

NASA
Contractor Report 187175

AVSCOM
Technical Report 90-F-6

Computer Numerical Control Grinding of Spiral Bevel Gears

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August 1991

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Released as
PUBLICLY AVAILABLE
July 1995

Prepared for
Lewis Research Center
Under Contract NAS3-25030
and
Propulsion Directorate
U.S. Army Aviation Research and Technology—AVSCOM



(NASA-CR-187175) COMPUTER
NUMERICAL CONTROL GRINDING OF
SPIRAL BEVEL GEARS (Textron Bell
Helicopter) 89 p



US ARMY
AVIATION
SYSTEMS COMMAND

N96-10758

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PREFACE

The work described in this report was performed for the U.S. Army and administered by James Corwin, Nirmal Singh, and Jonathan Pratcher of the Aviation Systems Command (AVSCOM), St. Louis, Missouri. The project was authorized as part of the U.S. Army Manufacturing Technology (Mantech) Program. The Contracting Officer was Mr. Glen Williams of National Aeronautics and Space Administration and the Contracting Officers Technical Representative was Mr. Robert Handschuh of U. S. Army AVSCOM, at the National Aeronautics and Space Administration, Lewis Research Center, Cleveland, Ohio.

Technical tasks in this program were performed under the technical direction of Wayne Scott, Bell Helicopter Inc. (BHTI).

Acknowledgment is given to the following BHTI personnel for their contributions to this project: Chuck Allen, Hans Kossler, Glen Lavender, Jerry Lee, Frank Marcenaro and Chester Skrodzki. Acknowledgment is also given to Peter Dibble, Harry Dodd, Mark Fenton, Harry Pedersen, Frank Peppers, and Jack VanElzakker, all with The Gleason Works, Rochester, New York, for their technical assistance and material contributions.

The first part of the document discusses the importance of maintaining accurate records of all transactions. It emphasizes that every entry should be supported by a valid receipt or invoice. This not only helps in tracking expenses but also ensures compliance with tax regulations. The second part of the document provides a detailed breakdown of the company's revenue for the quarter. It shows a steady increase in sales, particularly in the electronics and software sectors. The third part of the document outlines the company's financial goals for the next quarter, including a target for profit margin and a plan to reduce operational costs. The final part of the document concludes with a summary of the overall financial performance and a statement of confidence in the company's future prospects.

I. INTRODUCTION

As the world has technologically advanced, the efficiency of transmitting power through drivetrain systems has undergone continuing improvements. Performance parameters, such as speed, horsepower increases and weight reduction have driven new designs which yield increased performance. Often, these new requirements for improved performance result in higher manufacturing cost. This is due, in many cases, to the failure of manufacturing technology to advance in meeting the manufacturing needs required to produce new designs for expanded performance and reduced cost. Such was the case of the manufacturing of precision aircraft quality spiral bevel gears.

Currently, most precision spiral bevel gear tooth geometry is produced on machinery which reflects pre World War II technology. Over the years this has required the machine operators to develop a high degree of skill in order to produce a quality part. Although some improvements have been made with production machinery, spiral bevel gear manufacturing costs are high; setup and maintenance of setup times average 80 hours per production lot. Much of this cost is tied directly to the inability of the spiral bevel grinder to hold developed settings and the inconsistency or inaccuracy of the corrective machine settings made during setup maintenance.

In the mid 1980's a program was proposed that would retrofit an older Gleason 463 Spiral Bevel Gear Grinder with state-of-the-art dynamic components, electronics and computer controls. This remanufactured/retrofitted grinder would exhibit improvements in accuracy, repeatability, and reliability, while at the same time offer reduced setup and maintenance of setup times and operator skill requirements.

This report covers the concept, design, fabrication, and testing of the remanufactured/retrofitted Gleason 463 CNC Spiral Bevel Gear Grinder.

II. BACKGROUND

In today's environment, most precision spiral bevel gear grinding is accomplished on machines technologically designed 40 years ago. This method of manufacture requires extensive man hours to "setup and maintain each individual setup". Constant attention is required by the machinist to manually calculate and adjust machine settings over long periods of time due to the inability of these machines to hold the developed settings and/or accuracy required. This is a major contributor to the increasing scrap rates in this manufacturing area.

These extensive man hours, necessary to set up and maintain setups, currently constitutes 46 per cent of the man hour cost required to finish grind an average lot of 20 spiral bevel gears.

For the purpose of clarity, setup and maintenance of setup has been defined as follows:

- Setup Time consist of two (2) factors.
Physical setup time is that time required to physically change the machine tool, arbor, cam, grinding wheel, etc., to the settings for a particular part.
- Development time is that time required to adjust the machine setting through a series of trial (setup) grinds until the first acceptable part is produced.
- Physical setup time plus (+) development time equals (=) Setup Time.
- Maintenance of Setup Time is that time required to "re-adjust or tweek" some machine settings to bring the contact patterns back into tolerance, after production part have been ground. This "tweeking" may require several trial grinds before the tolerance requirements are reestablished and production is resumed.

The repeatability of the grinding process from a part to part and setup to setup basis on the conventional Gleason 463 grinder is a substantial factor in the time required to produce a typical lot of 20 precision spiral bevel gears. Each time a part is setup on a conventional 463 grinder, the approximate same setup time, average 32 hours, is required to bring the part to a production basis. This is indication of the lack of repeatability from a setup to setup basis.

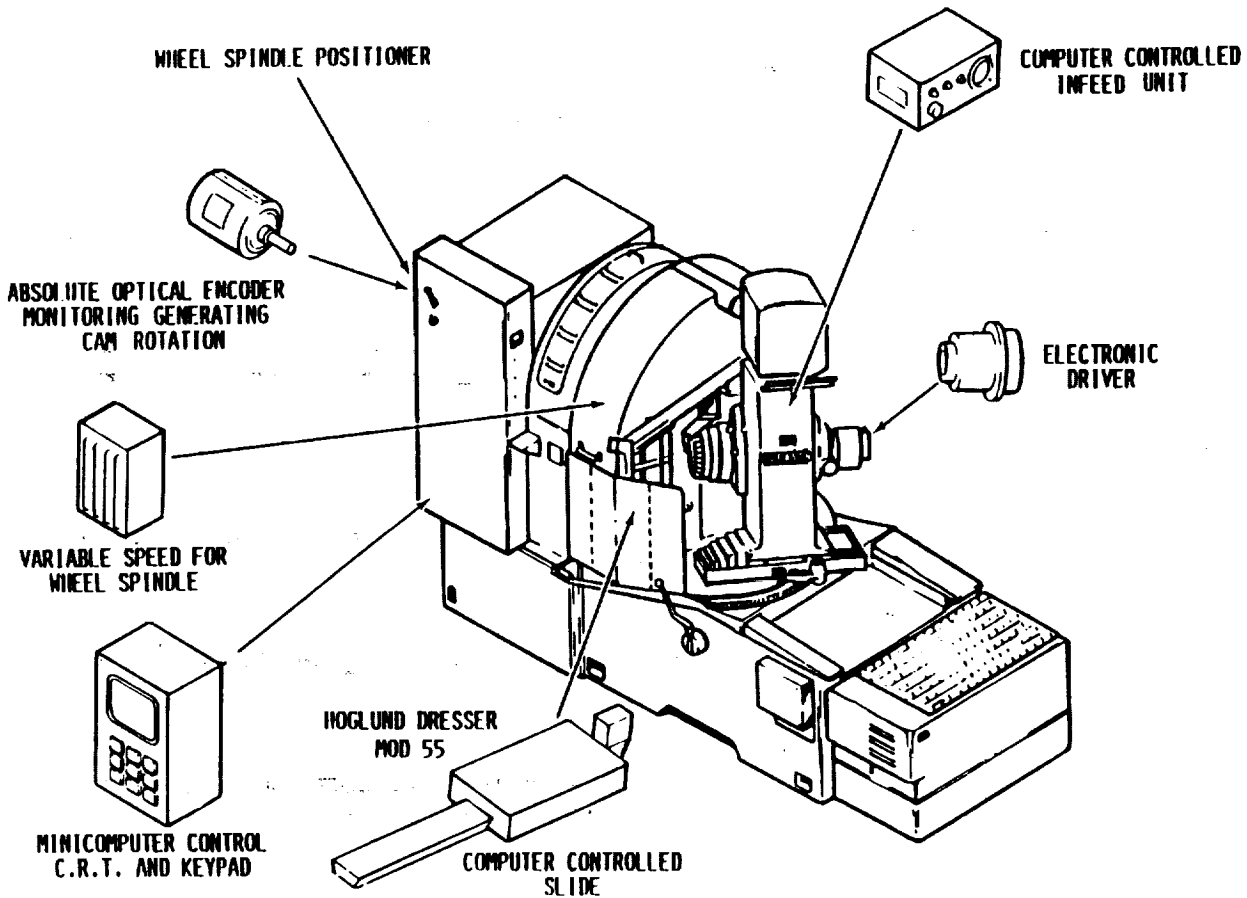
Once the setup is complete and production starts, normally only two (2) to five (5) parts can be produced before it is necessary to "adjust or tweek" some machine settings in order to reestablish the contact pattern tolerances. This "maintenance of setup" function will be repeated several times during the grinding process of a typical 20 piece lot. This is an indication of the lack of repeatability from a part to part basis.

Although some modification to these machines have been helpful in maintaining production requirements, no new technological advances were available until the mid 1980's.

In the mid 1980's, Bell Helicopter personnel initiated an effort to add new technology features to a conventional Gleason 463 grinder, see Figure 2-1. The objective was to improve the repeatability of the grinding process on both a setup to setup and a part to part basis. This was viewed as an avenue to reduce the high percentage of setup and maintenance of setup time in production runs.

Through a series of meetings with The Gleason Works Engineering personnel, ideas and concepts were refined. In May, 1986 a proposal for a rebuild/retrofit program utilizing a Gleason 463 Spiral Bevel Gear Grinder was submitted to the U.S. Army Aviation Systems Command (AVSCOM), St. Louis, Missouri.

In September, 1986 a contract was awarded to Bell Helicopter Textron Inc. (BHTI) for the development of computer numerical control (CNC) grinding of spiral bevel gears.



Proposed Changes - 1984

Figure 2-1

III. PROGRAM PLAN

The program contains three (3) phases, each having numerous tasks directed towards the development of computer numerical control (CNC) grinding of spiral bevel gears.

PHASE I - Definition Of The Prototype CNC Grinder

Task 1 - Baseline Grinder

In this task, the hardware necessary for the development of the baseline grinder will be identified. Included will be an analysis of the grinders capabilities and changes required to implement CNC on the prototype grinder.

Task 2 - Definition of Prototype

The design objection and criteria shall be outlined. This will include conceptual design drawings and specifications.

Task 3 - Economic Analysis

An estimate of projected savings in final grinding of spiral bevel gears and the cost of conversion from manual grinding to CNC grinding shall be performed.

Task 4 - Drawings and Oral Briefing

A briefing shall be given, consisting of the results obtained for all task in Phase I. Also, government personnel shall review the conceptual development design drawings. The authorization for continuance of work will be granted at this time.

PHASE II - Integration Of Hardware And Software Into Prototype CNC Grinder

Task 5 - Install the Conversion Hardware

Conversion hardware shall be installed on the baseline grinder. This shall include fabrication of necessary fixturing and all alteration and adaptations for hardware mounting.

Task 6 - Addition of CNC to the Converted Grinder

A Computerized Numerical Control (CNC) System shall be added to the prototype grinder. This shall include all electronic systems and controls necessary to provide compatible CNC for the spiral bevel gear grinder.

Task 7 - Demonstrate CNC Performance

Government personnel shall witness a demonstration of final grinding of one spiral bevel gear size on the CNC grinder.

Task 8 - Update of Economic Analysis

An update of the cost of conversion to CNC grinding and a cost estimate on finish grinding by CNC as compared to manual grinding shall be performed.

Task 9 - Drawings and Oral Briefing

An oral briefing shall be conducted for Government personnel providing detailed design drawings, specifications and operational information of the prototype CNC grinder. Additionally, the results obtained for all task in Phase II will be reviewed. The authorization for continuance of work will be granted at this time.

PHASE III - Pilot Production

Task 10 - Production Runs Using the Proof of Concept (POC) Grinder

Finish grinding of nine (9) lots of gears or pinions, with each lot having a minimum of 20 pieces shall be performed.

Among the nine (9) lots shall be at least five (5) different part numbers that reflect a range of gear diametral pitch and numbers of teeth. The production runs shall be used to demonstrate the P.O.C. grinder's ability to hold-maintain settings and the efficiency of changing from one specific part to another (different numbers of teeth and diametral pitch).

Task 11 - Update Economic Analysis

An update on cost estimates of finish grinding by CNC using information generated in Task 10 and compared to manual grinding shall be performed. Additionally a conversion cost analysis shall be completed.

Task 12 - Government/Industrial Briefing

A briefing shall be conducted which will present the results of Phase I, II and III to Government personnel and Industrial representatives. The briefing shall consist of the results of all the tasks of all phases of the contract.

Task 13 - Documentation

Reports of work will be prepared for any and all task performed under the contract. The outputs of this task shall be Monthly Technical Progress Narratives, Performance Analysis, Financial Reports, Interim Technical Reports and A Final Report.

IV. TECHNICAL APPROACH

This Manufacturing Technology (MANTECH) Program, sponsored by the Army Aviation System Command, was designed to reduce the cost of precision spiral bevel gear grinding. The objective of the program was to decrease the setup, maintenance of setup and pattern development time by 50 percent of the time required on conventional spiral bevel gear grinders. In addition, there was a requirement to accomplish this reduction while improving consistency of quality, part to part and setup to setup.

The contract award to Bell in September of 1986 was followed by the placement of an order with Gleason Works, Rochester, N.Y. for design and remanufacture/retrofit of a convention 463 grinder.

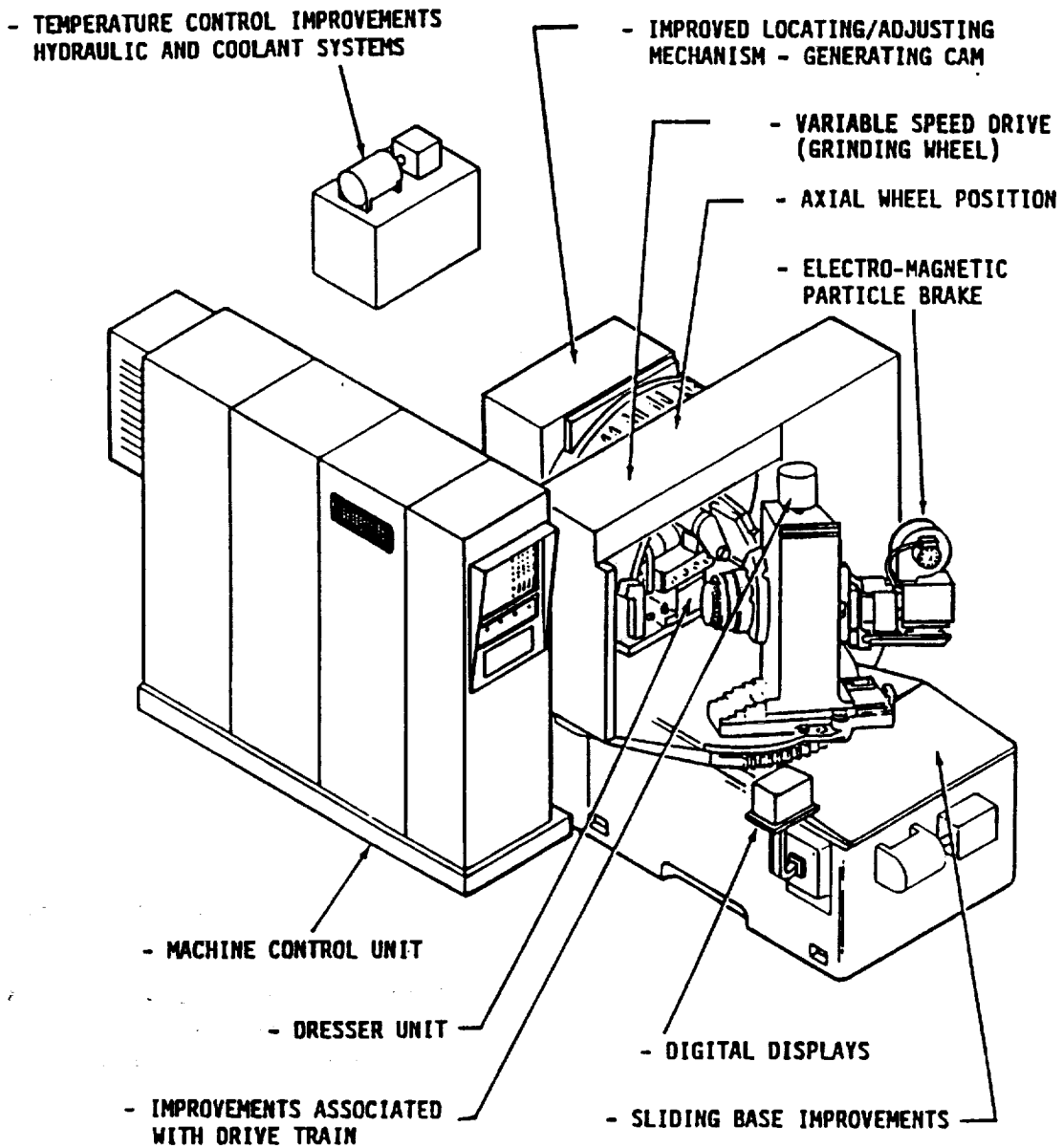
The project was conducted in three (3) phases, listed below and covered 42 months.

Phase I	Definition of the Prototype CNC Grinder
Phase II	Integration of Hardware and Software Into Prototype CNC Grinder
Phase III	Pilot Production

4.1 PHASE I - DEFINITION OF THE PROTOTYPE CNC GRINDER

Under Phase I, the concept for the improvements were finalized through a series of meetings between Bell Project Management and Gleason Project Management and Engineering. Internally, Bell Project Management solicited and received input on the project from Operations, the end users of the proposed new machine, and Design Engineering, designers of future details which might be produced on the proposed new machine.

The proposed improvements to the Gleason 463 grinder, as presented in the original proposal, have been carried over to reflect a ten (10) point sub-task retrofit program outlined in Table 4-1 and shown in Figure 4-1 as the conceptualized 463A CNC grinder. The detail information on these sub-task will be presented in the Phase II section of this report.



Conceptualized 463 CNC Grinder
Figure 4-1

Sub-Task	I	-	Machine Control Unit
Sub Task	II	-	Dresser Unit
Sub-Task	III	-	Variable Speed Drive (Grinding Wheel)
Sub-Task	IV	-	Sliding Base Improvements
Sub-Task	V	-	Axial Wheel Position
Sub-Task	VI	-	Electro-Magnetic Particle Brake
Sub-Task	VII	-	Digital Displays
Sub-Task	VIII	-	Temperature Control Improvements- Hydraulic and Coolant Systems
Sub-Task	IX	-	Improved Locating/Adjusting Mechanism-Generating Cam
Sub-Task	X	-	Improvements Associated with Drive Train

Ten (10) Point Sub-Task Retrofit Program

Table 4-1

Under Phase I, Task 1 - Baseline Grinder and Task 2 - Definition of Prototype, the design, specifications and resulting hardware were identified, manufactured and/or purchased.

The Phase I design effort concluded with 18 major parts requiring rework, 270 new mechanical details and numerous schematic. The break down as shown in Table 4-2 and 4-3 resulted in 350 plus detail designs to complete the design effort.

	<u>Manufactured</u>	<u>Purchased</u>
New Parts	233	37
Reworked Parts	18	--
Existing Parts	129	372
	-----	-----
	380	409

**463 Project - Part Data
Excluding Electrical and Hydraulic Control Parts**

Table 4-2

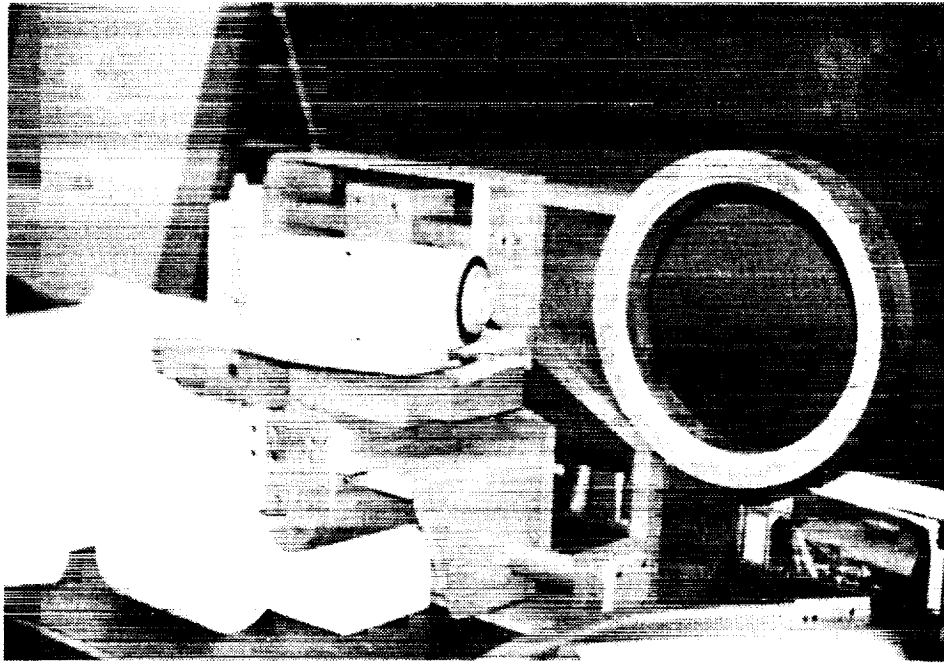
15	Layouts
31	Layout Sheets
270	New Mechanical Details
18	Major Part Reworks
	Machine Electrical Schematic
	Machine Hydraulic/Lube Schematic
	Filter/Chiller Schematic

463 Project Design Effort

Table 4-3

An example of Engineering required for the rebuild/retrofit program is shown in Figure 4-2 and 4-3.

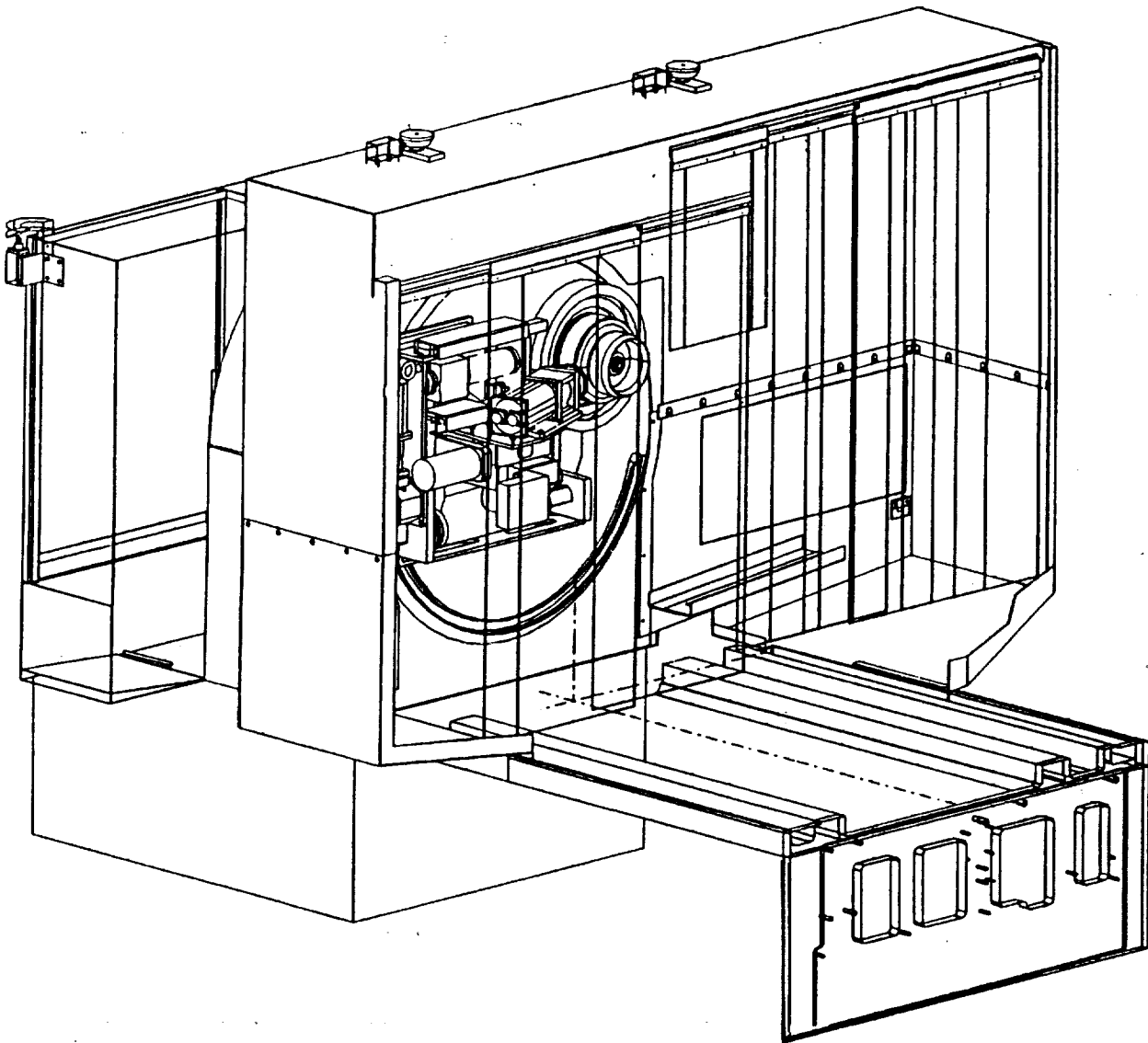
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Wooden Mock-up of New Rotary Dresser

Figure 4-2

During Phase I of the program several investigations were conducted to look at either problems on the conventional grinder or new technology which would yield improvements. As a result two (2) additional sub-task were added to the original ten (10). They were "Chiller/Coolant Filtration System" and "Stiffness Improvement in Grinding Wheel Spindle and Mounting Method."



Layout of New Guarding Requirements

Figure 4-3

These two (2) additional sub-task will also be discussed in greater detail in the Phase II section of this report.

Task 3 - Economic Analysis

At the completion of Phase I an economic analysis was conducted to look at the projected savings in the grinding of spiral bevel gears on the 463A CNC grinder and the estimated cost of conversion from manual to CNC grinding.

The projected savings in final grinding was identified as all occurring in the setup and maintenance of setup area. This saving was projected to be 50 percent.

The cost of converting to CNC grinding was estimated to be \$550K, excluding the cost for the chill/coolant filtration system and improvement to the grinding wheel spindle system.

Task 4 - Drawings and Oral Briefing

Phase I of the program ran for six (6) months, ending in March, 1987. The end-of-phase review, titled "Critical Design Review," was held at The Gleason Works, Rochester, New York on 24 March, 1987.

The detail design of the proposed grinder as well as all activity during Phase I were reviewed.

Approval to continue the program into Phase II was granted by the Government Project Officer.

4.2 PHASE II- INTEGRATION OF HARDWARE AND SOFTWARE INTO PROTOTYPE CNC GRINDER

During Phase II of the program a government owned Gleason 463 grinder was rebuilt and retrofitted into a CNC controlled machine.

Task 5 - Implementation of Conversion Hardware to Baseline Grinder

Task 6 - Add CNC to the Converted Grinder

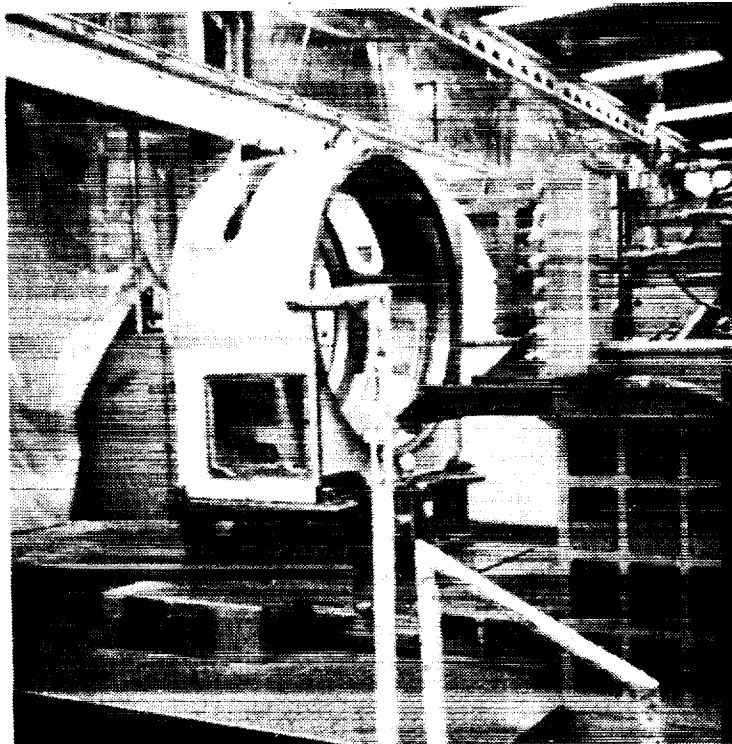
Task 5 Encompassed the rebuilding/retrofitting of the machine and the fabrication of new/redesigned hardware for the 463 CNC grinder. Task 6 covers the integration of the CNC control and software into the converted grinder. As there was an overlapping of these two (2) tasks, they will be summarized together with features of each covered as sub-task.

Under the rebuild program the machine was refurbished to an "as new condition". All sliding surfaces were remachined and hand scraped to their mating surfaces to restore original accuracies and alignments, see Figure 4-4.

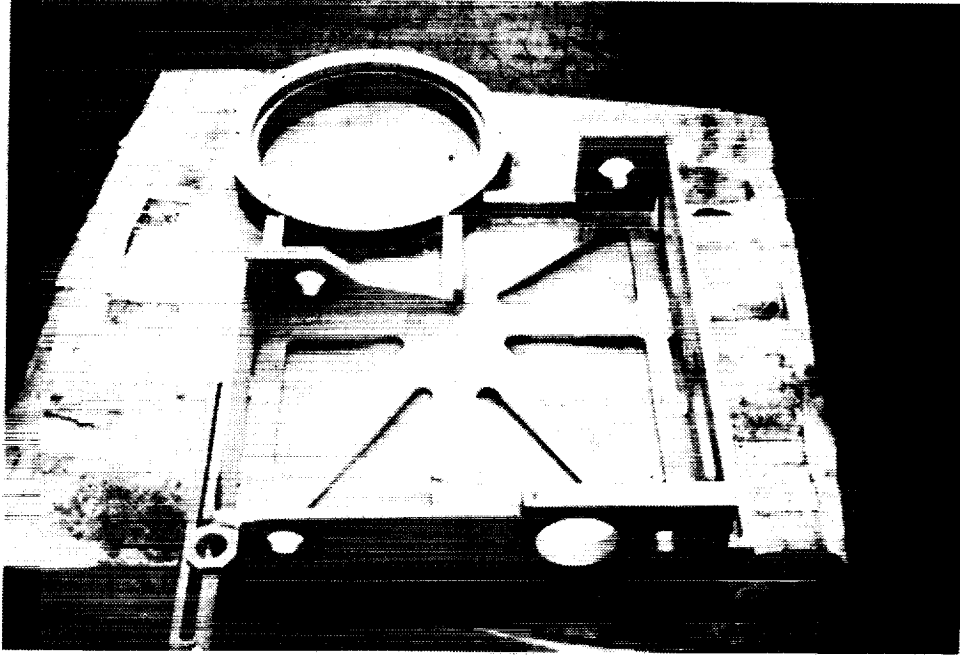


**Hand Scraping Sliding Surface
Figure 4-4**

All bearings, bushings, seals, packing, o-rings and gaskets applicable to the CNC grinder were replaced. Exception: Long delivery or special bearings may have been retained if, upon thorough inspection, they met new bearing specifications. Worn or damaged parts applicable to the CNC grinder were corrected, See Figure 4-5, or replaced with new original equipment manufactures (OEM) parts.

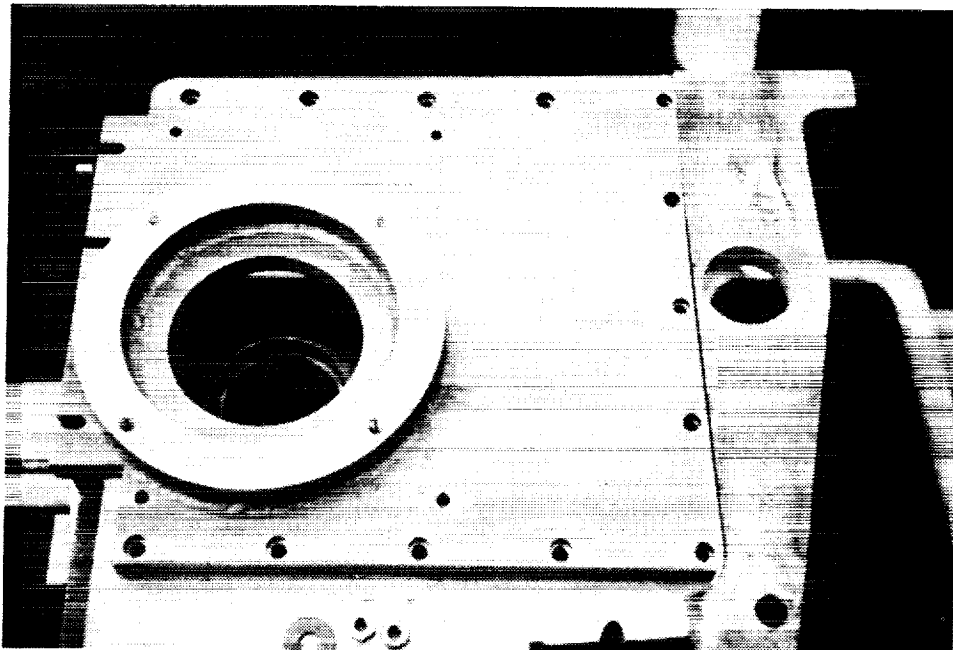


**Reboring the Cradle Housing
Figure 4-5**



**New Dresser Ring and Mounting Bracket
Figure 4-6**

The retrofit program included over 253 different parts which were modified or new fabrication. Examples of these would be the dresser ring and mounting bracket, shown in Figure 4-6, mounting pad for the work spindle motor and mounting plate for the new main drive motor, shown in Figure 4-7.

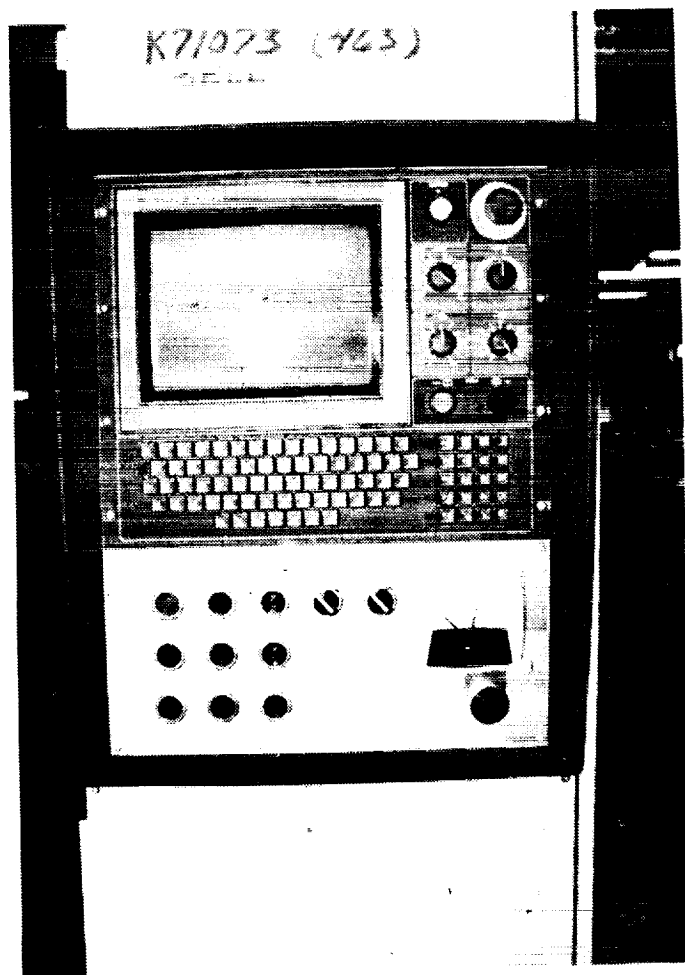


**New Mounting Plate for Main Drive Motor
Figure 4-7**

- **Sub-Task I - Machine Control Unit**

An Allen Bradley (AB) 8600 CNC controller, see Figure 4-8, is used as the main control unit of the grinder. The 8600 is a versatile, multi-axis/multi-process controller. It has many built in test and diagnostic functions which will aid in reducing machine down time. A number of open control card slots are available for future expansion, if required. The 80286 version main processor is used to provide improved speed and control capability.

Part summary data entry is provided via the 8600's CRT and keyboard. By utilizing the built-in, menu driven control software, an operator can create and maintain the different summaries. Up to fifteen (15) different part summaries can be held in the controller for easy access. Additional part summaries can be stored in optional bubble or EEPROM memory on the controller. Part summaries can also be kept in a variety of off line storage devices and accessed via the controller's RS-232 communications port.



**8650 CNC Controller
Figure 4-8**

The control software monitors and controls the grinding process and the various machine components and provides for fault monitoring and emergency control override in the event of a failure. The fault monitoring feature will reduce maintenance down time by identifying the area of failure for the maintenance technician.

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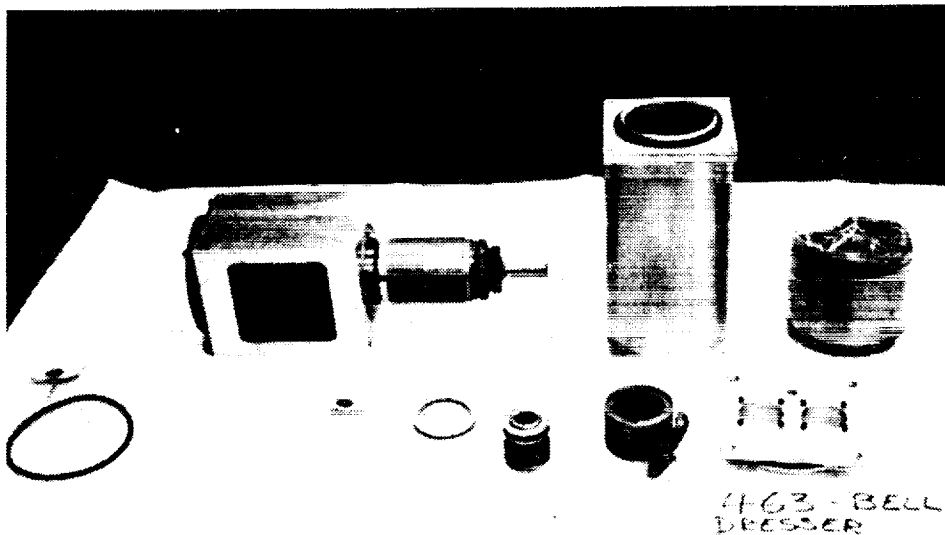
The CRT and keyboard are installed in one end of an environmentally controlled, three door, free standing electrical enclosure. All electrical connections to the enclosure are made through quick disconnect plugs for ease of installation and maintenance. The enclosure houses the main 8600 control unit, the axis drives, the EGB, and all the system I/O and power components.

All motors on the grinder, with the exception of the three (3) DC motors on the dresser, are Inland brushless A/C utilizing samarium-cobalt magnets for increased power to weight ratio. Standardizing to common drives and motors, where possible, will help reduce maintenance cost.

- **Sub-Task II - Dresser Unit**

The grinding wheel dressing system on the 463 CNC grinder incorporates the mechanics of a Normac X-Y slide assembly and a Gleason/Inland designed spindle and motor assembly. The spindle motor, an Inland 8,000 RPM, brushless A/C servo, is integral to the spindle as shown in Figure 4-9 as a sub-assembly.

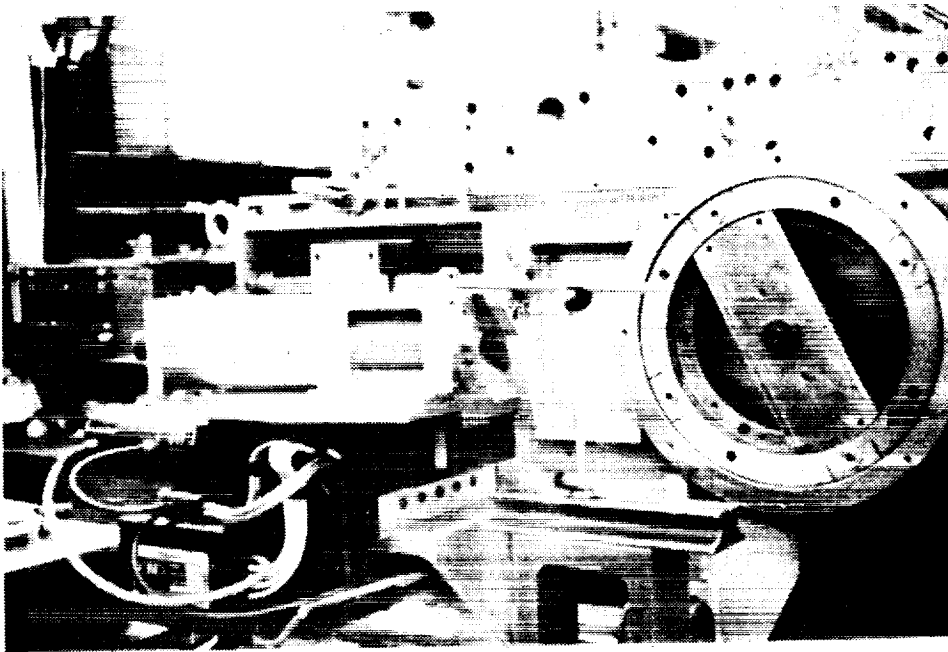
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**Dresser/Motor Sub-Assembly
Figure 4-9**

Dressing of the grinding wheel is accomplished by a diamond coated rotary disk mounted on the spindle. This rotary dressing tool/spindle assembly is attached to the X-Y slide assembly, as shown in Figure 4-10, in one of two positions.

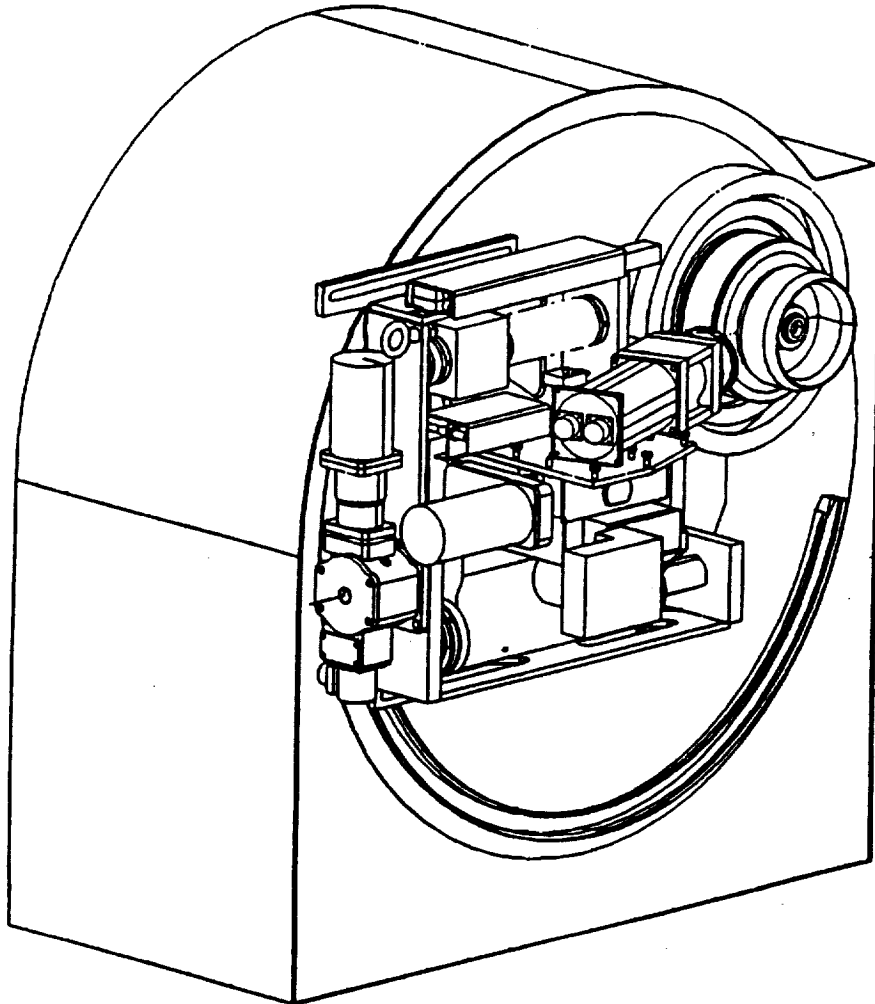
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**Spindle/Motor Assembly Mounted
On X-Y Slide
Figure 4-10**

This allows the dressing system to account for the full diameter range of the grinding wheels used on the grinder while keeping the length of the 2 axis slide to a minimum. This inner or outer position is a manual setting based on the upper or lower range of the grind wheel size with the break point being 11 inches. Once the initial manual setting is made from a part summary, all other dresser setting and operations are controlled by the 8600 controller.

The dresser assembly is mounted on a dresser ring on the face of the cradle as shown in Figure 4-11. This dresser ring rotates about the grinding wheel spindle axis to allow the angular position of the dresser to be set for different part configurations. Locks on the cradle face secure the dresser in the proper position.



**Dresser Assembly Mounted On Cradle Face
Figure 4-11**

When a dress of the grinding wheel is required, the dresser operates in the following manner:

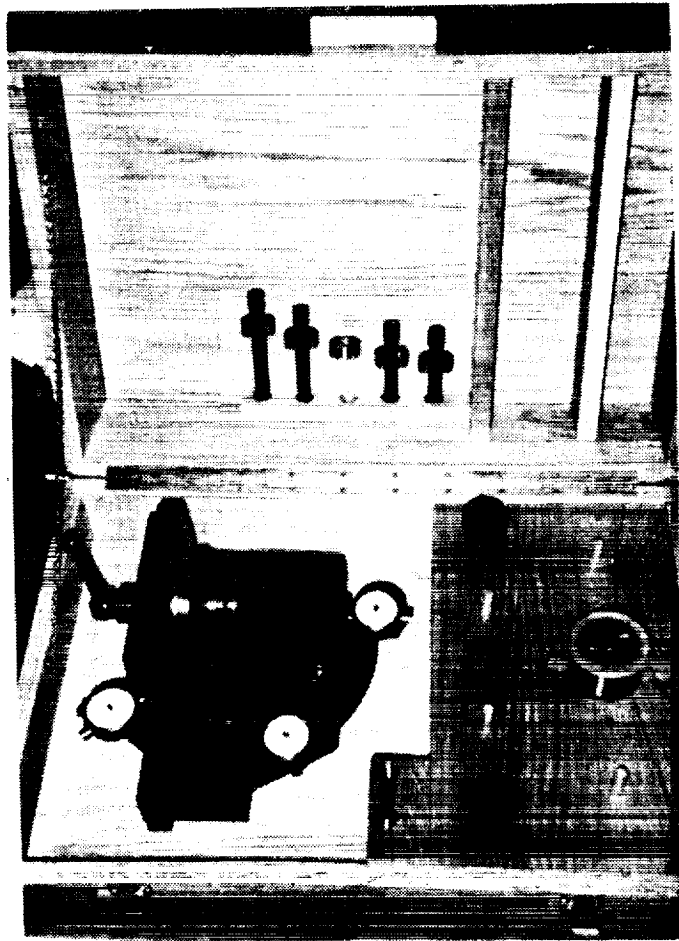
- A dress of the grinding wheel is called for by the controller.
- The Z axis slide moves the X-Y axis/rotary dressing tool assembly to a parked position in front of the grinding wheel. This position is determined by data from a part summary input earlier by the operator relative to grinding wheel point diameter. This Z axis movement is powered by a Baldor variable speed, DC motor thru a five (5) millimeter lead screw and tracked by an encoder.
- With the Z axis in proper position, the X and Y axes contour the grinding wheel profiles from part summary data controlled by the 8600 controller.

These linear slides are also powered by Baldor variable speed, DC motors and tracked by encoders.

- When contouring is complete the Z axis slide moves the dresser tool/X-Y axes assembly to a "home" position outside the grinding wheel/work piece interface area. This allows a more open access to the area during machine setup and grinding cycles.

The diamond coated rotary disk are available in five (5) sizes to cover the range of grinding wheel sizes for the 463 CNC grinder. A Dresser Roller Gage Fixture, see Figure 4-12, is used to check for wear of critical features on the diamond dressing disk. This is normally part of the grinder setup for each part configuration. Any wear on critical features of the dressing disk can be noted and input into the 8600 controller as offset data to control grinding wheel geometry.

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**Dresser Roller Gage Fixture
Figure 4-12**

- **Sub-Task III - Variable Speed Drive (Grinding Wheel)**

The 463 CNC grinder is equipped with a new type of drive motor for the variable speed grinding wheel drive. The motor is an Inland, variable speed, 4,500 RPM maximum, brushless, A/C servo motor, duty rated at 11 horsepower with continuous torque. The use of this new motor, located inside the cradle, will decrease the cost of maintenance with several features: improved life cycle, ease of removal, and quick disconnect plugs through the front of the cradle to eliminate the slip rings.

The increased speed and torque allows a decrease in the number of pulley sets to cover the full range of wheel sizes on the 463 CNC grinder.

There are two (2) matched sets of wheel pulleys supplied with the machine. These are as follows:

- 50 Teeth-Motor Pulley) 1.25 Ratio
- 40 Teeth-Spindle Pulley) "Speed UP"

- 34 Teeth-Motor Pulley) 1.647 Ratio
- 56 Teeth-Spindle Pulley) "Speed Down"

The set up summary will call for a particular set of pulleys, depending on grinding wheel point diameter, to provide the correct grinding wheel RPM and torque. The grinding wheel point diameter ranges are as follows:

<u>Point Diameter</u>	<u>Ratio</u>	<u>Result</u>
3-1/2" - 11"	1.25 : 1	Speed up, wheel - motor slower
11" - 19"	1.647 : 1	Speed down, wheel- motor faster

NOTE:

The range of the 1.25 ratio pulley set is for wheels having a point diameter from 3.5" to 11.0".

The range of the 1.647 ratio pulley set is for wheels having a point diameter from 11.0" to 19".

The new motor will be monitored and controlled by the AB 8600 controller for power and speed as a safety interlock to prevent crashes and/or over speeding of the grinding wheel.

The AB 8600 generates an analog reference voltage using the internal data values provided by the operator. This reference voltage represents the maximum safe operating speed of the wheel and is used to keep the wheel from exceeding its safe operating RPM. The reference value is compared to a voltage proportional to the actual RPM of the spindle. If the actual RPM ever exceeds the reference voltage, the 8600 controller will stop the wheel spindle and abort the grind cycle.

The actual RPM signal voltage is generated from a proximity switch which is activated by a specially built ten lobed cam mounted on the wheel spindle. Wheel rotation then generates a pulse train that is converted to the actual RPM reference signal using a frequency to voltage conversion circuit.

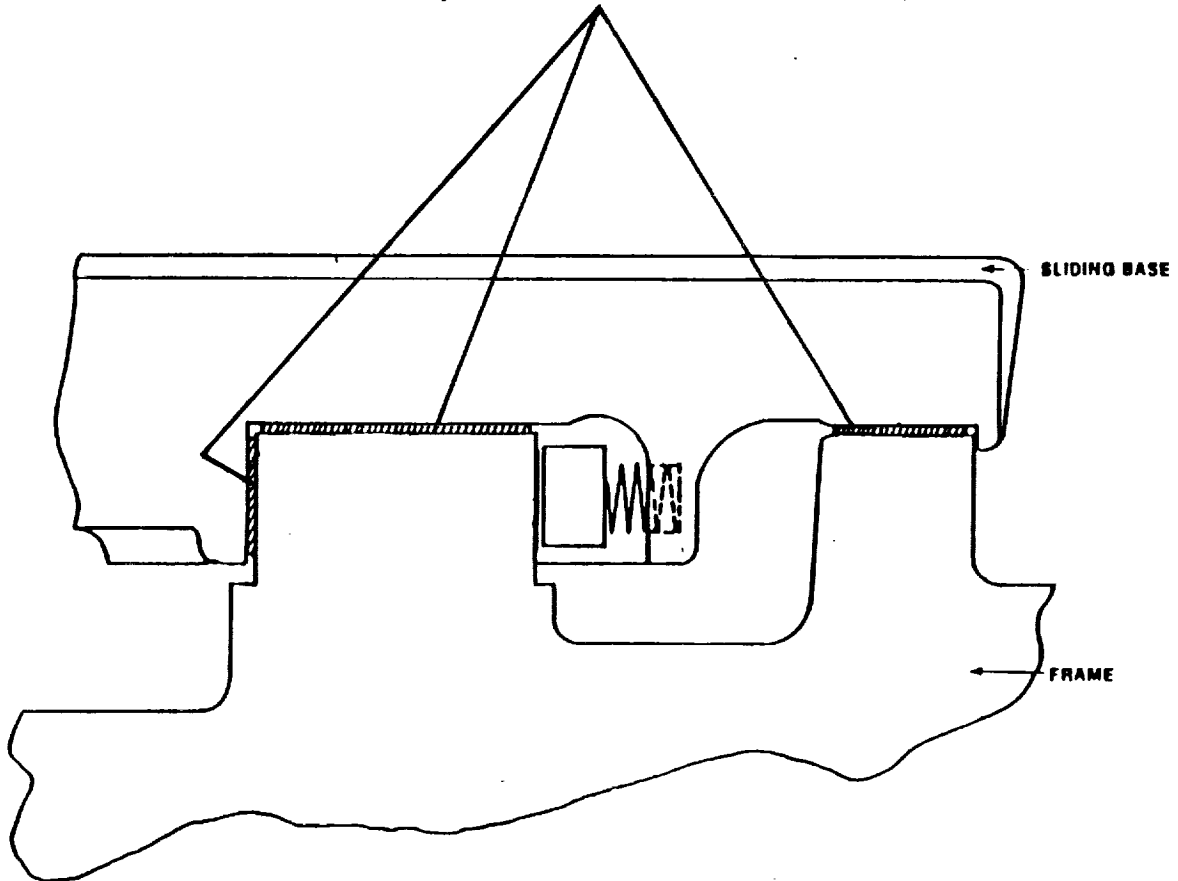
When the spindle is commanded to turn, it is first accelerated to 800 RPM. After a four second delay, the RPM is read and used to check that the correct pulleys are installed on the spindle motor drive. If the actual RPM differs from the calculated RPM, the wheel is shut down and an error message is generated on the screen. If no error occurs, the wheel will then accelerate to its commanded speed.

This feature will prevent the possibility of over speeding and exploding grinding wheels.

- **Sub-Task IV - Sliding Base Improvements**

Sliding base improvements to the 463 CNC grinder were made in the areas of lateral control, reduced friction, power and incremental grind positioning.

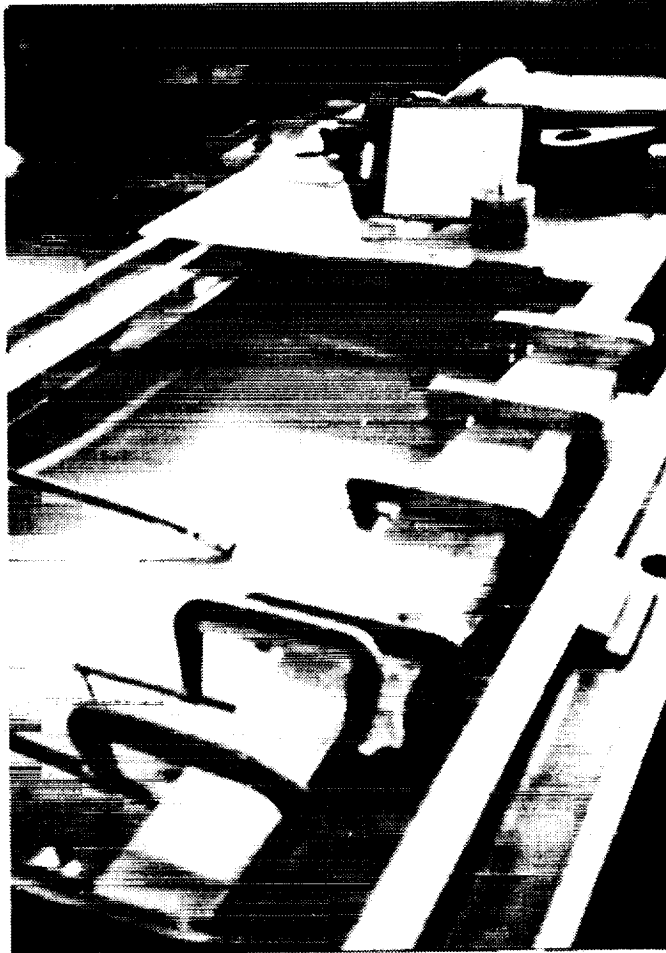
As shown in Figure 4-13, the underside of the sliding base and the sides of the guideways were remachined. The frame way surfaces were milled flat and scraped for surface texture. A TURCITE facing was applied to the sliding base on two (2) sliding and one (1) guideway surfaces.



**Sliding Base Improvements
Figure 4-13**

A hardened steel wear strip was bonded to one (1) side of the frame guideway. See Figure 4-14. A pair of spring loaded, returnable rollers were mounted on the sliding base and roll along the steel strip. This arrangement will improve the lateral control of the sliding base and reduce friction.

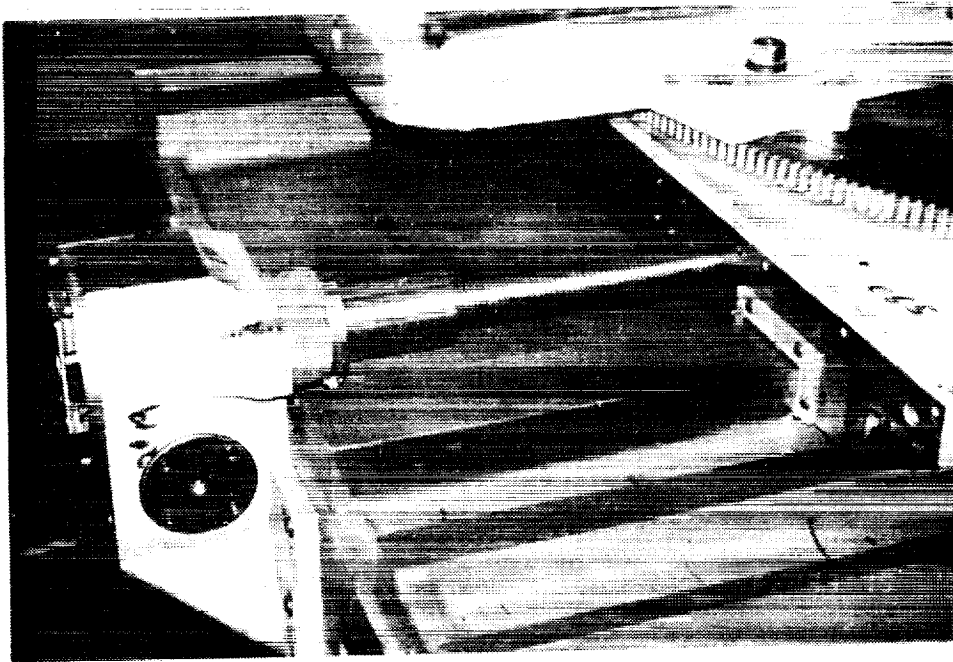
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Bonding Of Steel Strip On Frame Guideway
Figure 4-14

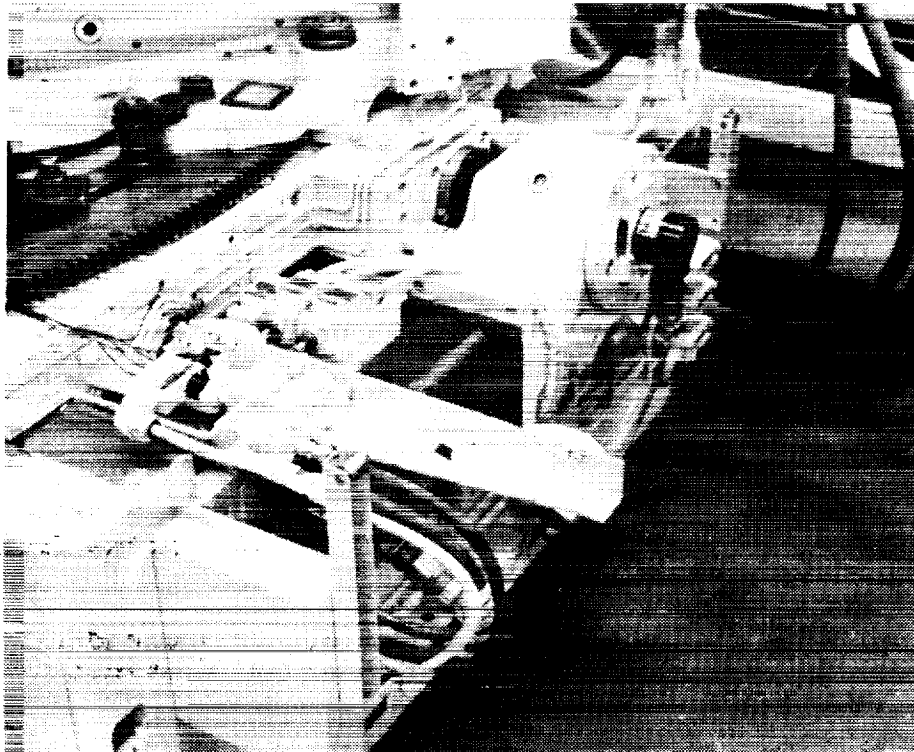
The sliding base drive is provided by an Inland, 2900 RPM, brushless, A/C motor thru a six (6) millimeter, preloaded ball screw.

Position of the sliding base is controlled thru the 8600 controller and a Teledyne Gurley encoder. Figure 4-15 and 4-16 show the sliding base ball screw, drive motor and encoder.



Sliding Base Ball Screw
Figure 4-15

The full withdraw position of the sliding base will be sensed by a limit switch. This will also establish the zero position of the servo system during each withdraw. A zero position referencing move must be initiated at each machine startup.



Sliding Base Drive Motor And Encoder
Figure 4-16

The incremental grind positions of the sliding base for various grind cycles are stored within the CNC controller as electronic "stop drums". The operator, during setup, will select one (1) of the four (4) electronic stop drums at the controller keyboard or may choose to edit one (1) of the stop drums for optimization of a particular part. The operator will add dress or pause requirements at any station of the stop drum as needed. An example of a typical electronic stop drum is shown below in Table 4-4.

PINION GRINDING SETTINGS							
MENU 5							
STATION	POSITION	DRESS	PAUSE	STATION	POSITION	DRESS	PAUSE
1	0.0000	0	0	13	0.0237	0	1
2	0.0013	0	0	14	0.0237	0	0
3	0.0026	0	0	15	0.0280	0	0
4	0.0039	1	0	16	0.0290	0	0
5	0.0039	0	0	17	0.0290	0	0
6	0.0064	0	1	18	0.0303	0	0
7	0.0104	1	0	19	0.0343	0	0
8	0.0104	0	0	20	0.0343	0	0
9	0.0117	0	0	21	0.0356	0	0
10	0.0157	1	0	22	0.0396	0	0
11	0.0157	0	0	23	0.0420	0	0
12	0.0197	0	0	24			

SLIDE BASE PARAMETERS

1)	STOPDRUM (1-4)	=	2	2
2)	SLIDING BASE	=	9.926"	9.989"
3)	START STATION	=		
4)	EDIT STOPDRUM	=		

**Electronic Stop Drum
Table 4-4**

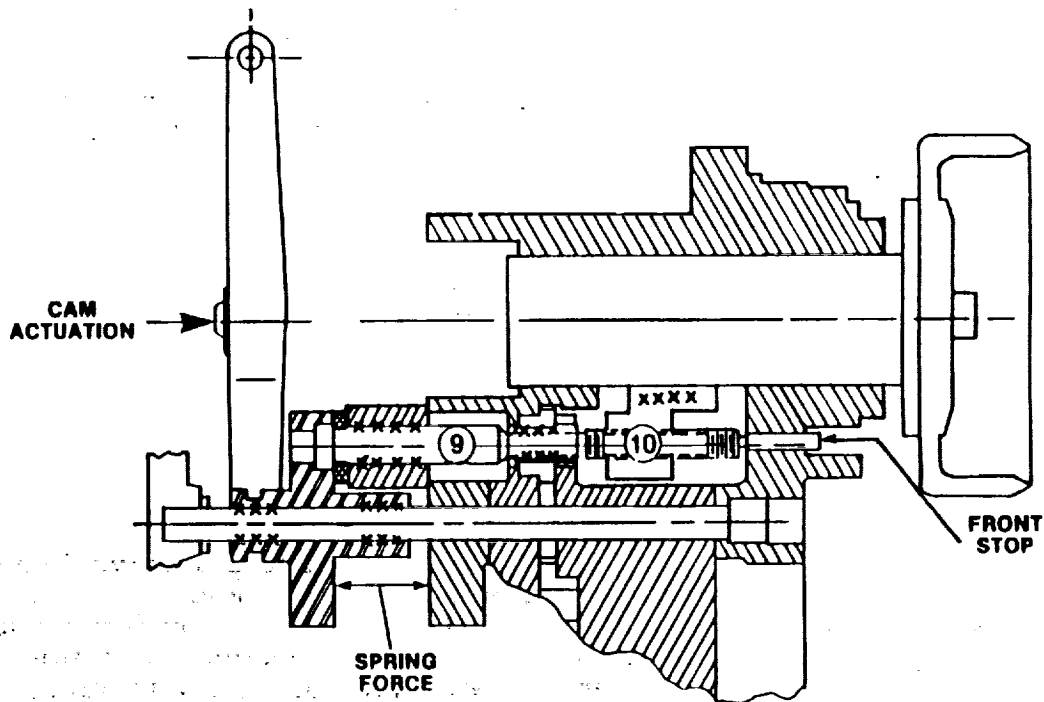
Station 1 would be at 0 or finish position. That is, the sliding base would have moved the part being ground to its closest point with the grinding wheel. Station 2 would be one and three ten-thousandths (.0013) of an inch out from finish, and so forth. Grinding of a part would start at a station some predetermined distance out from finish and "step" down in incremental amounts to the finish station.

A number one (1) located in the "dress" or "pause" column would initiate that action at the station in which it was located. For example, the number 1 under the dress column in line with Station 4 would result in a dress of the grinding wheel as the grind cycle stepped from Station 5 down to Station 4.

Using the Datam button on the 8600 controller the operator can move the sliding base in a manual mode. This feature is for setup, division of stock on parts, etc.

- **Sub-Task V - Axial Wheel Position**

The axial wheel system operates from the feed cam, located at the rear of the machine, through a mechanical lever system. This lever system moves the grinding wheel out to a grind position against a positive stop during the cradle roll and allows the grinding wheel to retract for clearance during the reverse cradle roll. Two major improvements to the axial wheel positioning system have occurred. First, the frictional forces through the system have been equalized. This was achieved primarily through processing modifications in the manufacturing and assembly of the system. Secondly, the forward wheel stop has been redesigned to give improved repeatability of the grind position of the grinding wheel. Figure 4-17 shows a drawing of the axial wheel feed system. Note the sliding surfaces marked with X's.



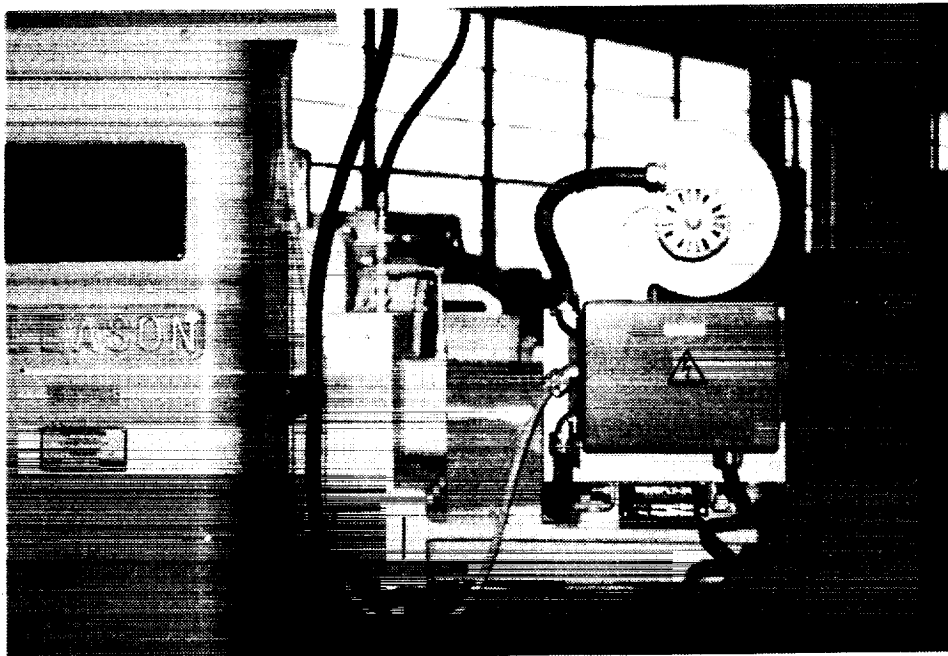
**Sliding Surfaces Of The Axial Feed Mechanism
Figure 4-17**

- **Sub-Task VI - Electro-Magnetic Particle Brake**

The electro-magnetic particle brake is attached to the work spindle to provide a smooth, continuous load to the work spindle drive system for control of backlash.

The unit has been incorporated into the prototype 463 CNC machine with two (2) changes. First the adjustable torque setting is established through the 8600 CNC control. Second, the power supply on the 463 CNC grinders electro-magnetic particle brake has been changed to a more regulated supply in order to reduce "pulsing" which could become evident in the work head drive system. Figure 4-18 shows the electro-magnetic particle brake mounted on the back of the work head.

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**Electro-Magnetic Brake
Figure 4-18**

- **Sub-Task VII - Digital Displays**

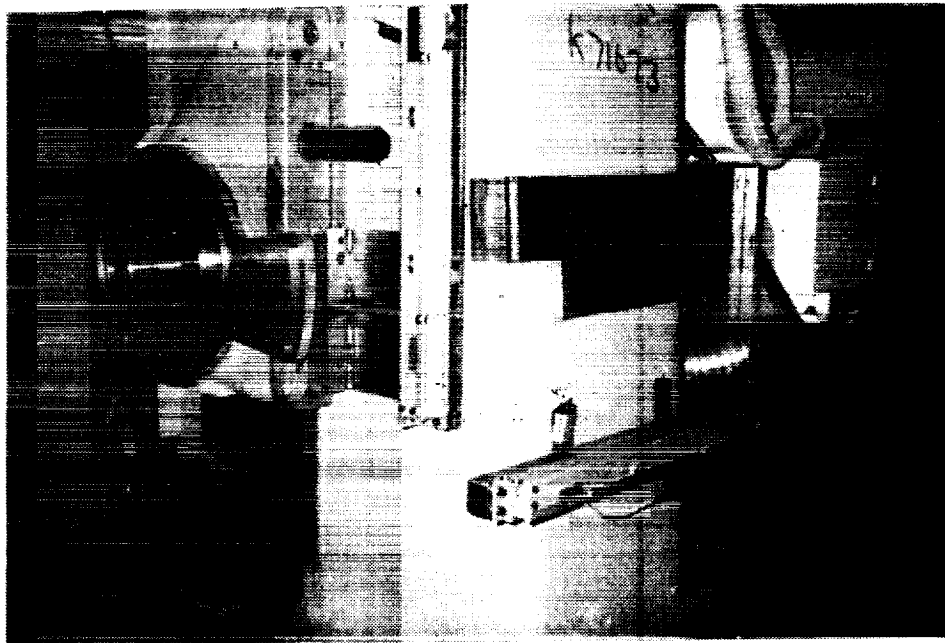
Three (3) digital readouts were added to features which require manual settings. These digital readouts will supplement the present vernier scales in the following locations:

- (A) **Horizontal Head Setting.** This is the dimension from the center of the pivot of the swinging base to the front face of the work spindle.
- (B) **Vertical Heading Setting.** This is the dimension from the centerline of the machine cradle to the centerline of the work spindle.
- (C) **Eccentric Angle Setting.** This is an angular dimension that controls the distance between the grinding wheel axis and cradle axis.

The addition of the digital displays will decrease the time required to make settings, but moreover, it will add greater precision to adjustments and assure repeatability of previous setups. The readouts for all three axes will be located above the workhead column, giving the operator readable access when setting any of the three (3) axis.

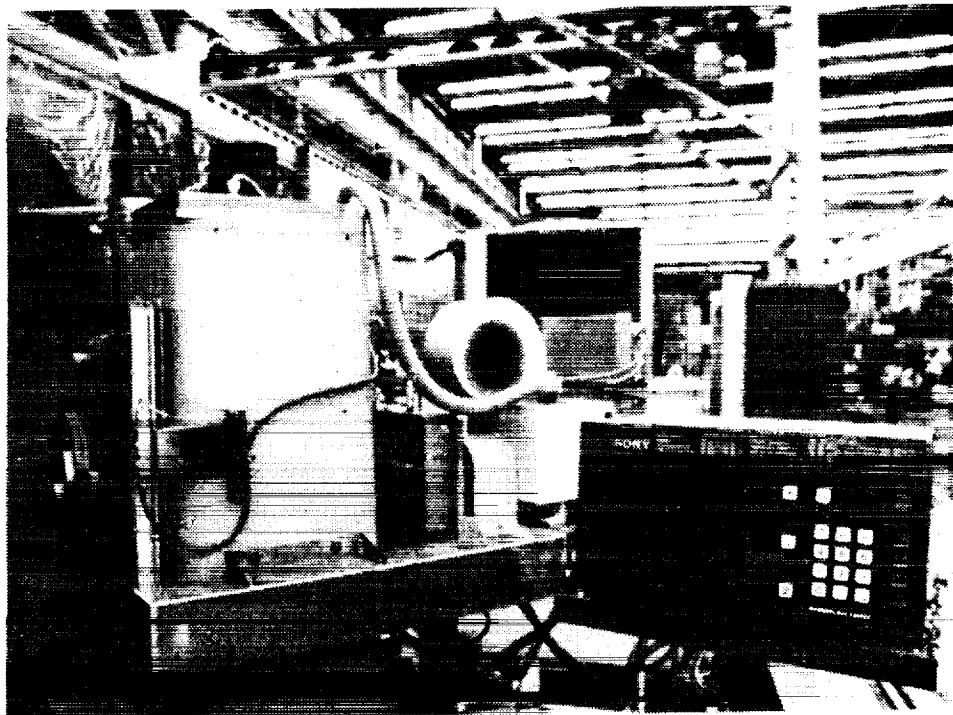
Figures 4-19 and 4-20 show the location of the vertical and horizontal scales on the workhead and the digital readout located atop the workhead column.

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Vertical and Horizontal Scales
Figure 4-19

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Digital Readouts
Figure 4-20

- **Sub-Task VIII - Temperature Control Improvements - Hydraulic And Coolant Systems**

The temperature control system implemented on the 463 CNC grinder will maintain machine temperature stability through the grinding process after it has been achieved relative to ambient. The goal was to reduce localized temperature variations which cause distortions in overall machine alignment. These distortions result in a nonparallel spread or contraction of the relative position of the work piece and grinding wheel in a manner that affects both tooth geometry and spacing.

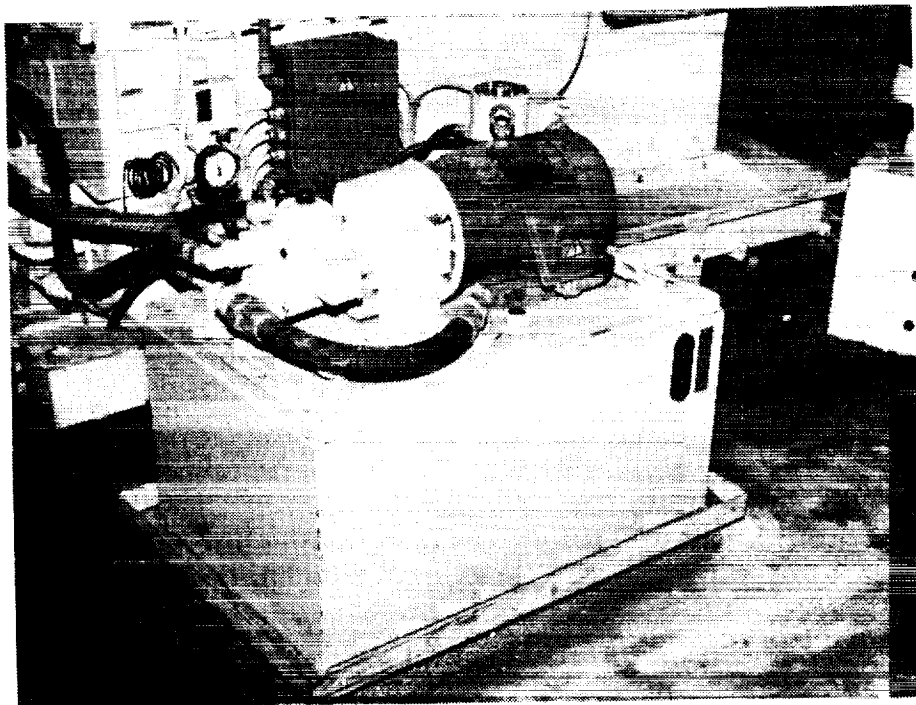
Tests have shown that variations in temperature from one part of the 463 grinder to another create dimensional variations that affect the tooth thickness of the gears being produced. On small gears this variation will be noted from one gear part to the next. On large gears, the temperature affects may cause tooth to tooth spacing variations.

Two methods of machine temperature control can be implemented to achieve optimal repeatability. The first is to control overall size variation by complete temperature control of the machine. The overall machine temperature will track ambient plus or minus a few degrees depending upon the rate of change in the ambient temperature. An optimum point of stability occurs when the ambient temperature is constant and the machine has been pre-run and normalized prior to the grinding of any parts. This, then, becomes a facility problem. The machine will operate best in an air conditioned environment where the ambient temperature does not vary from day to day or with the seasons.

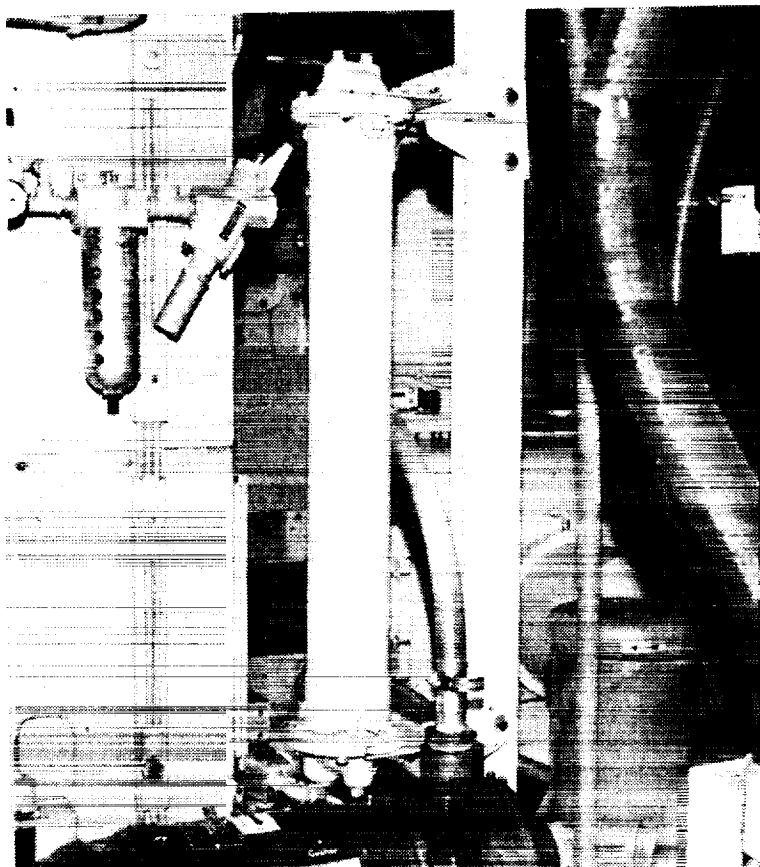
The second method, that of machine warm-up, is highly recommended because of the cost involved in temperature controlling of a space large enough for several Gleason grinders. Utilizing this method, a 30 to 60 minute cycling of the machine with coolant flow will cause the machine to reach a stable temperature condition. Part consistency can be maintained after the machine warms up and normalizes.

The 463 CNC grinder has several changes incorporated to shorten the warm-up cycle necessary to reach a stable temperature condition. Most notable of these is the free standing hydraulic unit, routing of hydraulic lines on the outside of the machine frame, incorporation of the hydraulic oil as lube oil for the machine, elimination of hydraulic actuation of the dresser unit, and the addition of a water/oil conduction style heat exchanger for both the hydraulic oil and grinding coolant. Figure 4-21 shows the remote hydraulic tank. The 463 CNC hydraulic system serves only three functions, (1) actuates the grinding wheel feed out mechanize, (2) the work piece clamping system, and (3) lubricates the entire machine.

The water/oil conduction style heat exchanger is shown in Figure 4-22.



Remote Hydraulic Tank
Figure 4-21



Heat Exchanger
Figure 4-22

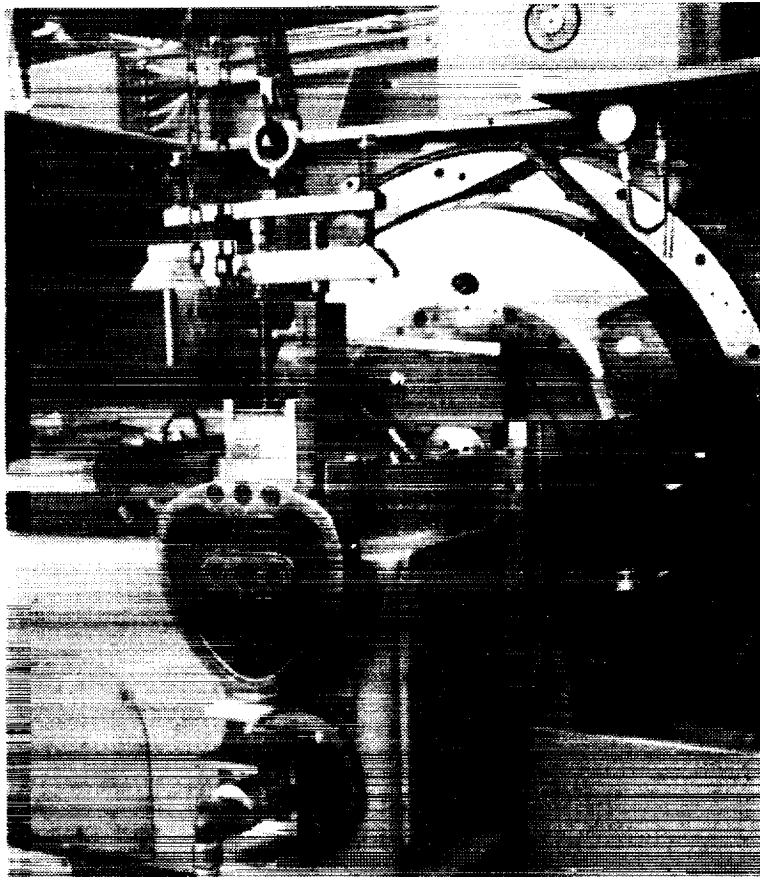
- **Sub-Task IX - Improved Locating/Adjusting Mechanism - Generating Cam**

The generating cam is used to impart rotary motion to the cradle member which carries the grinding wheel. Existing machines are supplied with a series of generating cams with profiles that are designed to give different amounts of motion. These cams are changed during the machine setup, depending upon the specific amount of motion required for the job. The cams are attached to a crank plate at the rear of the machine.

Each cam in the series provides a specific amount of cradle rotation and each has been designed to operate at a nominal distance from the center. Slight adjustments are made from the nominal to provide certain desired cradle rotation effects. This setting is precalculated for each work piece and is one of many items of setup data provided to the operator. The setting is made in a location where the visibility is poor. There is some history of dimensional error in some of the elements that control the cam position.

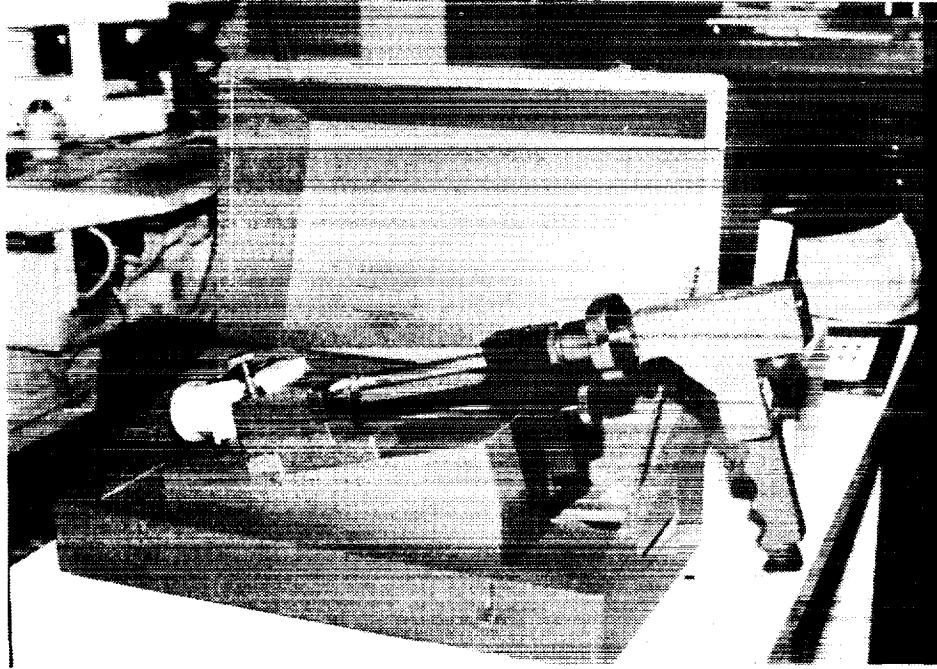
The 463 CNC grinder, while retaining the generating cam system, has incorporated improvements to the access and accuracy of cam settings.

New rear machine guards with an overhead hoist and support cradle cut the operators work load involved in changing cams substantially. Figure 4-23 shows the new guards open, exposing the unobscured access to the cam bracket.



**Improved Access To Cam
Figure 4-23**

Accuracy and repeatability of cam setting will be assured with the transfer gage shown in Figure 4-24. The bench top transfer gage is portable and capable of serving several grinders. The summary setting or changes are set on the gage outside the machine to an accuracy of one thousandths of an inch (.001) and then transferred to the cam assembly in the grinder by attaching the transfer gage to the top plate above the cam slide and setting the cam to the gage as shown in Figure 4-25.



**Transfer Gage
Figure 4-24**

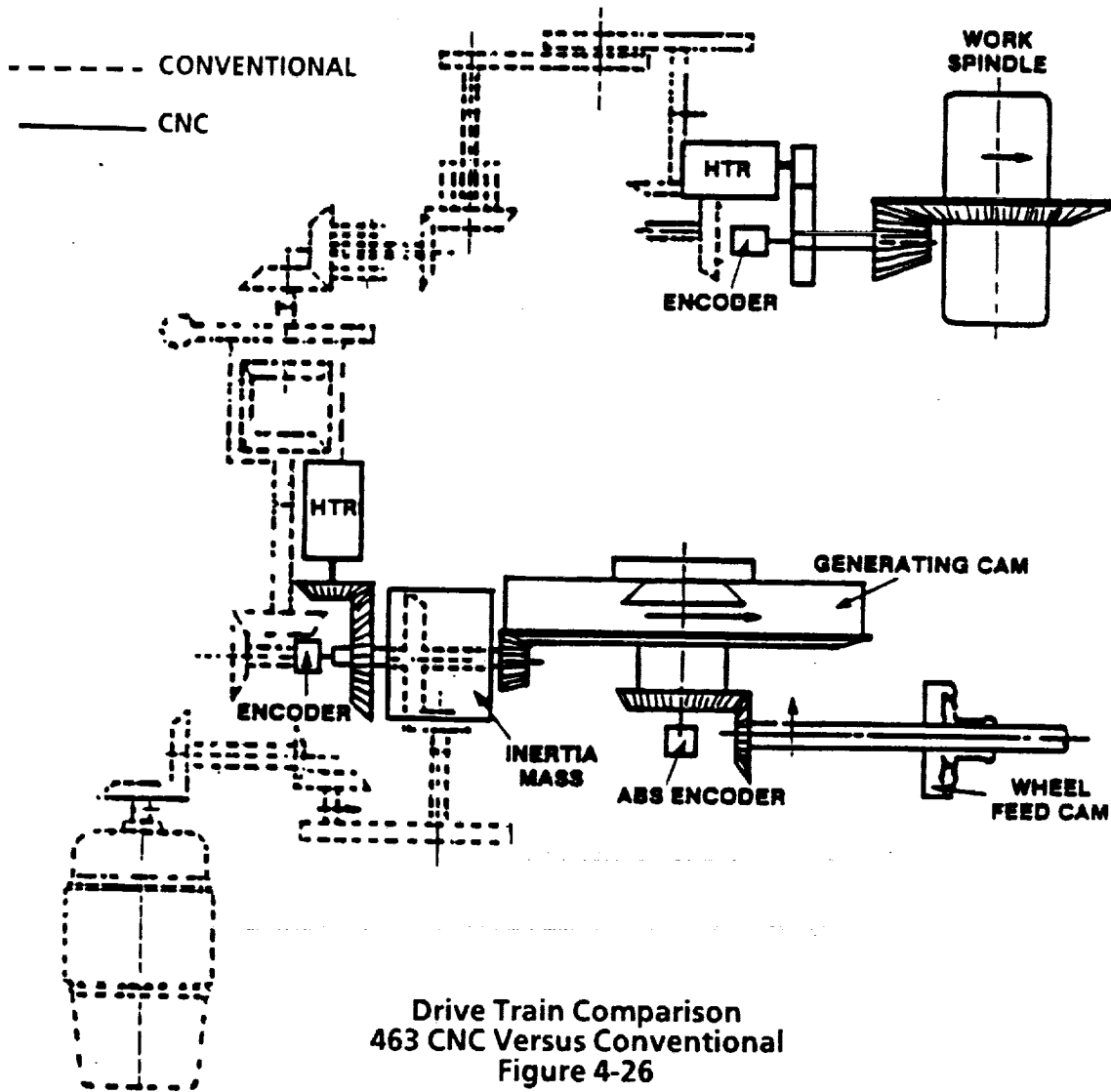


**Setting The Cam
Figure 4-25**

- **Sub-Task X - Improvement Associated With The Drive Train**

Improvements in the 463 CNC drive train center around the replacement of the overhead drive system with an electronic coupling between the cradle/cam drive and the work spindle drive.

The old system of fifteen (15) gear meshes connected by sliding shafts and index gear has been replaced by a new system with separate A/C servo-motor drives for each of the work spindle and cradle/cam drives. This new system has been reduced to four (4) gear meshes (see Figure 4-26) with no sliding shafts, index or feed gears. This reduction in the number of gear meshes in the drive train will result in improved consistence of American Gear Manufacturers Association (AGMA) Class 13 and better toothspacing on ground details.



This electronic coupling which ties the cradle/cam and the work spindle drives together is the Electronic Gear Box (EGB) System. The EGB performs the electronic equivalent of a mechanical gearbox. It is essentially a high performance servo positioning system with wide dynamic range and high accuracy. Unlike conventional CNC systems in which input data in the form of position demands are entered via a part program or manual instructions, the EGB works on the Master Slave principle in which the slave axis follows the positional data generated by the master axis.

In the grinding application, the master axis is the cradle cam. The slave axis is the workspindle. Subject to input speed and ratio limitations, the slave axis will follow simultaneous movements of the master axis.

During the machining cycles the cradle speed is constantly monitored via the cradle cam encoder. This signal is used to command the EGB. The EGB drives the work spindle at the correct ratio to the cradle movement using control data that was previously loaded into the EGB during the grinder setup sequence.

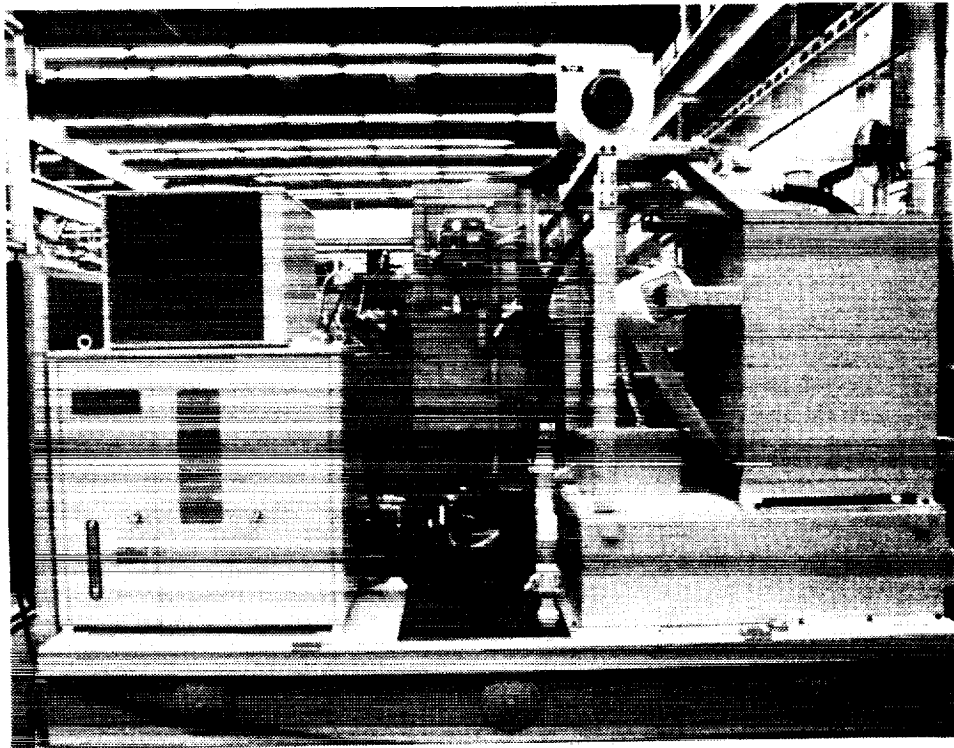
The EGB is dependent on the 8600 controller mainly for setup information and fault monitoring data transfer. Once the EGB control data is downloaded, the EGB runs independently from the 8600 doing its sole job function of making the work spindle turn as a ratio of the speed of the cradle.

- **Sub-Task XI - Chiller/Coolant Filtration System**

The chiller/coolant filtration system for the 463 CNC grinder is designed to give improved coolant filtration with reduced maintenance support and provide chilled water for the water/oil conductive style heat exchangers covered in Subtask VIII.

The chiller/coolant filtration unit, see Figure 4-27, consists of four (4) basic elements: The dirty coolant oil tank, the clean coolant oil tank, the Oberlin filter unit and the Hansen chiller unit.

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Chiller/Coolant Filtration Unit
Figure 4-27

The dirty coolant oil tank has a capacity of 250 gallons (945 liters) and is used as a collection tank for dirty coolant returning from the machine. The tank has an internal flush system to keep contaminants from accumulating on the bottom surface of the tank. Dirty coolant is pumped from the tank to the Oberlin filter unit.

The Oberlin Pressure Filter is an automatic filter using filter pump pressure to force liquid thru a filter media and the filter cake which builds up. It is this depth filtration which provides high quality filtrate. It can handle differential filter pressures up to 30-35 psig. The filter cake is dried before discharge by forcing pressurized air thru it. The cake is discharged automatically into a catch tub at the end of the unit when the differential filter pressure reaches its set point.

During the filtering cycle, dirty coolant flows from the dirty coolant tank, through the pump, into the upper shell of the filter via the inlet valve. Pump pressure forces the oil through accumulated grinding swarf and a filter media, into a transfer tank, through a vapor box and into the clean oil tank which is located directly below the filter unit.

The clean coolant oil tank has a capacity of 135 gallons (510 liters) and is used for storing clean coolant oil which has passed through the filter. It has its own pump to supply clean coolant to the machine. The tank is fitted with an overflow "stand-pipe". If demand for clean coolant is less than the supply from the filter, the clean coolant will overflow into the "stand-pipe" and into the dirty coolant oil tank.

The Hansen chiller unit is mounted above the dirty oil tank. Chilled water provided from the Hansen chiller to the water/oil heat exchangers for the hydraulic oil and coolant systems is tracked to air ambient temperature.

NOTE: In areas where a water source was available without large seasonal changes in water temperature a chiller might not be required.

The filter/chiller unit is sized to provide requirements for two (2) grinders. The unit has its own controls independent of the CNC control. The only tie-in between the systems is a signal to tell the operator to activate the filter/chiller unit, thus making the filter/chiller optional for any particular environment.

- **Sub-Task XII - Stiffness Improvements In Grinding Wheel Spindle And Mounting Method**

The overall performance of a grinding machine is dependent on many factors, but the rigidity of the machine system is probably the most significant. Rigidity greatly influences the control of shape and size in the workpiece. For example, an infeed of .002" on a very stiff machine will cause a greater amount of work material to be removed than will be removed on a more compliant machine. The results are different because a certain threshold pressure must be achieved between the wheel surface and the work surface before material can be removed from the work. On the more compliant machine a greater portion of the feed is used to reach the threshold pressure. Only the feed beyond this point results in the removal of material.

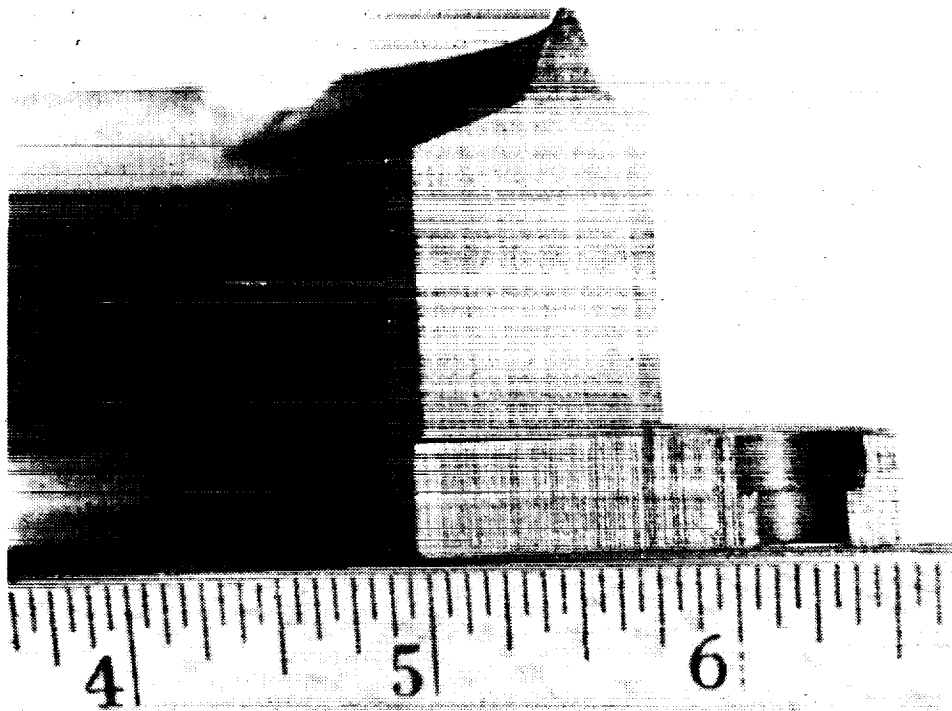
During Phase I discussions, several questions on the compliance in the convention 463 grinding wheel spindle were raised.

During an evaluation of tooth spacing problems associated with the development of a new FORMATE gear grinder, engineers found that the spring rate between the grinding wheel and gear tooth surfaces significantly influences the quality level of the gears produced. Parts ground on the FORMATE grinder exhibited first-to-last tooth spacing errors that were many times greater than the allowable pitch variation. The large error was the result of changes in the grinding wheel sharpness and the forces that occur between the grinding wheel and the tooth surface. When the first tooth was ground with a sharp freshly dressed wheel, the forces and deflections were low. When the last tooth was ground, the abrasive grains had become dull so that the threshold pressure and deflections were substantially larger, causing additional work material to be left on the last tooth. This was a clear indication that a stiffness problem existed in the machine system. Stiffness measurements were made of the entire machine system, including the wheel/wheel adapter, machine, and the workholding equipment, to identify the most compliant members. It was found that the deflection of the grinding wheel/wheel adapter was several times greater than the entire remainder of the machine system.

During Phase I, an evaluation of the conventional 463 grinding wheel spindle was started. Substantial complaints was found in the grinding wheel configuration and the grinding wheel spindle. New grinding wheel configurations were made and tested. These test wheels were produced by Norton, Worchester, Massachusetts, utilizing a new approach to grinding wheels for spiral bevel gear grinding. A disposable steel plate with mounting holes is used for backing and the abrasive material, produced as a cylinder, is bonded to the steel plate. Figure 4-28 shows the cross section of the new steel backed grinding wheel. The increased wall thickness of the grinding wheels not only contributes to the improved stiffness but also decreases the number of sizes of grinding wheels required to cover the normal full range of the 463 grinder. The improved grinding wheel system, with eighteen (18) abrasive cylinder sizes required to cover the full range of the 463 CNC grinder, replace 75 (75) different wheel size required for the same range on the conventional 463 grinder. This feature will offer substantial saving in grinding wheel inventory.

Deflection testing of the steel backed grinding wheels showed a two and one half (2.5) times increase in stiffness compared to a conventional grinding wheel.

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Steel Backed Grinding Wheel
Figure 4-28

A proposal for additional work, beyond the original scope, to increase the grinding wheel spindle and configuration stiffness was submitted and approved during Phase II.

This work included redesign of the grinding wheel spindle and incorporation of the steel backed wheel system. The redesign of the spindle involved adding more balls to the ball sleeve quill and rework to the cradle housing to accommodate reseized triplex bearings to replace the duplex bearings of the conventional 463.

Drawings of the steel backed grinding wheel were released to all grinding wheel manufactures.

With completion of the fabrication and assembly of the machine, debug of the software was progressing steadily. For clarification, several meetings between Bell Project Management and Gleason Software Engineering were held to outline the machine sequences and requirements for grinding aircraft quality gears in a production environment.

- **TASK VII - Demonstrate CNC - Controlled Grinder**

During the early phase of the start up and debug of the machine, several problems were found which caused delays in the original time schedule. The most important of these problems were changes to the machine due to safety inspection, redesign and rework of the dresser spindle motor as a result of over heating, an interference problem in the traverse of the dresser and an interference and over heating problem of the labyrinth seal in the grinding wheel spindle. These problems, while not being major, added significant time to the program which caused a delay in the first demonstration of grinding. A contract extension was applied for and approved.

An informal, contractually unscheduled, review and demonstration of the CNC spiral bevel gear grinder was held at The Gleason Works, Rochester, N.Y. on April 19, 1988. Attendees were government project and administration personnel, project and industrial personnel from Bell Helicopter Textron, Textron Lycoming, and The Gleason Works. The review of the program was presented, covering the challenges, prime design directives, and features of the machine. Repeatability of the grinder was demonstrated with a comparison of data from gears ground before and after complete setup/breakdown and reset up of all machine settings. Additional data shown was pitch and index variation charts showing excellent results which met AGMA class 13 standards. A grinding demonstration was presented using a standard Gleason run-off part, a 40 tooth, 5 pitch diametral pitch, approximate 8 inch diameter gear. The review/demonstration was closed with an overview of the remaining task in Phase II.

After the first machine demonstration, start up of operator and maintenance training was initiated. Bell Helicopter production and maintenance personnel were placed at The Gleason Works in Rochester, New York, for hands on training. Budget for this effort was provided by Bell Helicopter. During the operator training the operator instructions were drafted and printed.

Upon completion of the operator and maintenance training, a machine acceptance run-off was conducted. Utilizing a 17 tooth, diametral pitch pinion, 20 parts were ground and checked for repeatability only. With few problems, the repeatability, both part to part and setup to setup, showed excellent results and the machine was accepted by Bell Helicopter.

- **TASK VIII - Update Economic Analysis**

At the completion of Phase II an updated economic analysis, showing projected saving in final grinding and cost of conversion from manual to CNC grinding was submitted.

Based on limited test grinding and the grinding of a 20 piece lot of a Bell pinion for machine acceptance the following projection for saving in grind cost were submitted:

- A 50 percent decrease in setup time for each part number.
- Better than a 50 percent decrease in the maintenance of setup time during production runs.

The cost of conversion at the completion of Phase II was approximately 750K which included the chiller/coolant filtration system and the grinding wheel/spindle improvements.

- **TASK IX - Drawings and Oral Briefing**

The End of Phase II Review was held at The Gleason Works, Rochester, New York, on June 2, 1988.

A review of the program was presented, covering the challenges, prime design directives, and features of the machine. Repeatability of the grinder was demonstrated with a comparison of data from gears ground before and after a complete setup/breakdown and resetup of all machine settings. Additional data shown was pitch and index variation charts showing excellent results which met AGMA class 13 standards.

All design drawings, specifications, and operational information was made available for review by the government project personnel.

A demonstration of the 463 CNC machine, grinding a Bell Helicopter pinion, concluded the review.

Approval of Phase II was requested by Bell Helicopter and received from the government contracting officer. The machine was shipped to Bell Helicopter Machining Center, Grand Prairie, Texas, for Phase III, development and testing in a production environment.

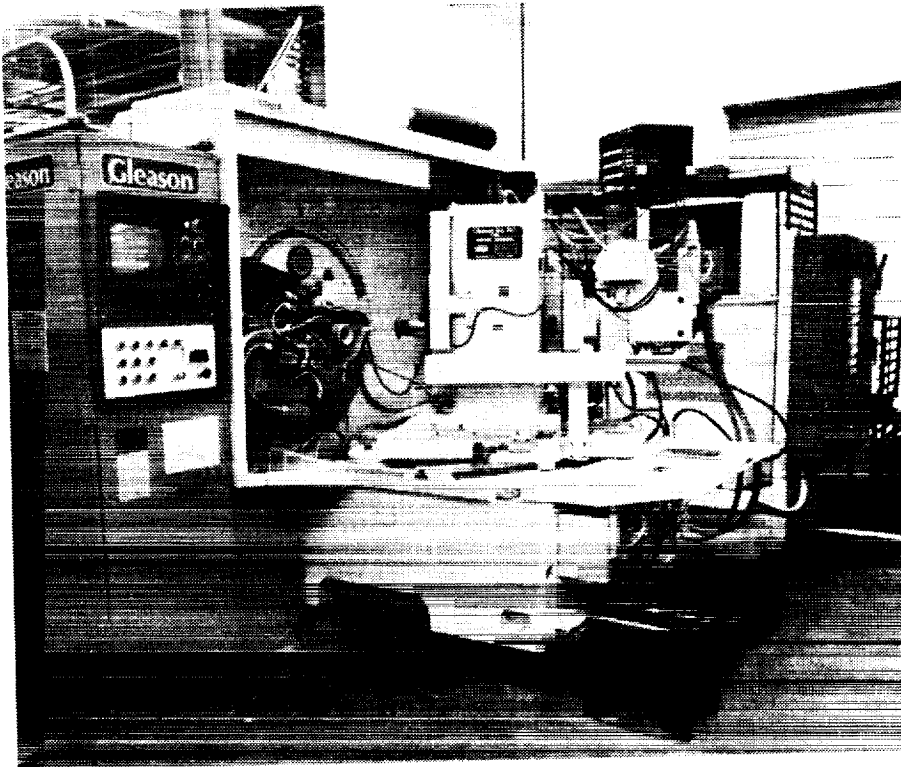
4.3 PHASE III - PILOT PRODUCTION

During Phase III of the program, the 463 CNC grinder was installed at Bell's Machining Center, Figure 4-29, for development and testing in a production environment. Six (6) different parts representing various ranges of size and diametral pitch were processed through nine (9) test for:

- Setup times
- Repeatability - Part to part and setup to setup

The original test plan, Appendix A, was modified by changing some of the part numbers, which were to be utilized for the testing. This was done in order to use production parts on a normal flow through the manufacturing area. The modified test plan is shown in Table 4.5 thru 4.7.

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463 CNC Grinder Installed at Machining Center

Figure 4-29

TEST NO.	GEAR DESCRIPTION	OBJECTIVE
TEST 1	Part No. 212-040-151 Gear No Teeth -23 Diametral Pitch -6.111	To test the ability of the machine to hold developed setting by producing nine (9) parts minimum without a major change to machine settings. To test for a 50% reduction in setup and maintenance of setup time over a 20 piece production run.
TEST 2	Part No. 206-040-441 gear No. Teeth -40 Diametral Pitch - 8.969	To test the ability of the machine to hold developed setting by producing nine (9) parts minimum without a major change to machine settings. To test for a 50% reduction in setup and maintenance of setup time over a 20 piece production run .
TEST 3	Part No. 206-040-440 Pinion No. Teeth -17 Diametral Pitch -8.969	To test the ability of the machine to hold developed setting by producing nine (9) parts minimum without a major change to machine settings. To test for a 50% reduction in setup and maintenance of setup time over a 20 piece production run.

Modified Bell In-House Test Plan

Table 4-5

TEST NO.	GEAR DESCRIPTION	OBJECTIVE
<p>TEST 4</p>	<p>Part No. 206-040-441 Gear No Teeth -40 Diametral Pitch -8.969</p>	<p>To test the ability of the machine to hold developed settings from setup to setup of the same part number.</p> <p>To test the ability of the machine to hold developed setting by producing nine (9) parts minimum without a major change to machine settings.</p> <p>to test for a 50% reduction in setup and maintenance of setup time over a 25 piece production run.</p>
<p>TEST 5</p>	<p>Part No. 406-040-421 Gear No. Teeth -48 Diametral Pitch - 8.25</p>	<p>To test the ability of the machine to hold developed setting by producing nine (9) parts minimum without a major change to machine settings.</p> <p>To test for a 50% reduction in setup and maintenance of setup time over a 25 piece production run .</p>
<p>TEST 6</p>	<p>Part No. 204-040-700 Pinion No. Teeth -29 Diametral Pitch -5.391</p>	<p>To test the ability of the machine to hold developed setting by producing nine (9) parts minimum without a major change to machine settings.</p> <p>To test for a 50% reduction in setup and maintenance of setup time over a 25 piece production run.</p>

Modified Bell In-House Test Plan

Table 4-6

TEST NO.	GEAR DESCRIPTION	OBJECTIVE
TEST 7	Part No. 212-040-141 Gear No Teeth -23 Diametral Pitch -6.111	<p>To test the ability of the machine to hold developed settings from setup to setup of the same part number.</p> <p>To test the ability of the machine to hold developed setting by producing nine (9) parts minimum without a major change to machine settings.</p> <p>To test for a 50% reduction in setup and maintenance of setup time over a 20 piece production run.</p>
TEST 8	Part No. 204-040-700 Pinion No. Teeth -29 Diametral Pitch - 5.391	<p>To test the ability of the machine to hold developed setting by producing nine (9) parts minimum without a major change to machine settings.</p> <p>To test for a 50% reduction in setup and maintenance of setup time over a 25 piece production run .</p>
TEST 9	Part No. 204-040-701 Gear No. Teeth -62 Diametral Pitch -5.391	<p>To test the ability of the machine to hold developed setting by producing nine (9) parts minimum without a major change to machine settings.</p> <p>To test for a 50% reduction in setup and maintenance of setup time over a 25 piece production run.</p>

Modified Bell In-House Test Plan

Table 4-7

Task 10 - Production Runs Using The Proof-Of-Concept Grinder

Under Task 10 the 463 CNC grinder ran production parts. Table 4-8 lists the part numbers and their quantity ground during the task period. Note that only nine (9) of the different setups involving six (6) part numbers were test.

TEST NUMBER	PART NUMBER	APPROXIMATE QTY
	206-040-441	56 PIECES
1	212-040-151	41 PIECES
2	206-040-441	30 PIECES
3	206-040-440	40 PIECES
	204-040-701	3 PIECES
	204-040-700	72 PIECES
4	206-040-441	136 PIECES
5	406-040-421	30 PIECES
	406-040-021	30 PIECES
6	204-040-700	20 PIECES
7	212-040-151	33 PIECES
8	204-040-700	8 PIECES
9	204-040-701	12 PIECES

TOTAL NUMBER OF PIECES GROUND DURING TESTING 511 PIECES

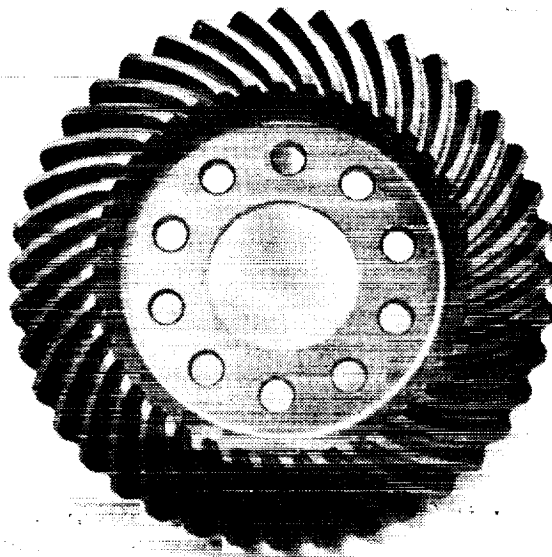
Production Part Numbers Produced On The 463 CNC During Phase III

TABLE 4-8

A summary of each of the test is listed below. Test results and development activities, which occurred through the task, are covered in the next sections of this report.

- **Test 1** - Part number 212-040-151 was utilized for this test. This part is a 23 tooth, 6.111 inch diametral pitch gear. Physical setup was completed in 1.99 hours and pattern development was completed in 6.17 hours. This gave a total setup time of 8.17 hours. During this run 41 parts were produced.
- **Test 2** - Part number 206-040-441 was utilized for this test. This part is a 40 tooth, 8.969 inch diametral pitch gear, Figure 4-30. Physical setup was completed in 4.29 hours and pattern development was completed in 4.11 hours. This gave a total setup time of 8.40 hours. During this run 30 parts were produced.

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Test 2 Gear

Figure 4-30

- **Test 3** - Part number 206-040-440 was utilized for this test. This part is a 17 tooth, 8.969 diametral pitch pinion, Figure 4-31. The drive or loaded, side was ran on the CNC grinder. Physical setup was completed in 2.34 hours and pattern development was completed in 4.15 hours. This gave a total setup time of 6.49 hours. During this run 40 parts were produced.

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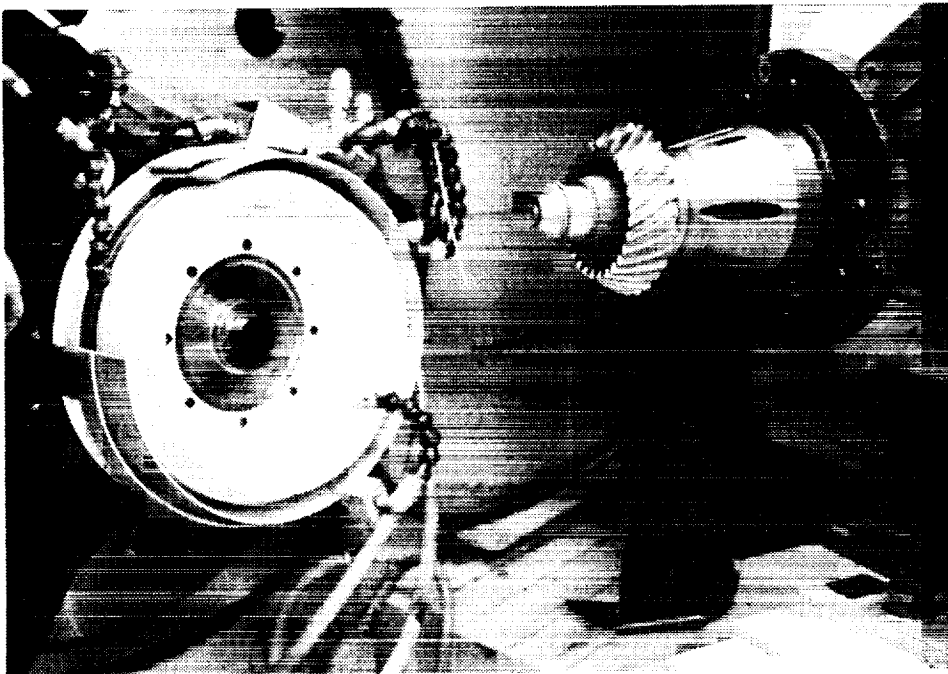
Test 3 Pinion

Figure 4-31

- **Test 4** - Part number 206-040-441 was utilized for this test. This part is the same part used in Test 2 and was the first resetup of a part previously setup on the CNC machine. Physical setup was completed in 8.09 hours and pattern development was completed in 5.05 hours. This gave a total setup time of 13.14 hours. During this run 154 parts were produced.

- **Test 5** - Part number 406-040-421 was utilized for this test. This part is a 48 tooth, 8.25 diametral pitch gear. Physical setup was completed in 5.46 hours and pattern development was completed in 3.33 hours. This gave a total setup time of 8.79 hours. During this run 30 parts were produced.
- **Test 6** - Part number 204-040-700 was utilized for this test. This part is a 29 tooth, 5.391 diametral pitch pinion, Figure 4-32. The drive or loaded, side was ran on the CNC grinder. Physical setup was completed in 5.86 hours and pattern development was completed in 4.36 hours. There was an additional 18.46 hours of development time for surface finish. Detail of the surface finish development will be covered in the Development Activities of this report. This gave a total setup time of 28.68 hours. During this run 20 parts were produced.

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Test 6 Pinion

Figure 4-32

- **Test 7** - Part number 212-040-151 was utilized for this test. This was a resetup test using the same part utilized in Test 1. Physical setup was complete in 1.91 hours and pattern development was complete in 6.22 hours. This gave a total setup time of 8.13 hours. During this run 33 parts were produced.
- **Test 8** - Part number 204-040-700 was utilized for this test. This was a resetup test using the same part utilized for Test 6. Physical setup was completed in 8.55 hours and pattern development was completed in 5.23 hours. This gives a total setup time of 13.78 hours. During this run 8 parts were produced.
- **Test 9** - Part number 204-040-701 was utilized for this test. This part is a 62 tooth, 5.391 diametral pitch gear. Physical setup time was 7.85 hours and pattern development time was 12.0 hours. This gave a total setup time of 19.85 hours. During this run 12 parts were completed.

3.3.1.1 Development Activities

Under the contract the development of the CNC grinder was to be conducted in a production environment. To that end, very little grinding or development was completed at the machine tool builder, the Gleason Works. At the start of Phase III, Pilot Production, the 463 CNC grinder was moved to Bell Helicopter's Machining Center in Grand Prairie, Texas.

Inter-mixed with the testing activities was a number of development related activities and one (1) mechanical failure. The major activities are summarized below:

- **Software Improvements**

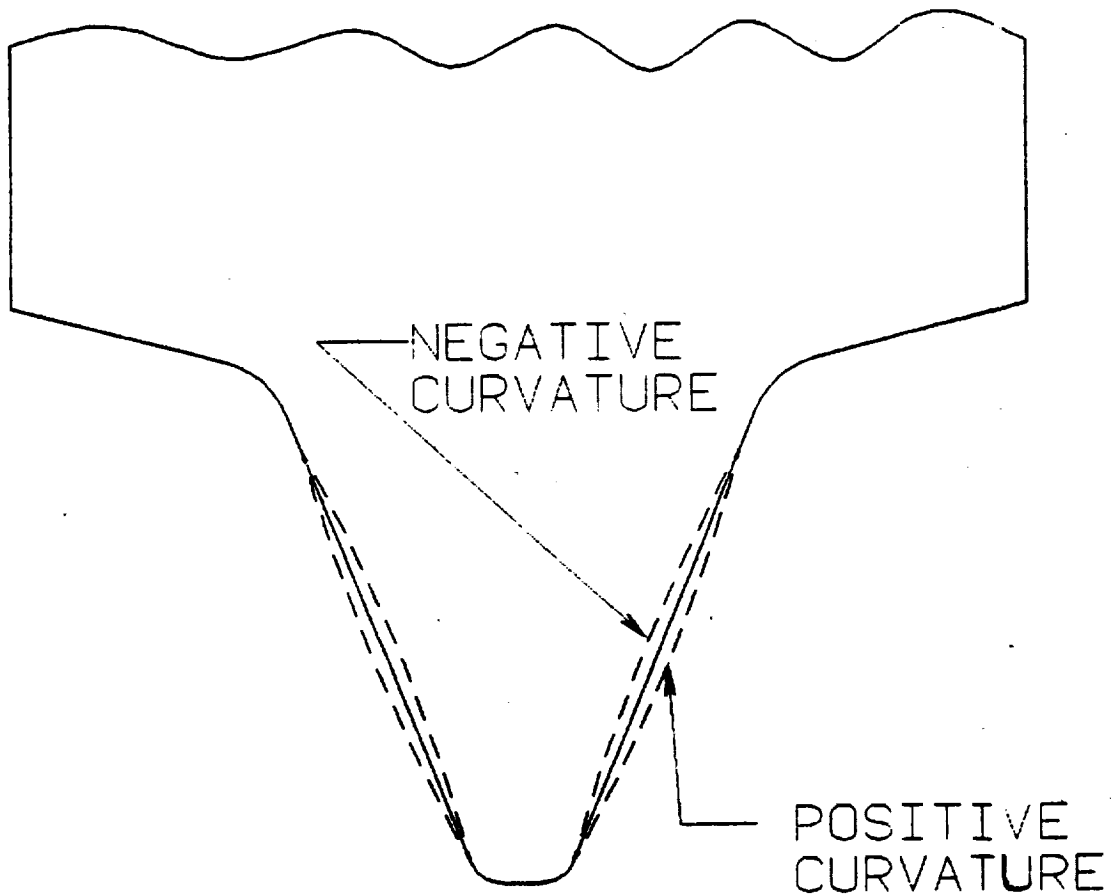
In a number of meetings between Bell and Gleason project and engineering personnel, the software format for the operation of the 463 CNC was completed during Phase I and II. This software controlled all sequencing of the grind cycles and all aspects of the grinding wheel dressing.

Overall the software gave very few problems. There was five (5) software problems, which surfaced during the Phase III effort, which required modification to the original software. Three of these related to the dressing of the grinding wheel. During the first few setups made on the 463 CNC it was found that changes input by the operator to modify the grinding wheel tip advance and the grinding wheel dress feed were not repeating. The grinding wheel tip advance controlled the shortening or lengthening of the wheel to effect whole depth of the parts being ground. This feature is changeable by the operator through the keyboard on the AB 8600 controller.

The grinding wheel dress feed is the feature that controls the incremental feed out of the grinding wheel for each dress. The operator can change this feature to control the amount dressed off the grinding wheel.

Minor changes were made to the existing software to correct these problems.

The most serious software development problem required major modification to that portion of software which controlled the negative or positive curvature of the profile portion of the grinding wheel, Figure 4-33.



Profile Curvature

Figure 4-33

Early in the test program it was possible to put negative or positive curvature in only one (1) side of the grinding wheel. Depending on the design of each part, there are some parts which might require this capability on either or both sides of a gear tooth. Major rewrite of this portion of the software was required to give that optimum to either or both sides of the grinding wheel.

The last two (2) software problems dealt with machine operations. The first, work spindle set-over function, controlled the alignment between the workpiece and the grinding wheel. To fine tune or divide stock on a workpiece, after it had been chucked in the work holding arbor, the operator could depress one of two buttons on the 8600 control panel.

These pushbuttons, when depressed for a period under three (3) seconds, will rotationally increment the work spindle. The amount of setover is programmed under "Machine Parameters" Input No. 21 and is calculated using the mean radius of the workpiece. If the pushbutton is depressed for a period of three (3) seconds or more, the work spindle will rotate at a very slow rate until the pushbutton is released.

The amount of the setover was not adjustable or variable early in the test program. Minor changes to the software corrected this problem.

The last software item fell in the machine operation area but involved a safety issue, the grinding wheel safety interlock. This safety interlock system is designed to prevent the operator from overspeeding and exploding a grinding wheel data input pertaining to the grinding wheel and pulley ratios is loaded at the time of setup.

This data is:

1. Wheel outside diameter
2. Wheel diameter
3. Surface feet per minute
4. Motor pulley number
5. Spindle pulley number
6. Wheel Off/On selector switch

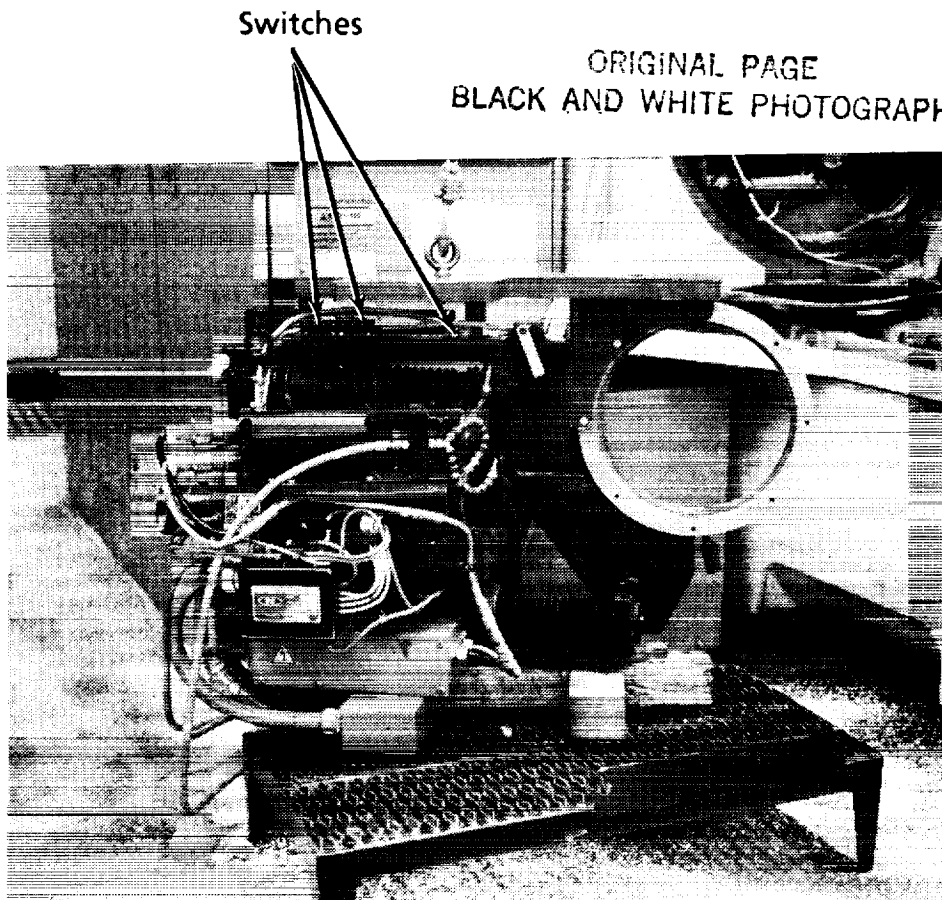
When the wheel is first started, a check is made to see if the Wheel Off/On selector switch is "Off". If the switch is "Off", the message "WHEEL ON" "OFF SELECTOR SW OFF" is displayed on the CRT. If the switch is "On", the clamp speed of the wheel is calculated. Once the clamp voltage is calculated, this value is output as a reference. This voltage is compared to a similar voltage generated from the rotation of the wheel spindle. Should the spindle speed voltage exceed the calculated reference voltage, the machine will shutdown. Before the wheel is allowed to reach its commanded speed, a check is made for direction of rotation and pulley ratio. If the pulleys selected and the voltage read do not agree, a "Wheel Start Ratioing Fault" is generated. When the checks are complete, the wheel will be allowed to run at the command RPM's.

At the first setup utilizing large diameter grinding wheel an error in the software was found that would not allow the grinding wheel spindle to start.

Minor modifications to the software corrected this problem.

- **Dresser Z Axis Switches**

The original dresser Z axis switches located on top of the dresser, Figure 4-34 , were micro type switches with a guard fitted over them. This guard was intended to offer protection against oil and grinding swarf. During the first three to five months of testing under Phase III, several "wrecks" where the dresser tool crashed into the grinding wheel were attributed to switch failure. These switch failures were caused by contamination from oil and grinding residue. Changes to the guard design failed to correct this problem. A change to proximity switch for the Z axis corrected the problem.



Dresser Z Axis Switches

Figure 4-34

- **Grinding Wheel Spindle Seals**

Incorporated into the new grinding wheel spindle design was a new sealing arrangement utilizing pressurized air and a laminate type seal. Through the first nine months of Phase III we experienced two (2) failures of this laminate seal. As the seal would deteriorate the particles of material would "ball up" causing heat buildup.

A change to a different type of material for the seal eliminated the problem.

- **Surface Finish**

One of the major development activities during Phase III, was in the area of surface finish on the ground details. Typically, Bell blueprint requirements for surface finish on spiral bevel details runs in the area of 22 - 24 Ra (arithmetical average). However, because of the requirements of accepting ground parts on precise dimensions of contact patterns a much better surface finish is required in order to produce crisp, clear contact patterns. On ground details with a surface finish above a 10 - 12 Ra the finish patterns are "fuzzy" and "cloudy", thus making it difficult to accurately measure lengths, widths and positions of contact patterns.

Where the older conventional 463 spiral bevel gear grinder utilized a three diamond, single point dressing arrangement, the experiences gained over years of use set a standard for acceptance of surface finish based upon pattern clarity. With the introduction of rotary dressing on the 463 CNC grinder a new learning curve for producing crisp, clear contact pattern was introduced. On the first gears and pinions utilized in the testing program very few problems were encountered with surface finish. All of these parts were shallow whole depth (.125") and short face widths (.5"). With the setup of the first part with a moderate whole depth (.230") and long face width (2.4") the surface finish became a problem. Patterns were "fuzzy" and matted, making measurements impossible. Extensive amounts of development time was expended to solve this problem. New dresser rolls with finer diamonds were ordered and test grinds started.

The speed ratio of the dressing tool and grinding wheel, see formula,

$$\frac{SFPM \text{ Dressing Tool}}{SFPM \text{ Grinding Wheel}} = \text{Speed Ratio}$$

was adjusted at each test grind and mixed with changes in direction of the rotation of the dressing tool.

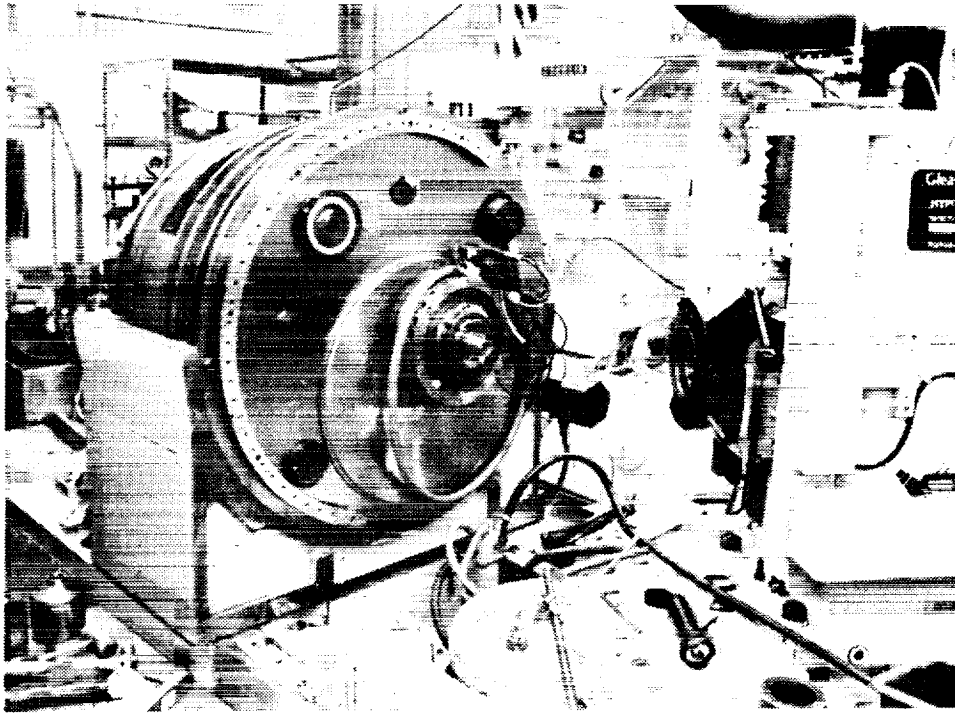
From this development work, several guidelines for rotary dressing on the 463 CNC grinder can be established.

1. Counter directional dressing gives basically the same surface finish as uni-directional dressing and longer tool life appears to come from counter-directional dressing.
2. Speed ratios for the same size grinding wheel will vary with changes to several factors such as grinding wheel surface feet per minute (SFPM), grind size and type of wheel (aluminum oxide, ceramic, etc.).
3. Each setup, even if the job has previously been setup, will require a little finesse to produce a surface under 10 - 12 Ra.

The results of the development work on rotary dressing is illustrated by two (2) evaluations. A gear and pinion ground on the 463 CNC grinder during Phase III testing were examined after transmission "green run" for surface finish and pattern acceptance. These two (2) reports from different models and green runs are presented in Appendix B.

- **Mechanical Failure**

During Phase III testing the machine experienced one (1) major machine failure. This failure was not related to any of the new technology but rather to the cradle bearing which was old technology. There was a loss of lubrication and subsequent bearing failure. Extensive time was lost, about three and one half months, to disassemble the machine and return the cradle and cradle housing to the Gleason Works for repair. Figures 4-35 and 4-36 show the extent of disassemble required.



**Cradle
Figure 4-35**

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**Cradle Housing
Figure 4-36**

4.3.2 Task II - Update Conversion to CNC Cost and Estimated Savings on Finish Grinding

The current cost of converting a conventional 463 Gleason Spiral Bevel Gear Grinder to the CNC version with the same options as configured on the prototype machine is approximately eight hundred and fifty thousand dollars (\$850,000). However, with the technology developed during the CNC grinder program and the development of an advanced controller Gleason is now building a total CNC spiral bevel gear grinder identified as the Phoenix. Unlike the 463 CNC grinder, which still utilizes a cradle and generating cam, the Phoenix uses no generating cam and replaces the cradle with a XY slide. This new totally CNC machine is projected to cost slightly over one million dollars (\$1,000,000.00)

The final cost of grinding with the 463 CNC grinder had been projected, early in the program, as a 50 percent reduction in setup and maintenance of setup time. This objective, as detailed in Section V Test Results, was met and surpassed with an average 65 percent savings on setup and maintenance of setup time. In addition there was an average of a 34 percent savings in grind cycle time.

4.3.3 Task 12 - Government/Industrial Briefing

The End-of-Contract briefing for government and industry was conducted on March 8, 1990 in Arlington, Texas. An overview of the project was presented to approximately 100 attendees. The presentation was conducted in the morning, followed by a tour of Bell's Machining Center and a demonstration of the 463 CNC Spiral Bevel Gear Grinder in the afternoon.

4.3.4 Task 13 - Documentation

The final task under this contract was completion of the documentation. During the course of the work, monthly Technical Progress Performances Analysis and Financial Reports were submitted. In addition, Interim Technical and Photographic History reports were submitted for Phases I and II.

As part of the documentation a Process Specification has been drafted and presented as Appendix C.

This final report and a Phase III Photographic History Report will complete the documentation requirement.

V. TEST RESULTS

During the Phase III testing of the 463 CNC grinder a baseline of setup time on conventional 463 grinder was utilized to measure the performance of the 463 CNC grinder. This baseline was established by Industrial Engineering by Historical data over one (1) year. This baseline of 32.5 hours is an average setup time and includes all physical setup, development and maintenance of setup time.

As each test was conducted in Phase III, Industrial Engineering performed a time study to capture the setup time. If a problem arose that related to development activity, this was **not** included in the setup time as this was viewed as a development problem that would be resolved and not be a problem on future setups.

The results of the nine (9) test conducted during Phase III is summarized in Table 5-9.

TEST	SETUP TIME HOURS	MAINTENANCE OF SETUP HOURS	TOTAL SETUP HOURS	SAVINGS
1	8.17	-	8.17	75%
2	8.40	-	8.17	74%
3	6.49	-	6.49	80%
4	13.14	-	13.14	59%
5	8.79	-	8.79	73%
6	10.22	-	10.22	69%
7	8.13	-	8.13	75%
8	13.78	-	13.78	57%
9	19.85	4.0	23.85	27%

Summary of Setup Hours

Table 5-9

As shown in Table 5-9 all test with the exception of Test 9, produced savings, which exceeded our objective of a 50 percent savings per setup. Test 9 utilized a part which had tight requirements on both sides of the teeth. This was the first time this part was setup on the 463 and development time was near double what would be expected on future setup.

On our second objective of improving repeatability on a part to part and setup to setup basis the results were very good on a part to part basic and only fair on a setup to setup basis.

On the repeatability of part to part grinding our objective specified nine parts minimum with out a major change to the machine. In all cases, except Test 9 where the product lot contained only eight (8) parts to grind, the objective was met. Two (2) outstanding examples of this was Test 4 and 6 where 136 and 35 parts respectively were ground with no changes to the machine to effect pattern. This by far exceeds the conventional 463 grinders, where three (3) to four (4) parts ground between changes to the machine to effect pattern is the norm.

On the repeatability of setup to setup the 463 CNC showed no trends toward a reduction in setup times of previously setup parts. resetups of parts will require approximately the same time each time. However, this still reflects a average saving of 65 percent over conventional 463 grinders.

Grind cycle time savings was not part of the original objectives of the program. However, because of the improvement in the grinding wheel/spindle configuration and the use of ceramic grinding wheels significant time saving in grind cycle time was realized. Time studies conducted by Industrial Engineering showed an average 34 percent saving in grind cycle time over conventional grinders.

Overall the project met or exceeded its objective of reducing the cost of grinding spiral bevel details.

VI. SUMMARY

This Manufacturing Technology (MANTECH) Program, sponsored by the Army Aviation System Command was design to reduce the cost of producing precision spiral bevel gears. The object of the program was to decrease the setup, maintenance of setup and pattern development time by 50 percent of that time required on conventional spiral bevel grinders. In addition there was a requirement to accomplish this reduction while improving consistency of quality, part to part and setup to setup.

The 463A CNC Spiral Bevel Gear Grinder completed the design and fabrication phase in June, 1988 at the Gleason Works in Rochester, New York. The grinder was moved to Bell Helicopter Textron Machining Center in Fort Worth for development and test in July, 1988. After some nineteen months of development testing the objectives of the program have been met. There has been a 50 percent or better reduction of setup, maintenance of setup and pattern development time. In addition each test has shown a 15 to 40 percent reduction in grind cycle time and virtual elimination of grinding burn problems.

This project has been an outstanding example of machine tool builder, user and government working together to develop new technology that will be carried into the industrial base now and into the future.

VII. APPENDIX

APPENDIX A
ORIGINAL TEST PLAN

BHTI IN-HOUSE TEST PLAN

TEST NO.	GEAR DESCRIPTION	OBJECTIVE
<p style="text-align: center;">TEST 1</p>	<p>Part No. 204-040-701 Gear No. Teeth -62 Diametral Pitch 5.39</p>	<p>To test the accuracy of the machine settings, digital read outs, etc., in relation to known correction moves established by inspection of details.</p> <p>To test the ability of the machine to hold developed setting by producing nine (9) parts minimum without a major change to machine settings.</p> <p>To test for a 50% reduction in setup and maintenance of setup time over a 25 piece production run.</p>
<p style="text-align: center;">TEST 2</p>	<p>Part No. 206-040-406 Gear No. Teeth -40 Diametral Pitch -9.18</p>	<p>To test the ability of the machine to hold developed setting by producing nine (9) parts minimum without a major change to machine settings.</p> <p>To test for a 50% reduction in setup and maintenance of setup time over a 25 piece production run .</p>
<p style="text-align: center;">TEST 3</p>	<p>Part No. 204-040-701 Gear No. Teeth -62 Diametral Pitch -5.39</p>	<p>To test the ability of the machine to hold developed setting by producing nine (9) parts minimum without a major change to machine settings.</p> <p>To test for a 50% reduction in setup and maintenance of setup time over a 25 piece production run.</p>

BHTI IN-HOUSE TEST PLAN

TEST NO.	GEAR DESCRIPTION	OBJECTIVE
<p style="text-align: center;">TEST 4</p>	<p>Part No. 204-040-401</p> <p>Gear No. Teeth -39 Diametral Pitch 6.0</p>	<p>To test the ability of the machine to hold developed setting by producing nine (9) parts minimum without a major change to machine settings.</p> <p>To test for a 50 % reduction in setup and maintenance of setup time over a 25 piece production run.</p>
<p style="text-align: center;">TEST 5</p>	<p>Part No. 212-040-500</p> <p>Pinion No. Teeth -38 Diametral Pitch -8.65</p>	<p>To test the ability of the machine to hold developed setting by producing nine (9) parts minimum without a major change to machine settings.</p> <p>To test for a 50 % reduction in setup and maintenance of setup time over a 25 piece production run.</p>
<p style="text-align: center;">TEST 6</p>	<p>Part No. 204-040-406</p> <p>Gear No. Teeth -62 Diametral Pitch -9.18</p>	<p>To test the ability of the machine to hold developed settings from setup to setup of the same part number.</p> <p>To test the ability of the machine to hold developed setting by producing nine (9) parts minimum without a major change to machine settings.</p> <p>To test for a 50 % reduction in setup and maintenance of setup time over a 25 piece production run.</p>

BHTI IN-HOUSE TEST PLAN

TEST NO.	GEAR DESCRIPTION	OBJECTIVE
<p>TEST 7</p>	<p>Part No. 212-040-450 Pinion</p> <p>No. Teeth - 22 Diametral Pitch 7.6</p>	<p>To test the ability of the machine to hold developed setting by producing nine (9) parts minimum without a major change to machine settings.</p> <p>To test for a 50 % reduction in setup and maintenance of setup time over a 25 piece production run.</p>
<p>TEST 8</p>	<p>Part No. 204-040-401</p> <p>Gear No. Teeth -39 Diametral Pitch -6.0</p>	<p>To test the ability of the machine to hold developed settings from setup to setup of the same part number.</p> <p>To test the ability of the machine to hold developed setting by producing nine (9) parts minimum without a major change to machine settings.</p> <p>To test for a 50 % reduction in setup and maintenance of setup time over a 25 piece production run.</p>
<p>TEST 9</p>	<p>Part No. 212-040-451</p> <p>Gear No. Teeth - 57 Diametral Pitch -7.6</p>	<p>To test the ability of the machine to hold developed setting by producing nine (9) parts without a major change to machine settings.</p> <p>To test for a 50 % reduction in setup and maintenance of setup time over a 25 piece production run.</p>

APPENDIX B

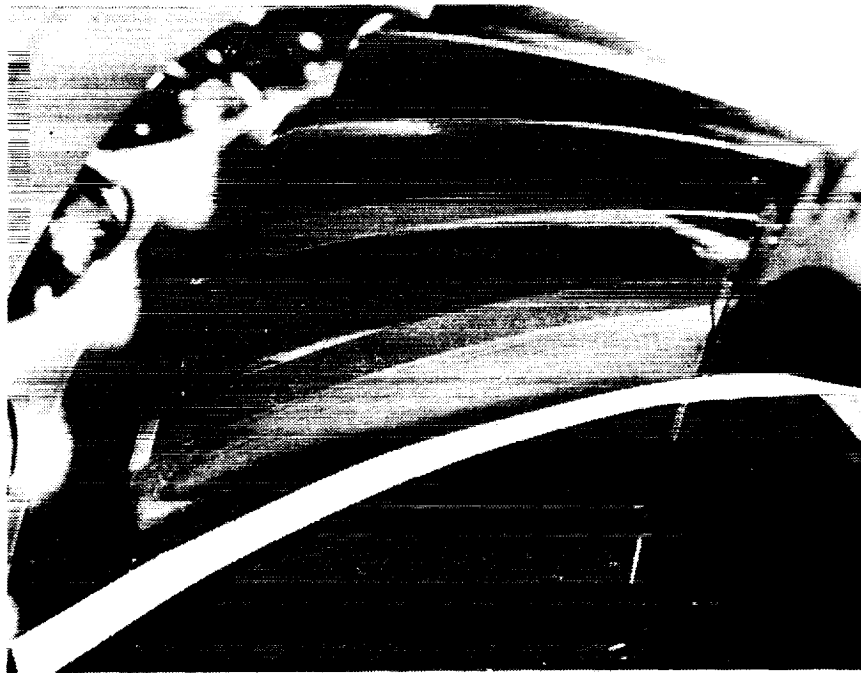
Evaluation of Green Run

Contact Patterns on Details

Ground on 463 CNC Grinder

A 204-040-700-101 Pinion, S/N A-AFS-5956 was evaluated after green run and was found to have acceptable appearance in terms of surface finish and overall condition of the gear teeth. While the contact pattern (see photo below) was readily defined at the heel with the help of Permalon dry film lube which is sprayed on the teeth prior to green run, this was not evident at the toe end of the teeth making it much more difficult to distinguish the boundaries of the contact pattern. It did appear, however, that the mean perimeter of the pattern at the toe end as well as the remaining areas of the teeth was within the limits defined in the 212-947-017 for spare quill assemblies.

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**Pinion 204-040-700-101 S/N AFA-5956
Tooth Contact Pattern After Green Run**

A 406-040-021-101 Gear, S/N AFS-632, was acceptance tested and subsequently evaluated for suitability of the spiral bevel gear tooth contact pattern. The contact pattern was typical of that seen on other input driven gears in the OH-58D transmission, and was found to be acceptable in accordance with BHTI specification 406-947-359. The shape of the contact pattern was normal and it characteristically left a zone of no contact at the tip of the tooth at the heel while the toe end of the contact pattern went off the tip. The surface finish was very good and also was considered typical of other similar gears.

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**Gear 406-040-021-101 S/N AFS-632
Tooth Contact Pattern After Green Run**

1. The first part of the document discusses the importance of maintaining accurate records of all transactions. This is essential for ensuring the integrity of the financial data and for facilitating the audit process.

2. The second part of the document outlines the specific procedures to be followed when recording transactions. These procedures are designed to ensure consistency and accuracy in the recording process.

3.

4.

5.

6.

APPENDIX C
PROCESS SPECIFICATION

Bell Helicopter **TEXTRON**

A Subsidiary of Textron Inc.

Bell Helicopter Textron
A Subsidiary of Textron Inc.

CODE IDENT NO. 97499

Post Office Box 482
Fort Worth, Texas 76101
(817) 280-2011

TECHNICAL DATA

REPORT NO.: 699-099-322 DATE: 5 December 1990
APPENDIX C

PROCESS SPECIFICATION FOR
SETUP AND PROCEDURE FOR
SPIRAL BEVEL GEAR MANUFACTURING
ON 463 CNC GRINDER

PREPARED BY	<u>F.L. Smock</u>	DATE	<u>12-5-90</u>
CHECKED BY	<u>H.W. Scott</u>	DATE	<u>12-5-90</u>
APPROVED	<u>C.H. Myers</u>	DATE	<u>12/5/90</u>
APPROVED	<u>D.P. Miller</u>	DATE	<u>12/5/90</u>
APPROVED	<u>R.W. Balke</u>	DATE	<u>12/6/90</u>

PROPRIETARY RIGHTS NOTICE IS ON PAGE C-3.

PROPRIETARY RIGHTS NOTICE

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U.S. Government in accordance with the provisions of
Contract No. NAS3-25030**

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PROCESS SPECIFICATION FOR SETUP
AND PROCEDURE FOR SPIRAL BEVEL GEARS

1. SCOPE

1.1 Scope. This specification describes the equipment and procedures for the manufacture, inspection, and quality control of spiral bevel gears produced on the 463 CNC Spiral Bevel Gear Grinder.

2. APPLICABLE DOCUMENTS

2.1 The following documents form part of this specification to the extent specified herein.

SPECIFICATIONS

Bell Helicopter Textron Inc.

QPS-105

Gear and Spline Tooth Elements

OTHER

The Gleason Works

Operating Instructions for the
Gleason No. 463 CNC Hypoid
Grinder (Arranged with Allen-
Bradley 8650 Controller)

3. REQUIREMENTS. This specification establishes the requirements for production of spiral bevel gears using the Gleason No. 463 CNC hypoid grinder arranged with Allen-Bradley 8650 controller (reference Gleason operating instruction manual). This specification also establishes inspection and quality control requirements for the manufacturing of these gears.

3.1 Equipment. The grinding machine combines advanced processes, exclusive software and controls to increase productivity, while providing the highest quality. An advanced machine controller stores machine settings, displays data in summary form and provides the precision servo and sequential control required to produce high quality gears. A fault monitoring program is stored in the controller to spot and display cycle irregularities. All electronic and manual setup functions for the machine and dresser, as well as the tool and wheel specifications, are stored in the memory of the CNC. Electronic changeover from part to part can be accomplished by calling up the new part code. Settings for the new part programs can be entered through a cassette reader, or manually through an integral keyboard. Various screens on the CRT (on controller) display summary setup data for all machine functions including: axis position and feed, dresser settings, sliding base control and wheel and dresser feeds. The grinder machine can also be optionally arranged for 2 inch to 10.75 inch diameter grinding wheels to cover a broader range of work. In addition, the machine can be arranged with its own coolant and filter system or it can be connected to a central coolant system. For a more descriptive explanation of grinder machine components, reference Gleason operating instruction manual.

The testing of bevel gears, by running them in their correct operating position, is performed on testing machines built specially for this purpose. On most machines one of the heads is adjustable vertically for testing hypoid gears, and the other head is adjustable in a horizontal plane to handle gears of various sizes and ratios. Power is applied to one (pinion) head with a range of speeds, the driven or gear head is equipped with a brake for applying loads as the gears are run together.

The adjustments available on bevel gear testing machines are invaluable when developing the gear tooth during grinding, since it is possible to determine the amount and direction of changes necessary in the grinding machine to produce the required tooth contact.

3.2 Materials. Not applicable.

3.3 Required procedures and operations.

3.3.1 Test Equipment. The spindle bores, faces, and tapers of all test equipment shall be wiped clean and free of burrs or material that would prevent proper seating of test bars and arbors. Test bars and arbors should be wrung into tapers with 0.006 inch to 0.012 inch clearance allowed for draw on the arbors. The test bars and arbors should be removed by the use of spanner wrenches or back-off screw or both as applicable. Check brake drum for cleanliness by wiping drum to remove oil residue.

3.3.1.1 Alignment procedures.

- a. Install test bar in drive head. Check run-out of bar with dial indicator. Maximum allowable run-out of the test bar is 0.00015 inch total indicated run-out (TIR). It may be necessary to rotate test bar in spindle to reduce run-out to 0.00015 inch TIR.
- b. With the angle vernier scale set on 90 degrees, 0 minutes, 0 seconds and all binder screws and clamps secured, mount a dial indicator to the face of the spindle of the brake head. Sweep the test bar in the drive head across a 3 inch minimum length. Change shaft angle as required to obtain an indicator reading of 0.0001 TIR. Record the reading on the angle vernier scale for future use.
- c. Install test bar in brake head. Check run-out of test bar to obtain 0.00015 TIR maximum. Again, it may be necessary to rotate test bar in spindle to reduce run-out to 0.00015 TIR. Place height block on test bar in drive head. Position brake head and sliding base perpendicular with test bar. Adjust vertical lead screw as required to allow the ground surface of height block to pass both over and under the test bar in brake head. Coat test bar with marking compound and check for uniform removal on top and bottom of test bar. Set dial on vertical lead screw on zero.
- d. Position brake head and sliding base to allow test bars to clear each other when changing shaft angle. Move the swinging base around. Add 90 degrees, 0 minutes, 0 seconds to the reading obtained to step b. Move the brake head in so the test bars almost touch. Rotate the height block until its ground surface is vertical. Adjust the cross on the vertical column to allow the height block to pass on either side of the test bar in brake head. Coat test bar with marking compound and check for uniform removal as in step c. The height block should now pass from one test bar to the other.

- e. Reposition the swinging base to the setting obtained in step b. Remove test bar from brake head and install arbor. Set mounting distance for brake head by using gage blocks equal to the blueprint mounting dimension less one-half the diameter of test bar, less the mounting dimension of the arbor. Set dial on brake head to zero.
- f. Remove test bar from drive head and arbor from brake head. Install arbor in drive head and test bar in brake head. Set mounting distance for horizontal base by using gage blocks equal to the blueprint mounting dimension less one-half the test bar, less the mounting dimension of the arbor. Set the dial on horizontal base to zero. Remove test bar and install arbor in brake head.
- g. For 90 degree shaft angle rear sets, the tester is ready for use. For shaft angles other than 90 degrees, move the sliding base using the correction factor obtained in step b.
- h. Install master gear set and check for correct backlash. Position the indicator tip perpendicular to the tooth at the heel end of the gear member. It may be necessary to rotate pinion in the arbor to obtain minimum backlash.
- i. Adjust brake as required to obtain proper contact pattern length. Always apply brake before starting machine and release only after the machine stops.
- j. The pattern tapes and backlash should duplicate the original patterns and backlash. If any variations are found, review the tester setup procedure to determine if some error has been made. Repeat any or all steps as necessary to duplicate original master tapes and backlash.

3.3.2 Grinding machine. All settings of the grinding machine for any particular part number shall be made in accordance with the part number summary from the blueprint. Instructions for these settings will be covered by the operators manual.

3.4 Recommended procedures and operations.

- a. Conduct test grind on the grinding machine utilizing grinding sample parts.
- b. Each sample part shall be inspected for pattern utilizing an approved mating working master. Pattern transfer

tapes shall be taken which match the tapes taken from the master set within allowable tolerances.

- c. Steps 3.4 a and b will be repeated, making adjustments to the grinding machine, until such time as patterns match the tapes taken from the master set within allowable tolerances. At which point the grind of production parts will start.

3.5 Certification Not applicable.

4. QUALITY ASSURANCE PROVISIONS. Examinations and tests to show compliance with section 3 shall be outlined in the following paragraphs.

- a. When required by the drawing, drive side profile pattern test shall be accomplished using production member and GVH thin tooth master. These tests shall be made at both the on center and heel vertical and horizontal position for the gear and pinion face profile positions and established by the drawing. Tapes for the pinion profile shall be taken from the pinion member.
- b. Uniformity and run-out of pattern shall be tested by brush coating three or four teeth in four quadrant point of gear. Inspection of pattern runout shall be in accordance with limits established by the drawing.

4.1 Responsibility for inspection. Unless otherwise specified in the contract or purchase order, the vendor is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified, the vendor may utilize his own facilities or any commercial laboratory acceptable to Bell Helicopter Textron, Inc. (BHTI). BHTI reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

4.2 Monitoring procedures for equipment used in process.

- a. Periodically the master gear and pinion shall be reinstalled in the tester. Tooth contact patterns will be pulled which shall duplicate the original patterns and backlash. If any variations are found, review the tester setup procedure to determine if some error has been made.
- b. Any subsequent setups, which are made with an approved set of masters, may be made with set gages. These setups however, shall produce a backlash and patterns which duplicate the original master sheet.
- c. This duplication shall be verified at the start of each shift and repeated if a change in inspection personnel is required.

4.3 Monitoring procedures for materials.

4.3.1 Inspection for stock removal.

- a. Stock removal limits are established by engineering drawing and shall be verified by an in-process inspection on each part.
- b. For spiral bevel pinions, four inspection stop stations shall be established, one each for drive side face and root, and one each for coast side face and root.
- c. For spiral bevel gears, three inspection stops shall be established, one each for the convex and concave side, and one for the root.
- d. Inspection stop for the face shall be determined by utilizing stop drum in-feed stations, maximum stock removal and sine of the pressure angle as provided by the dresser settings sections of the Gleason summary and the following formula:

$$\frac{\text{Maximum Stock Removal}}{\text{Sine (Pressure Angle)}} = \text{Back-off}$$

Stop drum back-off shall be equal to or less than this back-off figure.

- e. Inspection stop stations for roots shall be above finish size a distance which is equal to or less than the maximum stock removal limit.
 - f. Evidence of grinding at any of the above inspection points shall be cause for rejection.
 - g. The finish ground tooth shall have no unground areas.
 - h. The root and root radii of gear members produced by spread blades grinding methods shall have no steps or gables after finish grind.
 - i. The root radii of members produced by single side grinding shall have no steps after finish grind. The root flat between the radii shall be allowed to have a maximum of 0.002 step or gable provided it does not extent into the radius at any point along the tooth.
- 4.3.2 Extend inspection for pattern and backlash.
- a. Each production gear shall be inspected for pattern utilizing an approved mating work master. Pattern transfer tapes shall be taken which match the tapes taken from the master set within allowable tolerance.

- b. Pattern test of production parts shall be performed immediately following final grind.
- c. Center, toe and heel position contact patterns of tooth bearing on drive side shall be taken from the gear member unless otherwise specified.

4.4 Certification. Not applicable.

4.5 Test Methods Not applicable.

5. PREPARATION FOR DELIVERY. Not applicable.

6. GENERAL INFORMATION.

6.1 Intended use. The intent of this specification is to outline the procedures for the manufacture, inspection, and quality control of spiral bevel gears.

6.2 General information. Not applicable.

6.3 Definitions.

Evidence of grinding - Any ground area which is wider than a single grit scratch.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE August 1991		3. REPORT TYPE AND DATES COVERED Final Contractor Report Oct.86-Mar. 90	
4. TITLE AND SUBTITLE Computer Numerical Control Grinding of Spiral Bevel Gears				5. FUNDING NUMBERS WU-505-63-36 C-NAS3-25030 PE-IL162211A47A	
6. AUTHOR(S) H. Wayne Scott					
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Bell Helicopter Textron, Inc. P.O. Box 482 Fort Worth, Texas 76101				8. PERFORMING ORGANIZATION REPORT NUMBER None	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Propulsion Directorate U.S. Army Aviation Systems Command Cleveland, Ohio 44135-3191 and NASA Lewis Research Center Cleveland, Ohio 44135-3191				10. SPONSORING/MONITORING AGENCY REPORT NUMBER NASA CR-187175 AVSCOM-TR-90-F-6	
11. SUPPLEMENTARY NOTES Project Manager, R.F. Handschuh, Propulsion Systems Division, NASA Lewis Research Center, (216) 433-3969.					
12a. DISTRIBUTION/AVAILABILITY STATEMENT Released as PUBLICLY AVAILABLE July 1995				12b. DISTRIBUTION CODE INT- notes and	
13. Present day precision spiral bevel gear design requirements far exceed those of 40 years past. The increased horsepower and loads applied to today's rotor wing transmission and gear box assemblies have dictated tolerances and engineering requirements that challenge the capability of our current machine tools used to produce spiral bevel gears. In today's environment, most precision spiral bevel gear grinding is accomplished on machines technologically designed 40 years ago. This method of manufacture requires extensive man hours to "setup and maintain each individual setup". Constant attention is required by the machinist to manually calculate and adjust machine settings over long periods of time due to the inability of these machines to hold the developed settings and/or accuracy required. This is a major contributor to the increasing scrap rates in this manufacturing area. These extensive man hours, necessary to set up and maintain setups, currently constitutes 46 percent of the man hour cost required to finish grind an average lot of twenty (20) spiral bevel gears. Although some modifications to these machines have been helpful in maintaining production requirements, no new technological advances were available until the mid 1980's. The development of Computer Numerical Control (CNC) spiral bevel gear grinding has paved the way for major improvement in the production of precision spiral bevel gears. One approach to this new technology has been a Bell Helicopter Textron program to update a Gleason 463 spiral bevel gear grinder with improved technology. A few of the major changes incorporated into the remanufactured/retrofit program were: <ul style="list-style-type: none"> • CNC control of machine cycles and grinding wheel dressing. 					
14. SUBJECT TERMS Spiral bevel gears; CNC; Grinding; Machine design; Research and development; Gears				15. NUMBER OF PAGES 88	
				16. PRICE CODE A05	
17. SECURITY CLASSIFICATION OF REPORT Unclassified		18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified		19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	
				20. LIMITATION OF ABSTRACT	

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

13. Abstract (continued)

- Electronic gearbox or ratio device to replace the mechanical drive system.
- Redesign of the grinding wheel spindle and grinding wheels to improve machine rigidity.

This Manufacturing Technology (MANTECH) program, sponsored by the Army Aviation System Command was designed to reduce the cost of producing precision spiral bevel gears. The object of the program was to decrease the setup, maintenance of setup and pattern development time by 50 percent of that time required on conventional spiral bevel gear grinders. In addition there was a requirement to accomplish this reduction while improving consistency of quality, part to part and setup to setup. The 463A CNC Spiral Bevel Gear Grinder completed the design and fabrication phase in June, 1988 at the Gleason Works in Rochester, New York. The grinder was moved to Bell Helicopter Textron Machining Center in Fort Worth, Texas for development and testing in July, 1988. After some nineteen months of development and testing the objectives of the program have been met. There has been a 50 percent or better reduction of setup, maintenance of setup and pattern development time. In addition each test has shown a 15 to 20 percent reduction in grind cycle time and virtual elimination of grinding burn problems. This project has been an outstanding example of machine tool builder, user and government working together to develop new technology that will be carried into the industrial base now and into the future.

