3085

682

# TARADCOM
## LABORATORY
## TECHNICAL REPORT

NO. 12521

ISOTHERMALFORGING OF

LARGE GEARS BY P/M TECHNIQUES

CONTRACT DAAK 30-78-C-0099

by B. L. Ferguson, TRW
D. T. Ostberg, TARADCOM

20040121 184

Approved for Public Release, Distribution Unlimited

U.S. ARMY TANK-AUTOMOTIVE
RESEARCH AND DEVELOPMENT COMMAND
Warren, Michigan 48090

[redacted]

## FOREWORD

This final report covers work performed on Contract DAAK-30-78-C-0099. The contract with TRW Inc., Cleveland, Ohio was administered under the direction of Mr. Kerold F. Chesney (retired), Mr. Vinod Patel (deceased) and Mr. Donald Ostberg, U.S. Army Tank Automotive Research and Development Command, Warren, Michigan.

The program was assigned to the Powder Technology Section of TRW Materials Technology and Mr. J. N. Fleck, Section Manager. Engineering and technical responsibilities resided with Dr. B. L. Ferguson and Mr. J. C. Arnold respectively. Mr. F. T. Lally was a program consultant.

## ABSTRACT

The objective of this program was to extend the development of isothermal forging of steel powder parts to near-net shapes with plan areas larger than 100 square inches ($6.45 \times 10^{-2} m^2$). Previously, it had been determined that the application of isothermal forging to near-net shape parts production reduces the forging pressure needed to achieve both full density and a completely filled die cavity. Thus, larger parts may be forged with existing equipment.

The prototype component in this project was the final drive gear of the M60 tank (P/N 19207-7364141). This gear has an outside diameter of 19.4 inches ($4.93 \times 10^{-1} m$) and a plan area of 296 square inches ($1.91 \times 10^{-1} m^2$). The 66 teeth were to be forged to shape, allowing 0.005 to 0.010 inches ($1.3$ to $2.5 \times 10^{-4} m$) per tooth face for grinding and crowning after carburizing. Prealloyed 4600 grade steel powder was to be used.

Based on the finished part dimensions, a forging was designed, a hot die set for isothermal forging was designed, and a segmented preform and compaction tooling were designed. At this point quotations from tool builders indicated serious cost and time overruns. Coupling these problems with lubrication/die release problems experienced in a sister program,* a decision was made to halt this program until such problems were overcome or a suitable redirection option could be formulated.

This report covers the design steps completed on the program, the tooling quotations, alternative action possibilities, and concludes with a recommendation for redirection.

This is the third phase of the effort. The results of Phase I and Phase II are documented in TARADCOM Final Report Number 12519, "Forging of Powder Metallurgy Gears."


* Contract DAAK-30-78-0029

# 1.0 INTRODUCTION

Forging of steel powders has received increased attention as a manufacturing technology with the potential to lower production costs through improved material utilization and the minimization of machining operations. The size capability of powder forging (P/F) is related directly to the available press capacity, as anywhere from 30 to 70 tsi (410 to 965 MPa) is required to forge low alloy steel powders. In previous work on isothermal forging of machine gun cover plates from 4630 prealloyed steel powder, it was shown that forging pressures can be lowered to 10 tsi (138 MPa)[1]. The combination of isothermal forging and P/F means that parts with large plan areas can be forged isothermally to near-net shapes using existing presses.

To examine isothermal P/F as a cost reduction route, two M60 tank components were selected by the Army for study. The first project was on the final drive pinion (P/N 19207-7364142) and performed under Contract DAAK-30-78-C-0029[2]. This part has a plan area of ∿15 sq. in. ($9.7 \times 10^{-3} m^2$) and represents the first stage of a scaleup to large plan areas. This phase involves the final drive gear (P/N 19207-7364141). This is a straight spur gear with 66 teeth located on the oter diameter of 19.4 in. ($4.93 \times 10^{-1} m$). The finished gear is shown in Figure 1.

This gear is currently produced by machining a forged blank. To offer cost reduction, the P/M gear must be forged to near-net shape, meaning that gear teeth must be forged with only finish grinding stock remaining on each tooth face. To accomplish the goal of establishing a production processing route for P/F these large gears, a program was established and consisted of the following tasks:

<u>TASK 1</u> - Design preform and forging tooling to produce a P/F gear (P/N 19207-7364141) with mechanical properties comparable to a wrought gear. The forging tooling will be designed to produce a component without flash or draft angles. The preform will be designed according to minimum deformation principles and the forging will be designed using the procedures established previously in Contract DAAK 30-79-C-0029.

<u>TASK 2</u> - A pilot run of gears will be fabricated to insure quality and reproducibility. Five (5) gears shall be finished to specifications in Drawing Nos. 7364141 and 8689041 and shall meet the roll pattern shown in Drawing No. 8705731.

<u>TASK 3</u> - A detailed process specification shall be generated to describe the manufacturing process for ordnance procurement purposes.

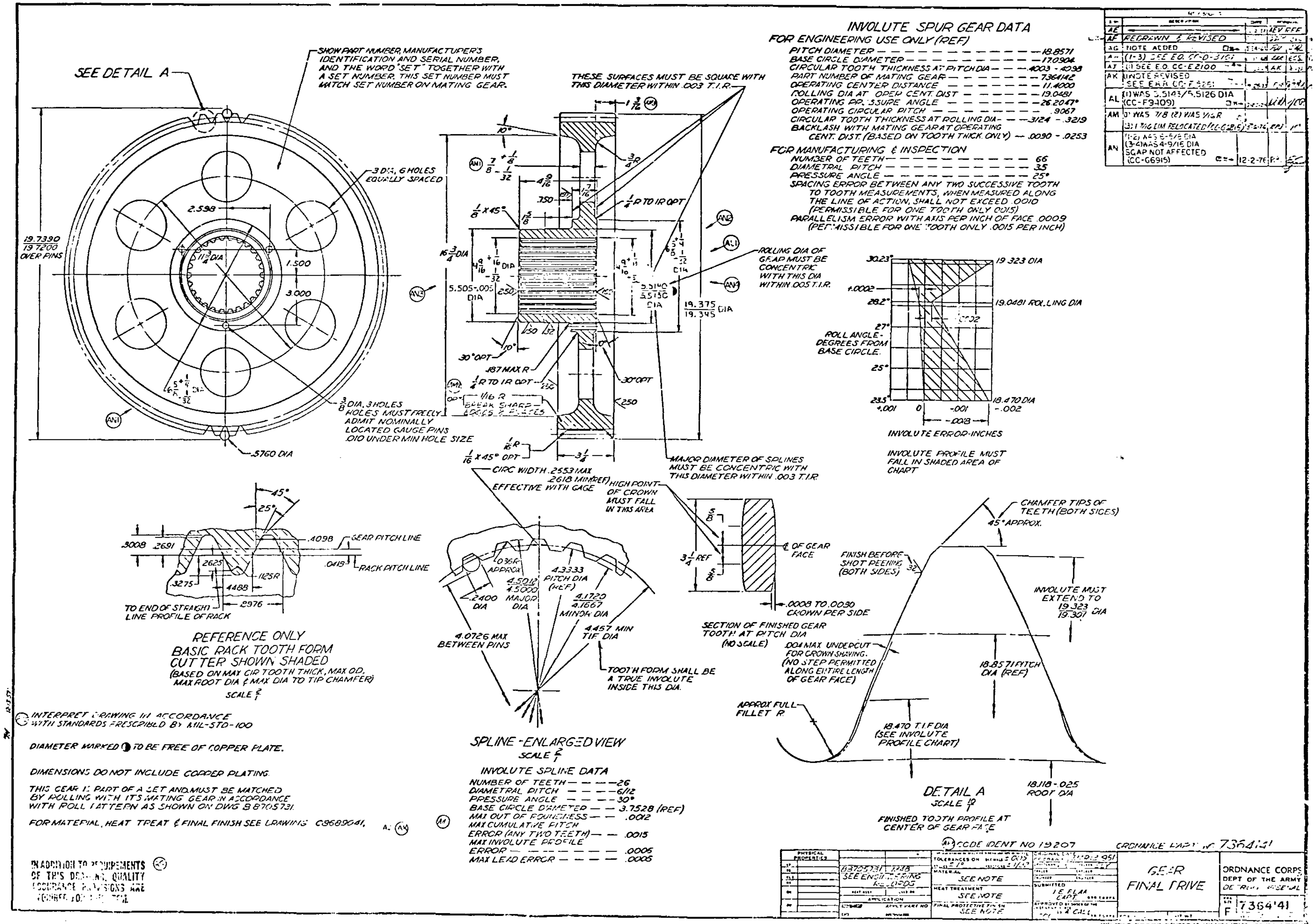



Figure 1. Final Drive Gear of M60 Tank.



882-D

TASK 4 - Perform an economic evaluation of the developed powder metallurgy forging process.

Because the nature of these tasks is sequential, they were addressed in their listed order. Due to problems that developed during Task 1, and problems that were brought to light in Contract DAAK 30-78-C-0029, only Task 1 was completed before the remaining effort on the program was terminated. These problems and possible solutions or redirections will be reported in the following sections.

# 2.0 PROCEDURES

Since the experimental program was halted during Task 1, it is only pertinent to outline the procedures used in this task.

The basic process consists of:

1. Blend graphite with cold compactible steel powder.
2. Compact the loose powder into a preform shape.
3. Sinter the preform at an elevated temperature in a reducing atmosphere to homogenize the microstructure, reduce the oxygen content of the preform and to metallurgically bond the powder particles together.
4. Isothermally forge the sintered preform to full density and near-net shape.
5. Finish machine, heat treat, and inspect the part.

To follow this route, a near-net shape forging and the associated preform had to be designed, as well as the forging and compaction tooling.

## 2.1 Design of the Isothermally Forged Gear

The design basis for the near-net shape forging is that the as-forged gear teeth should require only finish grinding. Since this gear also has spline teeth on the inner bore, these also should be forged. However, at this time it was felt that this was too ambitious since no information is available concerning concentricity control for these large parts. Other important features of the forged part are the elimination of draft on the bore and gear teeth, and the minimization of machining on the hub.

## 2.2 Design of the Hot Die Set

Based on the dimensions and tolerances of the forged part, a hot die set was designed. The guidelines of the die set were that it be a production die set, that it be fabricated from the appropriate materials needed to operate over the temperature range 1450 to 1750F (788 to 954C), that no flash or draft angles be permitted, and that it be fixtured for ease of loading and unloading these massive parts.

## 2.3 Preform Design

Based on past experience, the preform for isothermal forging of steel powders should be a minimum deformation design to minimize metal flow in the die cavity. Such design is necessary to allow low forging loads to be utilized and to optimize the forging cycle time. The minimum deformation design for this preform utilizes a three level preform. This mandates the ability to control density in each level of the preform.

This preform has essentially the same plan area of the forging and thus requires a large press if it is compacted as a unit. If a mechanical or hydraulic press is used, tonnage is the limiting factor, or if a cold isostatic press is used, the pressure vessel diameter is the limiting factor. To circumvent such limitations, the preform may be compacted in segments which are then sinter-bonded together. Because of the precision and density control associated with hard die tooling, it is recommended that hard die compacted segments be produced.

## 2.4 Design of the Compaction Tooling

Because the preform is multilevel, the compaction tooling must be designed to incorporate multiple ram motions into the compaction sequence. This allows control of density within each level. This multiple ram motion can be approximated by the use of split punches with springs and stop blocks. In this manner the amount of powder in each level can be controlled.

Secondly, the preform tooling must be designed to produce the segmented shape. This means that segment interlocking must be a feature of the tooling.

# 3.0 RESULTS

## 3.1 Design of Isothermally Forged Gear

The isothermally forged gear is detailed in Figure 2. As shown, this is a near-net shape forging with a minimum grinding allowance remaining on the tooth face. The gear geometry is listed in Table I.

Machining to be performed on the forged part includes tooth face grinding, cutting of spline teeth, turning of the bearing surface on the hub and drilling of the lightening holes.

## 3.2 Design of Hot Die Set

The hot die set needed to forge these gears consists of a ring die, upper punch, lower punch and a core rod, all of which are machined from cast IN 100, a Ni-base superalloy. Associated with these pieces are a heater ring and heater block which act to support hot die elements. Heat is supplied by cartridge heaters and monitored by strategically located thermocouples. The hot die set is depicted in Figure 3.

The dimensions of the ring die and punches were determined from the relationships between the desired forging dimensions and the thermal expansion coefficients for IN 100 and 4620 steel. The calculations followed this route:

1. 4620 Forging Dimension at 1650F (900C) = IN 100 Die Dimension at 1650F (900C)

$$D_{4620} \text{ at ambient } \left(1 + \alpha_{4620} \cdot \Delta T\right) = D_{IN\ 100} \text{ at ambient } \left(1 + \alpha_{IN\ 100} \cdot \Delta T\right) \qquad \text{eq. (1)}$$

where $\alpha$ is the respective thermal expansion factor, $\Delta T$ is the difference between ambient and the isothermal forging temperature and D is the respective dimension at ambient.

This translates to:

2. $$D_{IN\ 100} = D_{4620} \left[\frac{1 + \alpha_{4620}\ \Delta T}{1 + \alpha_{IN\ 100}\ \Delta T}\right] \qquad \text{eq. (2)}$$

Table I compares die and gear dimensions at ambient.

The top and bottom punches are designed to have a clearance gap of 0.004 inches ($1.02 \times 10^{-4}$m) per side between the ring die and punch, and between the core and punch.

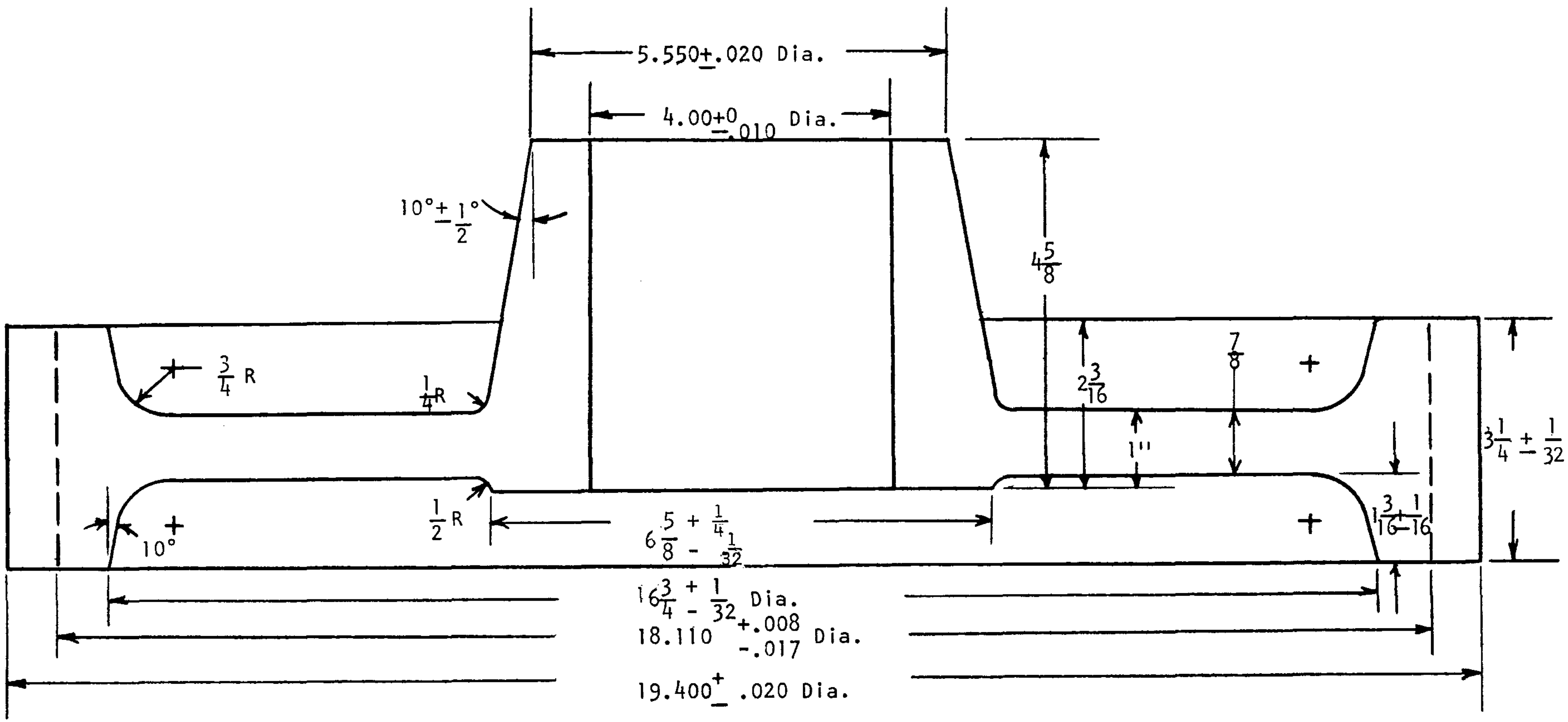


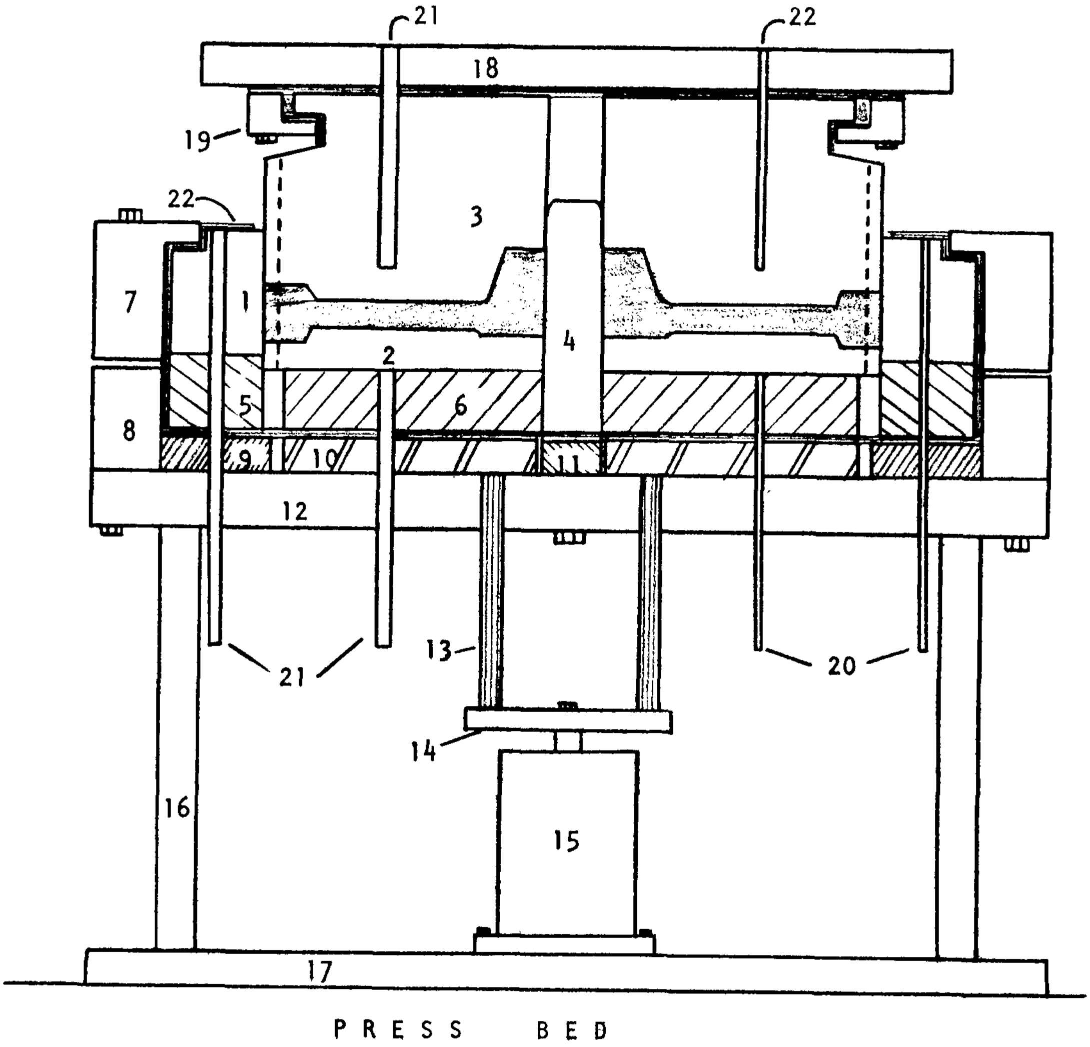

Figure 2. The Isothermally Forged Final Drive Gear. (Dimensions are in inches and 1 inch = .0254m).

TABLE I

Gear Geometry*

| | Forging at 70F (21C) | Ring Die at 70F (21C) |
|---|---|---|
| ° Pitch Diameter | 18.8571" | 18.8189" |
| ° Base Circle Diameter | 17.0904" | 17.0558" |
| ° Circular Tooth Thickness at Pitch Diameter | .4160" | .4152" |
| ° Number of Teeth | 66 | 66 |
| ° Diametral Pitch | 3.5 | 3.5 |
| ° Pressure Angle | 25° | 25° |
| ° Involute Extends to (Dia.) | 19.323" | 19.284" |
| ° Root Diameter | 18.115" | 18.070" |
| ° TIF Reference Diameter | 18.470" | 18.432" |
| ° Chamfer Angle | 45" | 45" |
| ° Tooth Tip Diameter | 19.400" | 19.361" |

* 1 Inch - 0.0254m




1. IN 100 Ring Die
2. IN 100 Bottom Punch
3. IN 100 Top Punch
4. IN 100 Core Rod
5. Superalloy Heater Ring
6. Superalloy Heater Block
7. Segmented Retainer Ring
8. Support Ring
9. Support Ring
10. Ejector Plate
11. Core Rod Spacer
12. Base Plate
13. Ejector Pins
14. Ejector Plate
15. Ejection Cylinder
16. Support Stand
17. Base Plate
18. Support Plate
19. Clamping Ring
20. Thermocouples
21. Calrod Heaters
22. Insulation

Figure 3. Hot Die Set for Forging the Final Drive Gear.

79-77

Several features of the hot die set are unique and are designed to minimize or eliminate conceivable difficulties in forging these parts. These include a removable bottom punch that follows the preform from the preheat step through the ejection step and a split retainer ring around the hot ring die.

The bottom punch will act as a support seat for the sintered preform during preheating and during transfer to the die from the furnace. It will be ejected with the forging to prevent sagging of the gear as the piece cools. This type of punch lends itself to production as a number of them can be employed. The bottom surface of the punch can be beveled to permit fast loading into the die cavity and notched to facilitate handling by transfer equipment.

The segmented retainer ring provides support for the hot ring die, with the magnitude of the support being controlled by the torque on the bolts that couple the sections together. This concept allows the placement of an insulation barrier between the ring die and stress ring so that load is transferred across the insulation. Therefore the working temperature of the stress ring is much lower than that of the hot die ring and a stainless steel may be used as the stress ring. During forging, the torque can be adjusted to an appropriate level of support. During ejection, the support can be removed to allow the ring die to release the forged part.

A detailed set of drawings associated with this die set was sent to several tool and die shops for quotation. Table II contains a list of these vendors and their response. Included in this table are the quotations for IN 100 castings or P/M processed billets for machining into tooling. From the cost and delivery quotations, it became evident that the program budget and schedule could not afford the tooling.

## 3.3 Preform Design

The preform for this gear will be compacted as seven separate sections. The center hub will be one section, as shown in Figure 4, and the remaining gear will be divided into six equal pie-shaped sections, as shown in Figure 5. The pie-shaped sections will have interlocking key slots to facilitate assembly prior to sintering. A cross section of the assembled preform which illustrates the multilevel nature of the preform is shown in Figure 6.

The multilevel preform shape and the minimum deformation process introduce a critical interdependence between dimensions and densities of the preform sections. Notice in Figure 6 that the height dimensions, $h_1$, $h_2$ and $h_3$, are not specified for this reason. Possible preform heights are listed in Table III along with possible densities for each section. To facilitate handling the minimum practical density is 75% of theoretical. The maximum density achievable by die pressing is 85% of theoretical. Also, the density gradients between levels should be minimized to minimize the formation of forging defects. Using these criteria the possible preform heights are narrowed to those indicated by markers in Table III.

## TABLE II

### Vendor Quotations for Hot Die Set

| IN 100 | Price | Delivery |
|---|---|---|
| Cast Masters<br>1145 Fairview Avenue<br>Bowling Green, Ohio 43402 | $ 40,821.50 | 4-5 Weeks AROPO* |
| Colt-Crucible<br>Compacted Metals Operation<br>Oakdale, Penna. 15230 | 53,150.00 ** | 8 Weeks AROPO |
| Kelsey-Hayes Company<br>7250 Whitmore Lake Road<br>Brighton, Michigan 48116 | 100,000.00† | 8 Weeks AROPO |
| **Die Set** | | |
| SKRL Tool & Die Company<br>34580 Lakeland Blvd.<br>Eastlake, Ohio 44095 | 124,115.00 | 60 Weeks |
| Jet Die & Engineering Inc.<br>6300 Aurelius Road<br>Lansing, Michigan 48902 | No Quote | |
| Cannon Tool Company<br>167 Valley Road<br>Cannonsburg, Penna. 15317 | 49,000.00<br>(Does not include machining of gear tooth shape in ring die or punches. | |

* AROPO - After Receipt of Purchase Order

** Material is off-chemistry IN 100 Powder in as-HIP condition

† Material is IN 100 powder in as-HIP condition.

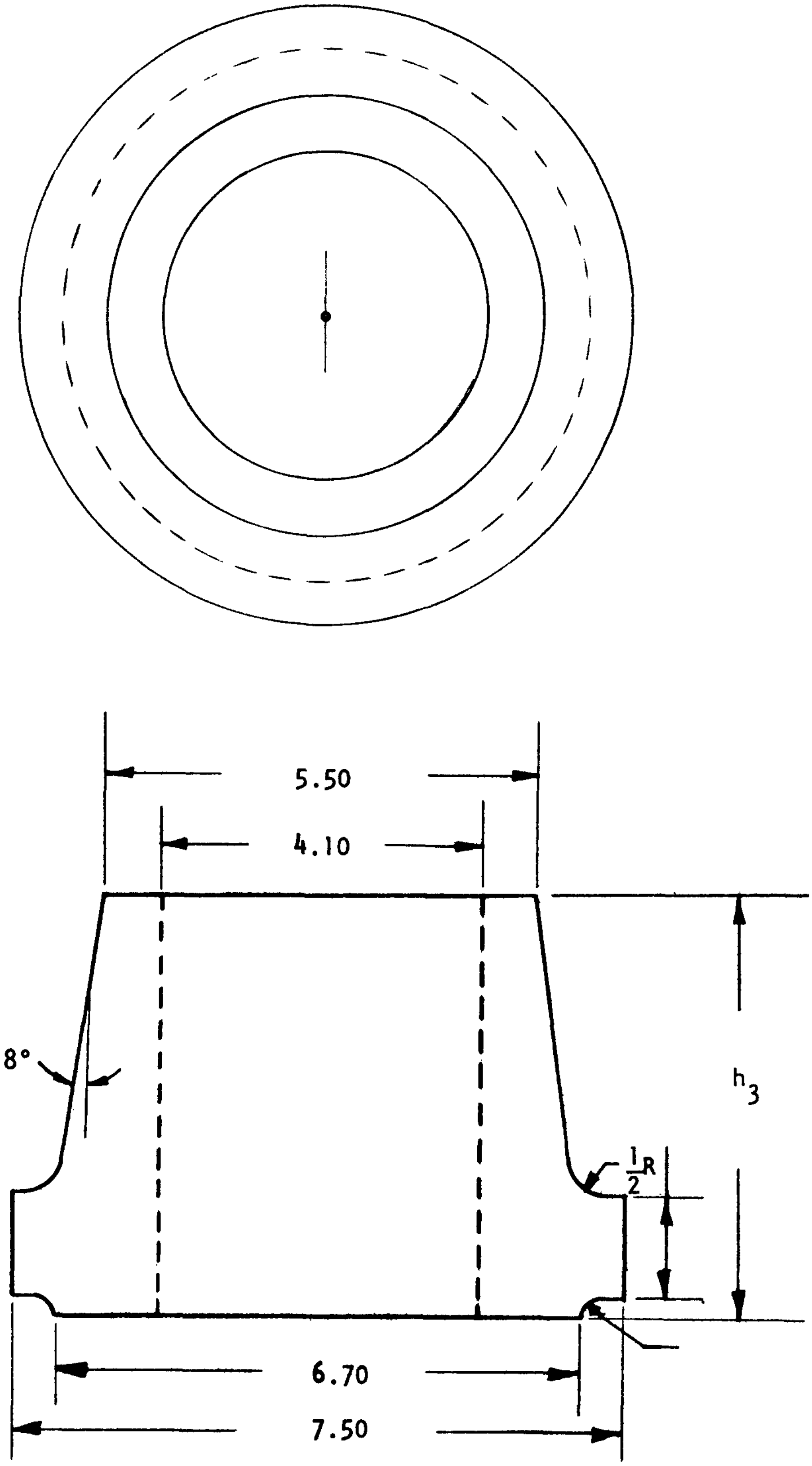



Figure 4. Center Hub Segment of Preform. (Dimensions are in inches and 1 inch = 0.0254m).

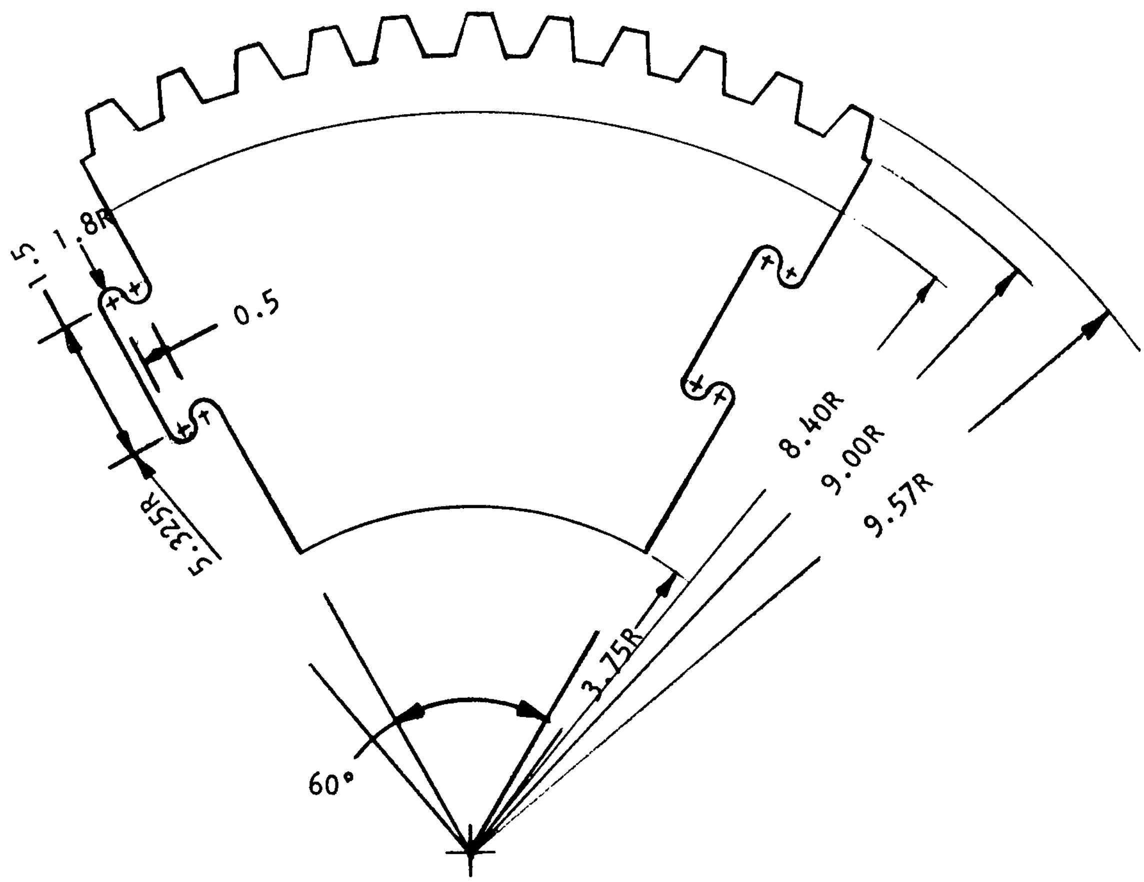



Figure 5. Representative Outer Segment of Preform. (Dimensions are in inches and 1 inch = 0.0254m).



79-324

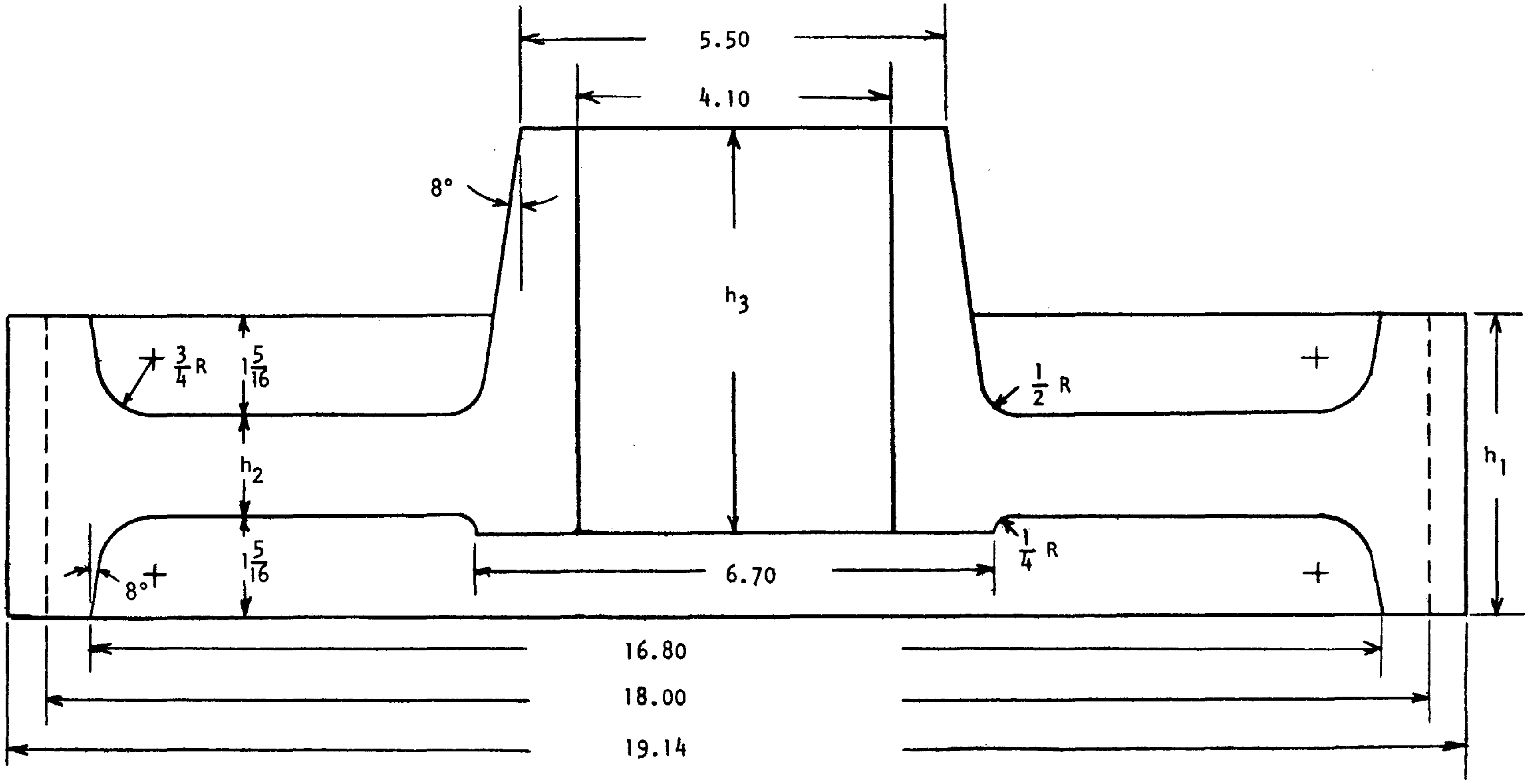



Figure 6. Assembled Preform for Final Drive Gear. (Dimensions are in inches and 1 inch = 0.0254m).

## TABLE III

### Preform Geometry and Density Possibilities

| | Gear Section | | Web Section | | Hub Section | |
|---|---|---|---|---|---|---|
| | $h_1$* | $\rho_1$ | $h_2$* | $\rho_2$ | $h_3$* | $\rho_3$ |
| | 3.425 | .75 | .800 | .90 | 4.800 | .75 |
| | " | .75 | " | .87 | " | .80 |
| | " | .75 | " | .84 | " | .85 |
| ° | " | .80 | " | .79 | . | .75 |
| ° | " | .80 | " | .76 | " | .80 |
| | " | .80 | " | .72 | " | .85 |
| | 3.450 | .75 | .825 | .86 | 4.825 | .75 |
| | " | .75 | " | .83 | " | .80 |
| | " | .75 | " | .80 | " | .85 |
| ° | " | .80 | " | .75 | " | .75 |
| | " | .80 | " | .72 | " | .80 |
| ° | 3.475 | .75 | .850 | .82 | 4.850 | .75 |
| ° | " | .75 | " | .79 | " | .80 |
| ° | " | .75 | " | .76 | " | .85 |
| | " | .80 | " | .71 | " | .75 |
| ° | 3.500 | .75 | .875 | .78 | 4.875 | .75 |
| ° | " | .75 | " | .75 | " | .80 |
| | " | .75 | " | .72 | " | .85 |
| | 3.535 | .75 | .900 | .74 | 4.900 | .75 |
| | " | .75 | " | .72 | " | .80 |

° Indicates possible first iteration selection

* Inches (1 inch = 0.0254m)

The basis of the preform heights in Table III is that punch contact during forging occurs simultaneously at the hub and gear tooth sections while a gap exists initially between the punches and web section of 0.125 inches per side ($3.18 \times 10^{-3}$m per side). This allows maximum loading on the two critical sections of the gear so that densification will begin in these critically loaded areas. Die fill will be accomplished first in these areas, with local metal flow into the gear teeth and finally from the gear and hub sections into the web section occurring. This pattern should result in complete die fill and acceptable mechanical properties.

The density variation with section height level is necessary since gross metal flow between sections cannot be accomodated by minimum deformation forging without suffering forging defects or final density gradients. Therefore, the total punch stroke should cause full densification simultaneously in each section of the forging. This means that sections with different height levels must have different starting densities to achieve full density simultaneously, as indicated by the heights and dimensions in Table III. The equations utilized to arrive at these numbers are based on geometrical considerations. First, the height relationships are:

$$h_1 = h_2 + 2.625 \qquad \text{eq. (3)}$$

$$h_3 = h_2 + 4.000 \qquad \text{eq. (4)}$$

where $h_1$, $h_2$ and $h_3$ are the heights of the gear, web and hub sections in inches. Secondly, the volumes in the gear tooth section, web section and hub section are:

$$V_1 = \frac{\pi}{4} (18.0^2-16.8^2)\ h_1 + 66 \left[(.5625)(.5)(.2+.2+2(.5625)(\tan 70°)\ h_1\right]$$

$$V_2 = \frac{\pi}{4} (16.8^2-7.2^2)\ h_2$$

$$V_3 = \frac{\pi}{4} (6.7)^2\ (h_2+.5) + \frac{\pi}{4}(7.2^2-6.7^{-3})h_2 + \left(5.5^2+6.7^2+(5.5)(6.7)\right)(h_3-h_2-.5)$$
$$(.2618) - \frac{\pi}{4} (4.1)^2 h_3$$

These reduce to:

$$V_1 = 96.96\ h_1 \qquad \text{eq. (5)}$$

$$V_2 = 180.86\ h_2 \qquad \text{eq. (6)}$$

$$V_3 = 2.96 + 11.38\ h_2 + 16.12\ h_3 \qquad \text{eq. (7)}$$

where $V_.$ $V_2$ and $V_3$ are the volumes of the gear, web and hub sections. Since the total preform mass is fixed at 125 lbs. (56.7 Kg), the gear, web and hub weights, $W_1$, $W_2$ and $W_3$, must total to 125 lbs. (56.7 Kg).

$$W_1 + W_2 + W_3 = 125 \text{ lbs.} \qquad \text{eq. (8)}$$

But, mass is the product of density and volume, so eq. (8) can be expressed as:

$$\rho_1 V_1 + \rho_2 V_2 + \rho_3 V_3 = 125 \text{ lbs.} \qquad \text{eq. (9)}$$

where $\rho_1$, $\rho_2$ and $\rho_3$ are the section densities.

Now, $V_1$, $V_2$ and $V_3$ can be substituted from eqs. (5), (6) and (7) into eq. (9) and the result is a height-density equation:

$$96.96\, h_1 \rho_1 + 180.86\, h_2 \rho_2 + 2.96\, \rho_3 + 11.38\, h_2 \rho_3 + 16.12\, h_3 \rho_3 = 125 \text{ lbs.} \qquad \text{eq. (10)}$$

Possible preform section heights and densities are determined by these steps.

1. Assume an $h_2$ value and calculate $h_1$ and $h_3$ from eqs. (3) and (4).
2. Assume $\rho_1$ and $\rho_3$ and calculate $\rho_2$ from eq. (10).

### 3.4 Design of the Compaction Tooling

The preform dies will be made of a wear resistant die steel. Clearance gaps between punches and either core rods or a ring die should not exceed 0.002 inch ($5.08 \times 10^{-5}$m).

The compaction tooling for the hub section consists of a ring die, core rod and a top and bottom punch. The compaction operation is simply a sequence of charging powder into the die cavity and pressing at the required pressure, using a die wall lubricant of zinc stearate.

The die set for the pie-shaped sections of the preform is depicted in Figure 7. It consists of a die block, top punch and a split bottom punch. The split bottom punch is necessary for control of the densities in the gear and web sections. Stop blocks are positioned under the web section punch so that the compaction pressure is not experienced by this section until compaction has begun in the gear section. This allows greater density to be achieved in the gear section, which is desired. The density gradient between the two sections is controlled by the fill cavity dimensions, the spring stiffness and the stop block heights.

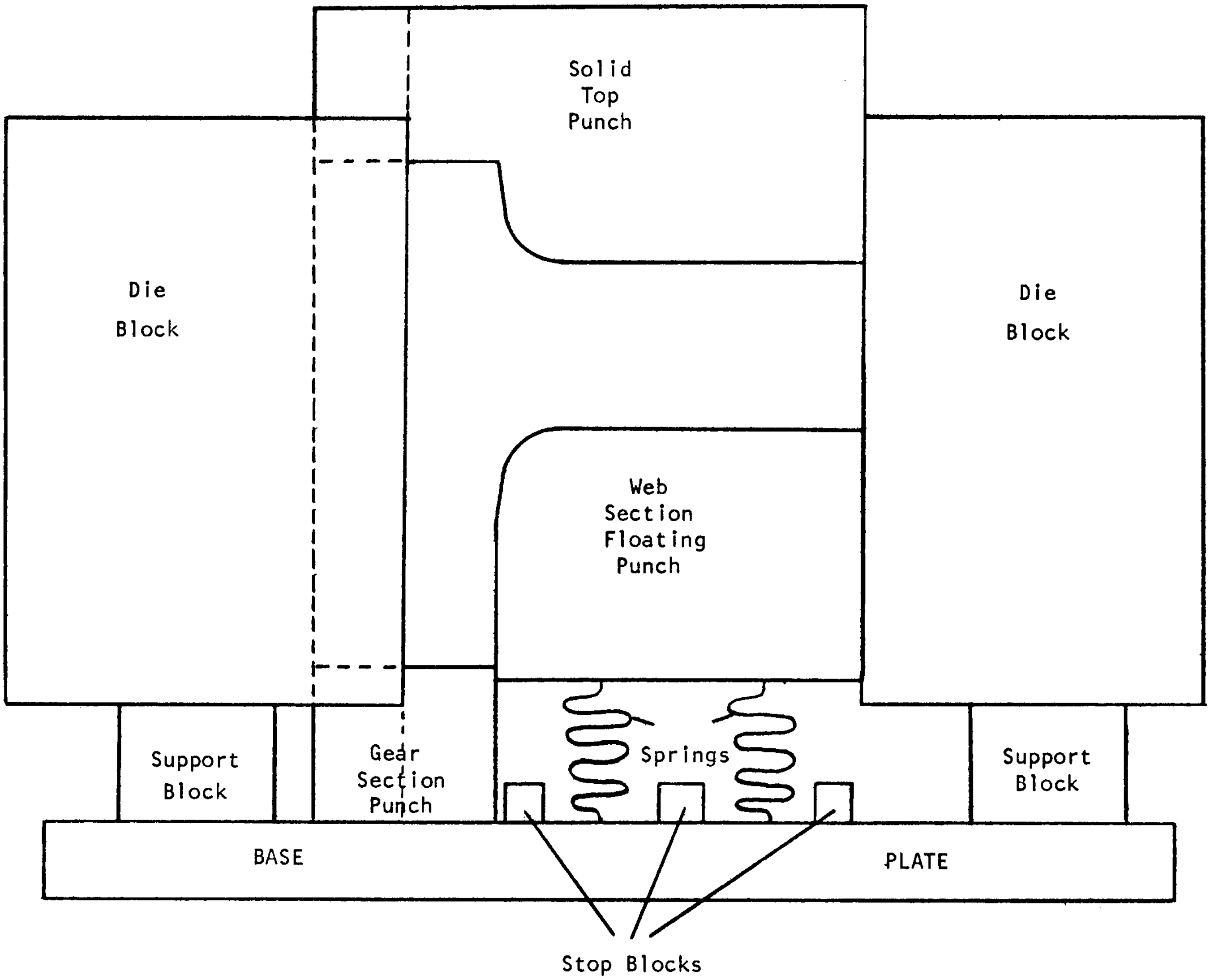



Figure 7. Split Punch Compaction Die Set Used to Compact the Six Outer Segments of the Preform.

## 4.0 DISCUSSION

Both the cost and time quotations for the hot die set present major problems to this program and dictate a redirection of effort,orasubstantial increase in budget and a substantial increase in the program schedule. Of equal importance is the failure experienced on Contract DAAK-30-78-C-0029 where the isothermally forged pinion could not be ejected from the hot die set. Coupling these factors together results in the assessment that this program should be halted.

### 4.1 Costs and Scheduling

The costs and delivery time for the hot die set continue to escalate such that an additional \$292,781 of support and $\sim$24 months must be added to the current contract. The projected cost overrun poses a funding problem, obviously. But the time slippage of 24 monts raises a more serious problem since this reduces the chance for implementation of this work. The M60 tank is being phased out because of the successful development of the XM-1 tank. This fact significantly diminishes the chance for implementation of this process without first requiring an expensive development program on an XM-1 part.

### 4.2 Lubrication-Coating-Die Release Problems

Contract DAAK-30-78-C-0029 was a predecessor of this contract and was the initial effort to isothermally forge parts of the large plan area. The mating pinion of the final drive gear was the part to be forged. While test coupon forging proceeded smoothly, a serious ejection problem was encountered while forging the full size pinion. No suitable coating was found that would both provide oxidation resistance to the heated preform and allow die release during ejection. Forgings could not be ejected from the die. With such a serious problem being encountered on the smaller part, it was felt that the effort to forge the large drive gear would be in vain.

### 4.3 Alternative Action

Once these major problems were recognized, alternative actions were examined. These alternatives covered a broad range of possible redirections, including alternate techniques for making the drive gear, a shift to a large diameter ring gear in the XM-1 tank, a lubrication-coating project, and a conventional P/M forging effort. The last alternative is the most promising. P/M forging has been demonstrated to be an effective, low cost manufacturing technology. However, the technology still suffers from lack of unity and a general lack of understanding converning the capability of P/M for various shapes and materials. A program to clear up these uncertainties that retard or hinder implementation is briefly described in Section 6.0.

## 5.0 SUMMARY

Contract DAAK-30-78-C-0099 has been halted due to cost and time overrun projections and unsuccessful completion of a preceding program on which this work was to be based. An alternate action is recommended.

Prior to this point, completed work had included design of an isothermally forged M60 tank drive gear, design of the hot die set, design of the preform according to minimum deformation principles, and design of the compaction tooling.

## 6.0 RECOMMENDATIONS

The recommended alternative is to examine several of the XM-1 accessory gears as potential P/M forged parts. Gears come in many shapes ranging from the simple pancake shape spur gear, to gears with integral shafts, to gears with teeth on outer and inner diameters, etc. P/M forging follows a compaction-sinter-forge route, with the forging being carried out cold, warm or hot. The particular process suited for a particular gear will depend on the part complexity and alloy being used. It is recommended that three levels of part complexity be examined, along with the three processing temperature regimes. Dimensional control, part performance and economic analyses will be determined to generate handbook-type information. This will greatly speed up the implementation of P/M forging as a cost reduction method of manufacturing military hardware.

## 7.0 REFERENCES

1. F. T. Lally and I. J. Toth, "Isothermal Forging of Precision Metal Powder Components," Contract DAAF 01-72-C-0502, July 1973.

2. B. L. Ferguson, "Forging of Powder Metallurgy Gears," Final Report on Contract DAAK-30-78-C-0029, Report 12519, May 1980.

## DISTRIBUTION LIST

| | Copies |
|---|---|
| DEFENSE DOCUMENTATION CENTER<br>ATTN: TIPDR<br>Cameron Station<br>Alexandria, VA 22314 | 12 |
| Commander<br>US ARMY MATERIEL DEVELOPMENT AND READINESS COMMAND<br>ATTN: DRCMT<br>5001 Eisenhower Avenue<br>Alexandria, VA 22333 | 1 |
| Director<br>US ARMY MATERIALS AND MECHANICS RESEARCH CENTER<br>ATTN: DRXMR-M<br>Watertown, MA 02172 | 2 |
| Director<br>US ARMY INDUSTRIAL BASE ENGINEERING ACTIVITY<br>ATTN: DRXIB-MT<br>Rock Island Arsenal<br>Rock Island, IL 61299 | 3 |
| Commander<br>US NAVY MATERIEL INDUSTRIAL RESOURCES OFFICE<br>ATTN: Code 044<br>Philadelphia, PA 19112 | 1 |
| Commander<br>AIR FORCE MATERIALS LABORATORY<br>ATTN: LTM<br>Wright-Patterson AFB, OH 45433 | 1 |
| Commander<br>US ARMY TACOM<br>ATTN: DRSTA-UL (Technical Library)<br>Warren, MI 48090 | 2 |

## NOTICES

The findings in this report are not to be construed as an official Department of the Army position.

Mention of any trade names or manufacturers in this report shall not be construed as advertising nor as an official indorsement or approval of such products or companies by the U. S. Government.

TARADCOM FINAL REPORT NUMBER 12521

Final Technical Report

# ISOTHERMAL FORGING OF LARGE GEARS BY P/M TECHNIQUES

Contract DAAK 30-78-C-0099

By

B. L. Ferguson
D. T. Ostberg

May 1980

Prepared For

U. S. Army Tank Automotive
Research and Development Command
Warren, Michigan

TRW Materials Technology
23555 Euclid Avenue
Cleveland, Ohio 44117

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

# REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

| | | |
|---|---|---|
| 1. REPORT NUMBER<br>12521 | 2. GOVT ACCESSION NO. | 3. RECIPIENT'S CATALOG NUMBER |
| 4. TITLE *(and Subtitle)*<br>Isothermal Forging of Large Gears by P/M Techniques | | 5. TYPE OF REPORT & PERIOD COVERED<br>Final Report |
| | | 6. PERFORMING ORG. REPORT NUMBER<br>ER-8057-F |
| 7. AUTHOR(s)<br>B. L. Ferguson<br>D. T. Ostberg | | 8. CONTRACT OR GRANT NUMBER(s)<br>DAAK-30-78-C-0099 |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>TRW Materials Technology<br>23555 Euclid Avenue<br>Cleveland, OH 44117 | | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS |
| 11. CONTROLLING OFFICE NAME AND ADDRESS<br>U. S. Army Tank-Automotive Research & Development Command<br>DRDTA-RCKM<br>Warren, MI 48090 | | 12. REPORT DATE<br>May, 1980 |
| | | 13. NUMBER OF PAGES |
| 14. MONITORING AGENCY NAME & ADDRESS *(if different from Controlling Office)* | | 15. SECURITY CLASS. *(of this report)*<br>Unclassified |
| | | 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE |

16. DISTRIBUTION STATEMENT *(of this Report)*

Approved for public release, Distribution Unlimited

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

18. SUPPLEMENTARY NOTES

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

Forging
Die Design
Isothermal Forging
Preforms

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

The objective of this program was to extend the development of isothermal forging of steel powder parts to near-net shapes with plan areas larger than 100 square inches ($6.45 \times 10^{-2} m^2$). Previously, it had been determined that the application of isothermal forging to near-net shape parts production reduces the forging pressure needed to achieve both full density and a completely filled die cavity. Thus, larger parts may be forged with existing equipment.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

20. ABSTRACT

The prototype component in this project was the final drive gear of the M60 tank (P/N 19207-7364141). This gear has an outside diameter of 19.4 inches ($4.93 \times 10^{-1}$ m) and a plan area of 296 square inches ($1.91 \times 10^{-1}$ $m^2$). The 66 teeth were to be forged to shape, allowing 0.005 to 0.010 inches (1.3 to $2.5 \times 10^{-4}$ m) per tooth face for grinding and crowning after carburizing. Prealloyed 4600 grade steel powder was to be used.

Based on the finished part dimensions, a forging was designed, a hot die set for isothermal forging was designed, and a segmented preform and compaction tooling were designed. At this point quotations from tool builders indicated serious cost and time overruns. Coupling these problems with lubrication/die release problems experienced in a sister program,* a decision was made to halt this program until such problems were overcome or a suitable redirection option could be formulated.

This report covers the design steps completed on the program, the tooling quotations, alternative action possibilities, and concludes with a recommendation for redirection.

This is the third phase of the effort. The results of Phase I and Phase II are documented in TARADCOM Final Report Number 12519, "Forging of Powder Metallurgy Gears."

* Contract DAAK-30-78-0029

TABLE OF CONTENTS

## LIST OF FIGURES



## LIST OF TABLES