-rolled steel	5/32
7	Backward	303 SS	3/16
8	Forward	303 SS	3/16
9	Backward	303 SS	5/32
10	Forward	303 SS	5/32
11	Backward	303 SS	Solid
12	Forward	303 SS	5/32

Table 3. Test Sequence II

Shot Number	Direction of Travel	Target Material	Hole Size (in.)
1	Backward	Hot-rolled steel	5/32
2	Backward	Hot-rolled steel	5/32
3	Backward	Hot-rolled steel	Solid
4	Backward	Hot-rolled steel	Solid
5	Backward	303 SS	3/16
6	Backward	303 SS	3/16
7	Backward	303 SS	5/32
8	Backward	303 SS	5/32
9	Backward	303 SS	Solid
10	Backward	303 SS	Solid

Test Results

The data of all tests discussed are reported in graphic form for simplification. The four graphs included as Figures 13, 14, 15, and 16 present test results for insulators having common characteristics and test conditions as listed below

Figure 13. (Models A, A', B, B', C and D)

1. Unthreaded pin
2. First shock only
3. Backward attitude only
4. All targets were mild steel (hot rolled)

Figure 14. (Models A, A', B', C and D)

1. Unthreaded pin
2. First shock only
3. Backward attitude only
4. All targets were 303 stainless steel

Figure 15. (Models E, F, G, and H)

1. Threaded pins
2. Uniform test sequence (Table 2)

Figure 16. (Models I and I')

1. Original design
2. All shocked backward

Results are discussed briefly on a comparative basis in the following tabulation.

Compare Sample	Primary Difference	Conclusion
A to A'	Side Gate to End Gate	Figure 13 gives slight indication of improvement using end gated mold. Figure 14, which reports higher shock levels, does not show an improved condition. Improvement was not proved and there was failure in the critical range.
B' to C	Pin type 2 to AY277540	There is very little data for C but A and A' both used the same AY277540 pin and did not demonstrate adequate strength. Performance was inadequate with both B' and C. No improvement is credited to pin type 2. (Figures 13 and 14).
A to B(A')	Side Gate to End Gate and AY277540 to Pin type 2	Figure 13 shows a good sample of Model B. Results for B were similar to A' (of the first comparison) with no failures at lower g-levels. Note that the only difference between A' and B is the pin type. Considering A in contrast with A' and B, there is evidence that either the end gate or type 2 pin improves shock resistance at levels below 2 million g's.
A' to C and B to B'	Eccentricity up to 0.014 inch Eccentricity up to 0.0035 for C Eccentricity up to 0.0025 for B' Pin types are consistent from A' to C and from B to B'	The combined data of Figures 13 and 14 do not indicate improvement as a result of better concentricity of plastic over metal.
B' to D	Nylon to Polycarbonate	Figure 13 shows no failures for Model D of eight shocks recorded, while seven failures out of ten shocks are shown for Model B'. Additionally the shock levels were higher in several tests for Model D than for Model A. Figure 14 shows one shock each for Models B' and D, and both are failures. The

Compare Sample	Primary Difference	Conclusion
		nylon failed at about 2.6 million g's, while the polycarbonate failed at 4.5 million g's. There was a significant improvement in shock resistance demonstrated by this comparison changing from nylon to polycarbonate.
E to F	Pin type 3 to Pin type 4	Figure 15 shows all three nylon samples had failed by the third shock for both pin models. No superiority can be attributed to either pin design.
E to G and F to H	Nylon to Polycarbonate	Figure 15 shows that the polycarbonate insulators survived through the third shock with only one insulator having a large crack. By the third shock, all nylon insulators had come apart. Polycarbonate was clearly demonstrated to be more shock resistant.
G to H	Pin type 3 to Pin type 4	Figure 15 shows 5 samples of Model G survived 12 shocks each with only 1 insulator developing a large crack. The large crack occurred on the eighth shock and survived four additional shocks without coming apart. Two pin type 4 insulators had come apart by the sixth shock and a third by the 8th shock. The remaining two insulators of pin type 4 had developed large cracks by the ninth and tenth shocks, but did not fail. Pin type 3 design is clearly superior to pin type 4 design.
I to I'	All insulators were of the original design. I' had been subjected to thermal shock tests which involved stabilization at and rapid change from temperatures of -30°F to 150°F.	All samples failed except one. The one which survived ten shocks had been thermal shocked. No effect could be attributed to the thermal-shock environmental test.

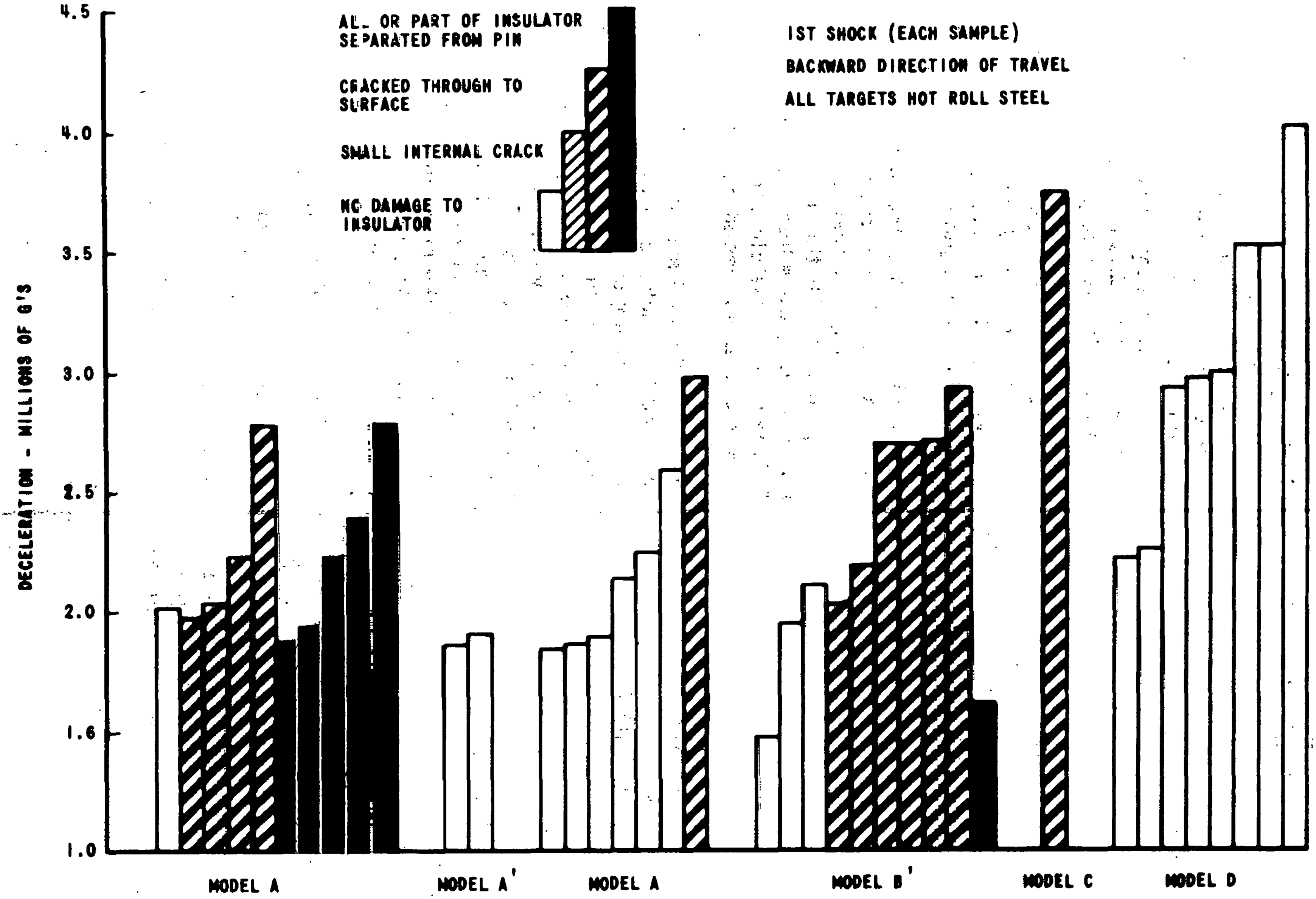


Figure 13. Results of Tests on Models A, A', B, B', C and D

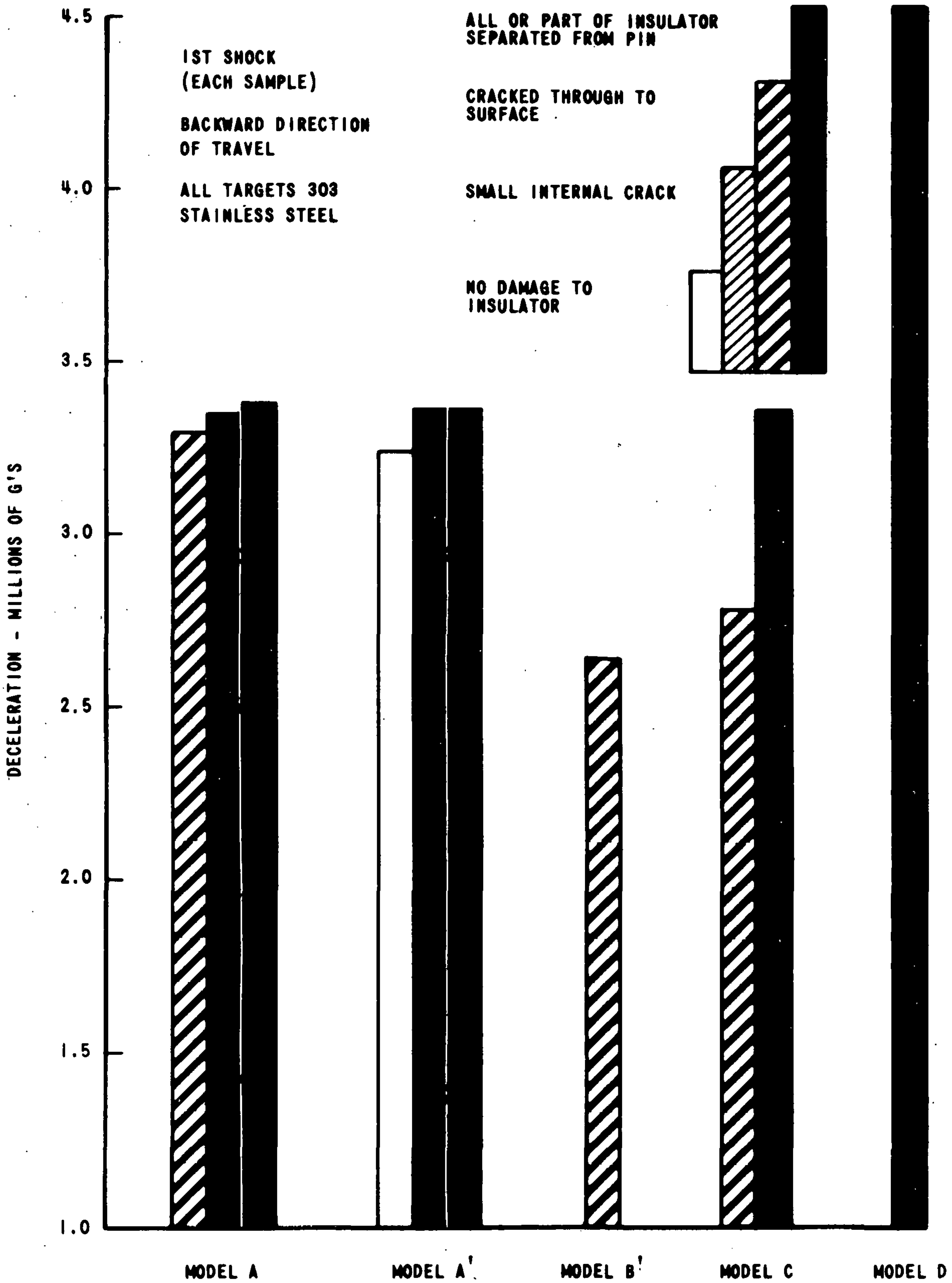


Figure 14. Results of Tests on Models A, A', B', C and D

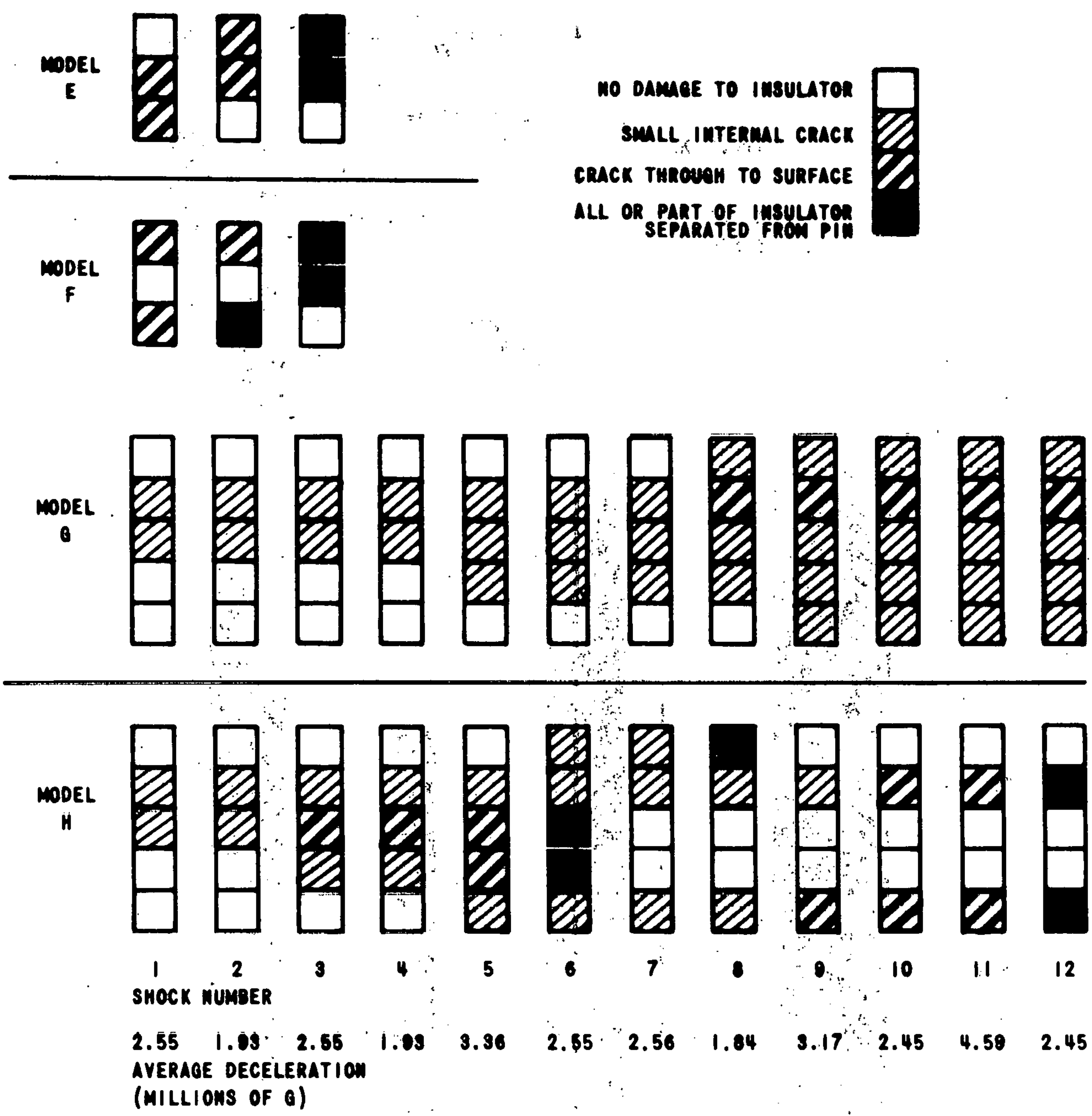


Figure 15. Results of Tests on Models E, F, G, and H

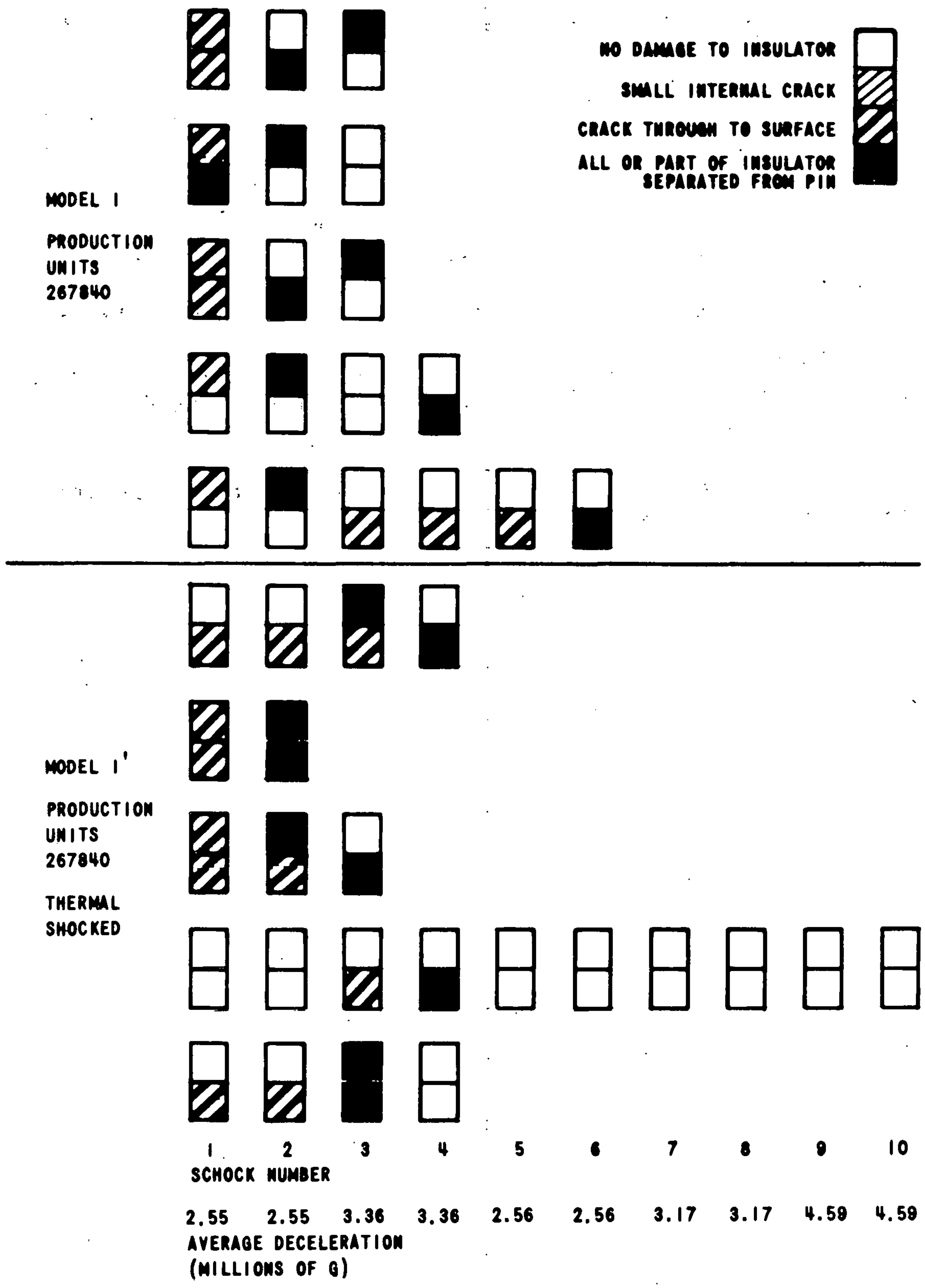


Figure 16. Results of Tests on Models I and I'

In the interest of clarity, the conclusions reached by the evaluation of data of the experiment are itemized below.

1. Either the end-gated mold or pin type 2 as opposed to side gated mold and pin AY277540 effected improved shock resistance at shock levels below 2 million g's.
2. Concentricity of the plastic over the metal pin does not effect shock resistance in the tolerance range from 0.0025 inch to 0.014 inch.
3. Polycarbonate plastic is significantly more shock resistant than nylon.
4. Pin type 3 is significantly superior to pin type 4 as verified by tests of polycarbonate insulators. (The pin with the larger internal metal volumn was superior.)
5. The Thermal Shock environment did not effect the shock resistance of nylon either to improve it or to degrade it.

APPENDIX A

TABLE OF COMPUTER CALCULATIONS

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Table A-1. Velocity and Deceleration: Definitions

Totals:	Total of four displacement measurements taken on target.
Average S:	Average of the four measurements.
Time B:	Time between photocell rise and accelerometer rise during a backward test (in microseconds).
Velocity B:	Velocity of projectile during a backward test as determined by time B.
Spec. G (M):	G level in millions as determined from Average S.
Time F:	Same as Time B, except for a forward test.
Velocity F:	Same as Velocity B, except for a forward test.

Total S	AVG. S	Time B	Vel. B	AVG. S	Spec G (M)	Time F	Vel. F
0.010	0.0025	240.00	358.33	0.0025	13.4400	260.00	360.58
0.011	0.0028	241.00	356.85	0.0028	12.2182	261.00	359.20
0.012	0.0030	242.00	355.37	0.0030	11.2000	262.00	357.82
0.013	0.0032	243.00	353.91	0.0032	10.3385	263.00	356.46
0.014	0.0035	244.00	352.46	0.0035	9.6000	264.00	355.11
0.015	0.0037	245.00	351.02	0.0037	8.9600	265.00	353.77
0.016	0.0040	246.00	349.59	0.0040	8.4000	266.00	352.44
0.017	0.0042	247.00	348.18	0.0042	7.9059	267.00	351.12
0.018	0.0045	248.00	346.77	0.0045	7.4667	268.00	349.81
0.019	0.0047	249.00	345.38	0.0047	7.0737	269.00	348.51
0.020	0.0050	250.00	344.00	0.0050	6.7200	270.00	347.22
0.021	0.0052	251.00	342.63	0.0052	6.4000	271.00	345.94
0.022	0.0055	252.00	341.27	0.0055	6.1091	272.00	344.67
0.023	0.0057	253.00	339.92	0.0057	5.8435	273.00	343.41
0.024	0.0060	254.00	338.58	0.0060	5.6000	274.00	342.15
0.025	0.0062	255.00	337.25	0.0062	5.3760	275.00	340.91
0.026	0.0065	256.00	335.94	0.0065	5.1692	276.00	339.67
0.027	0.0067	257.00	334.63	0.0067	4.9778	277.00	338.45
0.028	0.0070	258.00	333.33	0.0070	4.8000	278.00	337.23
0.029	0.0072	259.00	332.05	0.0072	4.6345	279.00	336.02
0.030	0.0075	260.00	330.77	0.0075	4.4800	280.00	334.82
0.031	0.0077	261.00	329.50	0.0077	4.3355	281.00	333.63

Table A-1. Continued. Velocity and Deceleration

Total S	AVG. S	Time B	Vel. B	AVG. S	Spec G (M)	Time F	Vel. F
0.032	0.0080	262.00	328.24	0.0080	4.2000	282.00	332.45
0.033	0.0082	263.00	327.00	0.0082	4.0727	283.00	331.27
0.034	0.0085	264.00	325.76	0.0085	3.9529	284.00	330.11
0.035	0.0087	265.00	324.53	0.0087	3.8400	285.00	328.95
0.036	0.0090	266.00	323.31	0.0090	3.7333	286.00	327.80
0.037	0.0092	267.00	322.10	0.0092	3.6324	287.00	326.66
0.038	0.0095	268.00	320.90	0.0095	3.5368	288.00	325.52
0.039	0.0097	269.00	319.70	0.0097	3.4462	289.00	324.39
0.040	0.0100	270.00	318.52	0.0100	3.3600	290.00	323.28
0.041	0.0102	271.00	317.34	0.0102	3.2780	291.00	322.16
0.042	0.0105	272.00	316.18	0.0105	3.2000	292.00	321.06
0.043	0.0107	273.00	315.02	0.0107	3.1256	293.00	319.97
0.044	0.0110	274.00	313.87	0.0110	3.0545	294.00	318.88
0.045	0.0112	275.00	312.73	0.0112	2.9867	295.00	317.80
0.046	0.0115	276.00	311.59	0.0115	2.9217	296.00	316.72
0.047	0.0117	277.00	310.47	0.0117	2.8596	297.00	315.66
0.048	0.0120	278.00	309.35	0.0120	2.8000	298.00	314.60
0.049	0.0122	279.00	308.24	0.0122	2.7429	299.00	313.55
0.050	0.0125	280.00	307.14	0.0125	2.6880	300.00	312.50
0.051	0.0127	281.00	306.05	0.0127	2.6353	301.00	311.46
0.052	0.0130	282.00	304.96	0.0130	2.5846	302.00	310.43
0.053	0.0132	283.00	303.89	0.0132	2.5358	303.00	309.41
0.054	0.0135	284.00	302.82	0.0135	2.4889	304.00	308.39
0.055	0.0137	285.00	301.75	0.0137	2.4436	305.00	307.38
0.056	0.0140	286.00	300.70	0.0140	2.4000	306.00	306.37
0.057	0.0142	287.00	299.65	0.0142	2.3579	307.00	305.37
0.058	0.0145	288.00	298.61	0.0145	2.3172	308.00	304.38
0.059	0.0147	289.00	297.58	0.0147	2.2780	309.00	303.40
0.060	0.0150	290.00	296.55	0.0150	2.2400	310.00	302.42
0.061	0.0152	291.00	295.53	0.0152	2.2033	311.00	301.45
0.062	0.0155	292.00	294.52	0.0155	2.1677	312.00	300.48
0.063	0.0157	293.00	293.52	0.0157	2.1333	313.00	299.52
0.064	0.0160	294.00	292.52	0.0160	2.1000	314.00	298.57
0.065	0.0162	295.00	291.53	0.0162	2.0677	315.00	297.62
0.066	0.0165	296.00	290.54	0.0165	2.0364	316.00	296.68
0.067	0.0167	297.00	289.56	0.0167	2.0060	317.00	295.74
0.068	0.0170	298.00	288.59	0.0170	1.9765	318.00	294.81
0.069	0.0172	299.00	287.63	0.0172	1.9478	319.00	293.89
0.070	0.0175	300.00	286.67	0.0175	1.9200	320.00	292.97
0.071	0.0177	301.00	285.71	0.0177	1.8930	321.00	292.06
0.072	0.0180	302.00	284.77	0.0180	1.8667	322.00	291.15
0.073	0.0182	303.00	283.83	0.0182	1.8411	323.00	290.25

Table A-1. Continued. Velocity and Deceleration

Total S	AVG. S	Time B	Vel. B	AVG. S	Spec G (M)	Time F	Vel. F
0.074	0.0185	304.00	282.89	0.0185	1.8162	324.00	289.35
0.075	0.0187	305.00	281.97	0.0187	1.7920	325.00	288.46
0.076	0.0190	306.00	281.05	0.0190	1.7684	326.00	287.58
0.077	0.0192	307.00	280.13	0.0192	1.7455	327.00	286.70
0.078	0.0195	308.00	279.22	0.0195	1.7231	328.00	285.82
0.079	0.0197	309.00	278.32	0.0197	1.7013	329.00	284.95
0.080	0.0200	310.00	277.42	0.0200	1.6800	330.00	284.09
0.081	0.0202	311.00	276.53	0.0202	1.6593	331.00	283.23
0.082	0.0205	312.00	275.64	0.0205	1.6390	332.00	282.38
0.083	0.0207	313.00	274.76	0.0207	1.6193	333.00	281.53
0.084	0.0210	314.00	273.89	0.0210	1.6000	334.00	280.69
0.085	0.0212	315.00	273.02	0.0212	1.5812	335.00	279.85
0.086	0.0215	316.00	272.15	0.0215	1.5628	336.00	279.02
0.087	0.0217	317.00	271.29	0.0217	1.5448	337.00	278.19
0.088	0.0220	318.00	270.44	0.0220	1.5273	338.00	277.37
0.089	0.0222	319.00	269.59	0.0222	1.5101	339.00	276.55
0.090	0.0225	320.00	268.75	0.0225	1.4933	340.00	275.74
0.091	0.0227	321.00	267.91	0.0227	1.4769	341.00	274.93
0.092	0.0230	322.00	267.08	0.0230	1.4609	342.00	274.12
0.093	0.0232	323.00	266.25	0.0232	1.4452	343.00	273.32
0.094	0.0235	324.00	265.43	0.0235	1.4298	344.00	272.53
0.095	0.0237	325.00	264.62	0.0237	1.4147	345.00	271.74
0.096	0.0240	326.00	263.80	0.0240	1.4000	346.00	270.95
0.097	0.0242	327.00	263.00	0.0242	1.3856	347.00	270.17
0.098	0.0245	328.00	262.20	0.0245	1.3714	348.00	269.40
0.099	0.0247	329.00	261.40	0.0247	1.3576	349.00	268.62
0.100	0.0250	330.00	260.61	0.0250	1.3440	350.00	267.86
0.101	0.0252	331.00	259.82	0.0252	1.3307	351.00	267.09
0.102	0.0255	332.00	259.04	0.0255	1.3176	352.00	266.34
0.103	0.0257	333.00	258.26	0.0257	1.3049	353.00	265.58
0.104	0.0260	334.00	257.49	0.0260	1.2923	354.00	264.83
0.105	0.0262	335.00	256.72	0.0262	1.2800	355.00	264.08
0.106	0.0265	336.00	255.95	0.0265	1.2679	356.00	263.34
0.107	0.0267	337.00	255.19	0.0267	1.2561	357.00	262.61
0.108	0.0270	338.00	254.44	0.0270	1.2444	358.00	261.87
0.109	0.0272	339.00	253.69	0.0272	1.2330	359.00	261.14
0.110	0.0275	340.00	252.94	0.0275	1.2218	360.00	260.42
0.111	0.0277	341.00	252.20	0.0277	1.2108	361.00	259.70
0.112	0.0280	342.00	251.46	0.0280	1.2000	362.00	258.98
0.113	0.0282	343.00	250.73	0.0282	1.1894	363.00	258.26

Table A-1. Continued. Velocity and Deceleration

Total S	AVG. S	Time B	Vel. B	AVG. S	Spec G (M)	Time F	Vel. F
0.114	0.0285	344.00	250.00	0.0285	1.1789	364.00	257.55
0.115	0.0287	345.00	249.28	0.0287	1.1687	365.00	256.85
0.116	0.0290	346.00	248.55	0.0290	1.1586	366.00	256.15
0.117	0.0292	347.00	247.84	0.0292	1.1487	367.00	255.45
0.118	0.0295	348.00	247.13	0.0295	1.1390	368.00	254.76
0.119	0.0297	349.00	246.42	0.0297	1.1294	369.00	254.07
0.120	0.0300	350.00	245.71	0.0300			

APPENDIX B

PIN DESIGN DRAWINGS

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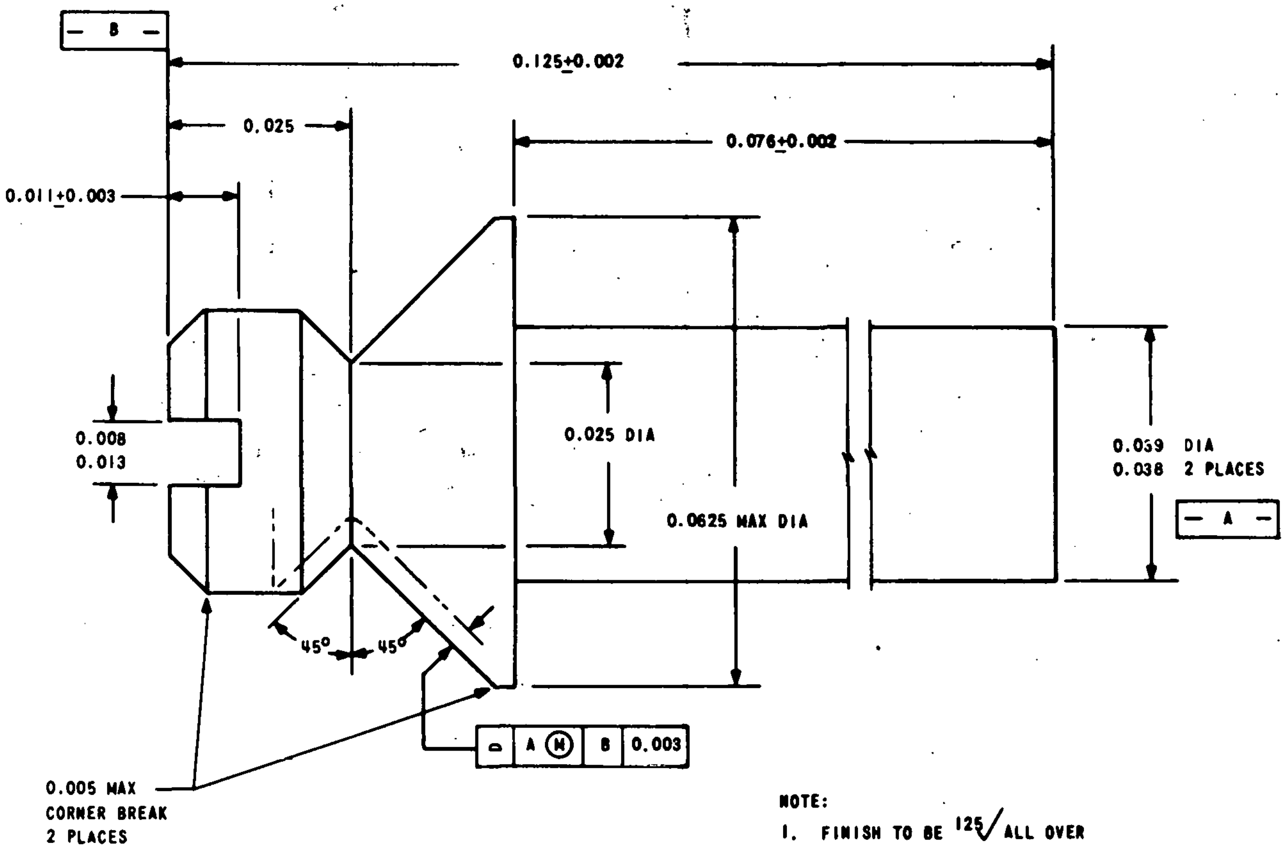


Figure B-1. Pin Type 1

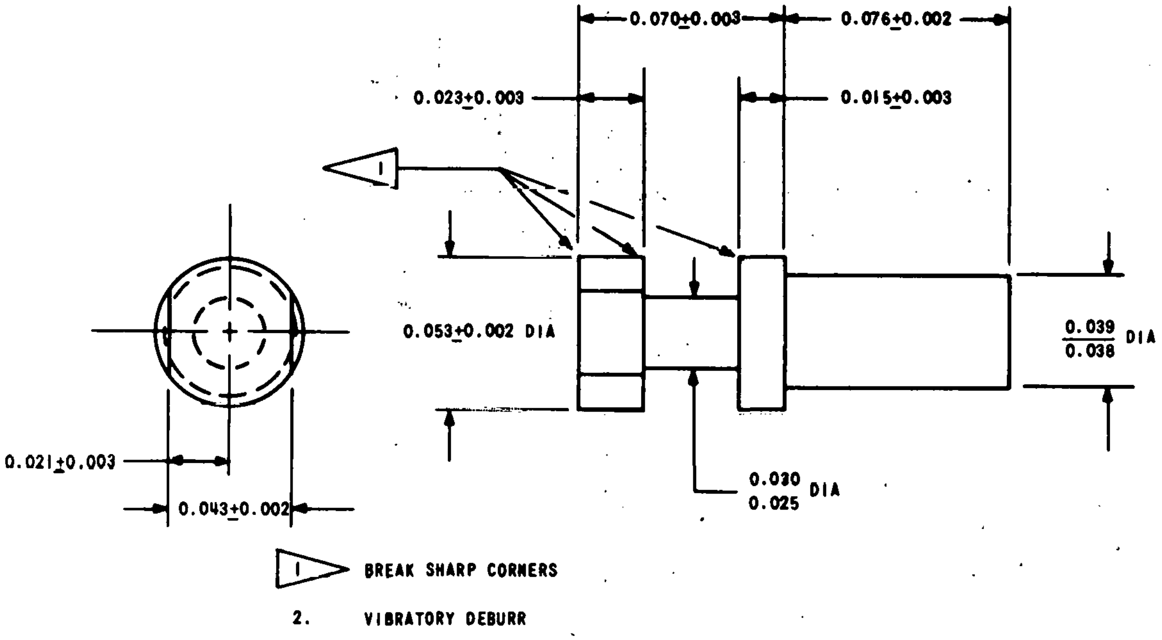
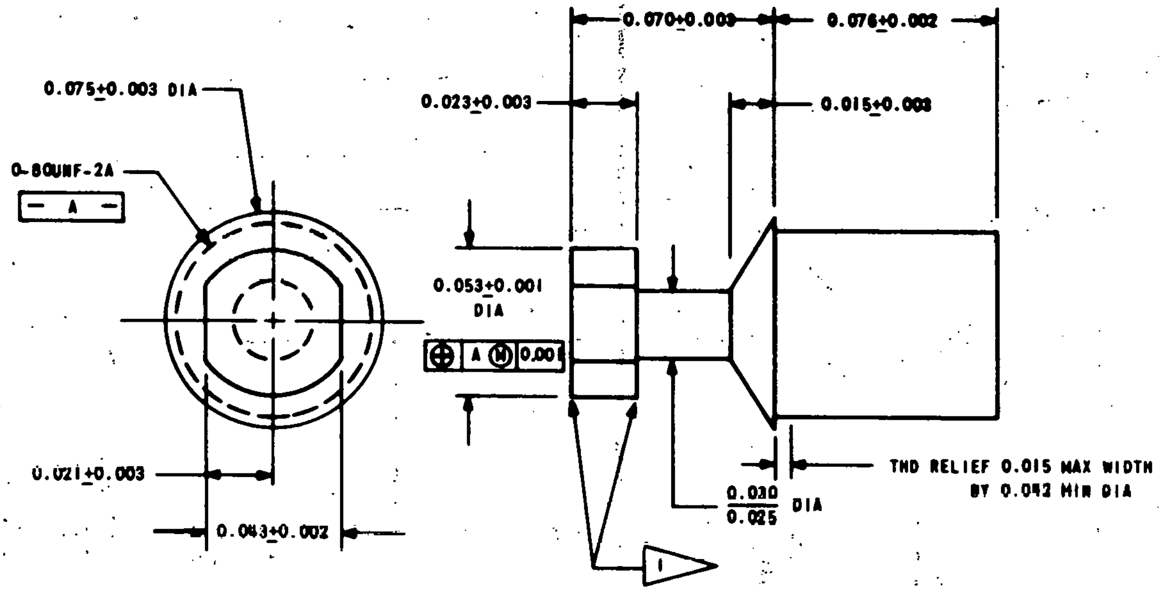


Figure B-2. Pin Type 2

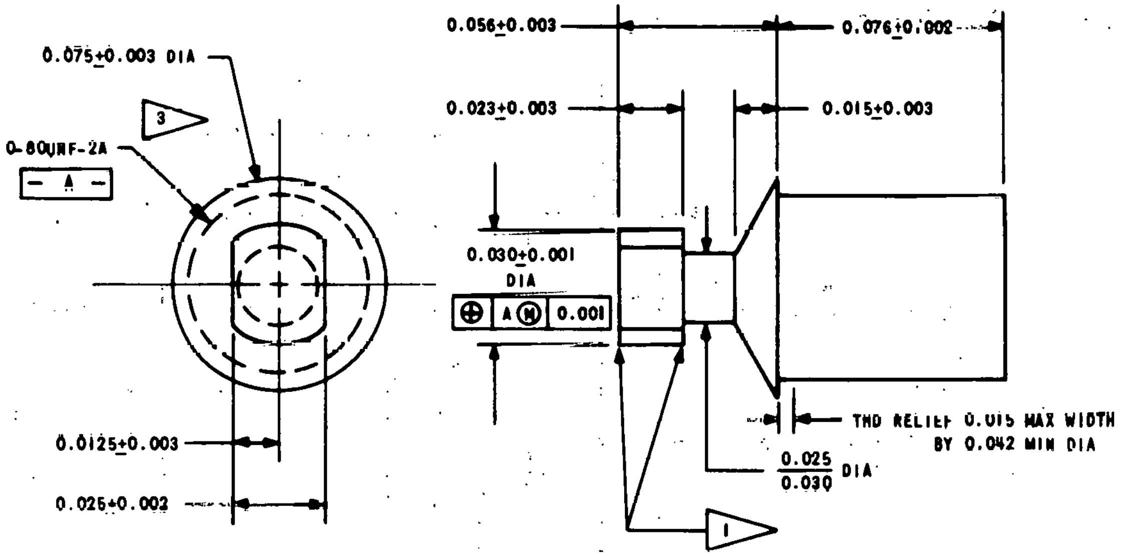


1 BREAK SHARP CORNERS

2\. VIBRATORY DEBURR

3\. MAJOR DIA TOL LIMITED TO 0.0563/0.0573

Figure B-3. Pin Type 3



1 BREAK SHARP CORNERS

2\. VIBRATORY DEBURR

3 MAJOR DIA TOL LIMITED TO 0.0563/0.0573

Figure B-4. Pin Type 4