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COMPUTERIZED GEAR GRINDING, ITS PRESENT AND FUTURE

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ABSTRACT:

The development of a new approach in gear grinding and the parallel utilization of microcomputers is described along with the reasons that started this research program.

A list of the substantial improvements already achieved and a brief description of the ongoing and future development is detailed.

In the late 70's, a program was initiated at Bell Helicopter Textron in order to investigate the scrap rate of some of our high cost gears currently in production.

This analysis showed that the highest scrap rate was pertinent to internal gears made of nitrided M50 steel. As shown by Table 1, the high dimensional accuracy, the specific structure of the M50 steel and the very hard nitrided surface combined together, creating the most difficult conditions for gear grinding.

It has been found that the surface grinding speed is an extremely important factor and since optimized had to be maintained very carefully. Any variation above this optimum value resulted in burns and cracks, while any drop below it produced a wheel profile breakdown with untolerable involute deviations.

Other important factors were the grinding wheel downfeed rate into the part, the speed of wheel dressing and the worktable speed.

Altogether, it was a critical process mostly relying on the operator skill for maintaining a reasonable ratio of quality vs scrap rate.

Over 30 years of continuous gear grinding development at B.H.T. has generated a great confidence in the "Form Wheel Grinding" process, and today this is the only grinding process specified for our current production.

Therefore, all the following information applies exclusively to this process.

As the term "Form Wheel" indicates, the grinding wheel is formed by the action of a suitable dressing device and diamond tools and the resulting shape represent exactly the form of the flanks and the root radius specified by the blueprint. The grinding wheel is being downfeeded at the proper rate into the gear that is adequately supported on a reciprocating worktable.

A well controlled metal removal will result from both flanks of the tooth and root radius.

By indexing the gear around its symmetry axis, all teeth will be ground in sequence.

It is a very straightforward and simple process capable of producing very good quality parts.

However, when very demanding blueprint requirements combine with material toughness and surface hardness, additional care must be exercised and the entire process is greatly complicated. Providing that the vertical wheel position can be held constant for all teeth and assuming a good quality index plate being available, there should not be any problem to achieve a satisfactory level of tooth spacing both adjacent and accumulative. In general, the grinding wheel is being formed and properly dressed at the beginning of the grinding cycle, and if the number of teeth is small, it can be assumed that its shape will remain unchanged.

Nevertheless, due to a number of practical reasons the wheel conditions will soon start to deteriorate both in shape and absolute diameter and this generates two distinct errors: wrong involute profile and tooth spacing variation.

Therefore, an accurate final downfeed position for each tooth will no longer guarantee the requested tooth spacing, due to slight changes in wheel diameter. During investigations conducted some years ago, one fact was discovered and has since been one of the major factors behind the computerized gear grinding development.

A chart of a test gear in rough grind conditions run on a tooth spacing checking machine indicated some sinusoidal variation of the tooth spacing error every seven (7) teeth, which was also the dressing frequency. It was obvious from this and other tests that because of the wheel deterioration, the metal removal was continuously changing and after each dress, it would jump back again. An error was constantly being introduced to compensate for an error.

In a manual grinding process, the extreme skill achieved by the operator will compensate for these recurring "peaks" with a very careful variance of wheel downfeed through an extremely large number of complete revolutions of the gear.

This will also increase disproportionately the time requested to complete the grinding process.

A turning point during this development was reached when a new concept of gear grinding evolved.

According to this concept, it was postulated that the ideal conditions were fulfilled only if the same wheel surface conditions could be achieved and held constant for each tooth.

This was at first sight considered impractical because the only way possible to achieve it was to dress the wheel every tooth.

Preliminary tests showed surprisingly good results in both involute profile and tooth spacing, the operator skill not being any more of great significance and grinding time was consistently less.

Due to the specific design of the hydraulic system logic of our equipment, dressing the wheel every tooth was a tedious and complex procedure, and this suggested the use of a microcomputer technology to achieve a complete automation and total freedom of manipulating the different phases of the grinding process.

The computerized grinding concept was born and the deeper we went into it, the more fascinating and exciting it became. The first cautious steps were soon followed by more demanding and sophisticated software developments in parallel with more testing in the shop. The finalized process was very straightforward and fast.

Relying on a 8 bit computer system, centered on INTEL 8085 CPU, and using a very sophisticated software program, the wheel downfeed was controlled with an accuracy of 20 millionths, each tooth being ground to finish size and then indexing to next tooth with a dressing station in between.

A number of additional features were added during the development as the constant surface grinding speed control for automatic compensation of the decrease in wheel diameter due to dressing, and an automatic wheel speed reduction during dressing for improved diamond life and better wheel surface.

An advanced microaccelerometer technology was used to detect wheel proximity to the tooth surface and to feed this input to the computer for calculation of wheel position and then compare the actual value with the blueprint limits.

A final inspection printout is released for each gear and shows the wheel position relative to each tooth with indications where the limits have been exceeded. (Fig. 2)

At the present time, the grinding process is totally under computer control and the software is designed to achieve this target by manipulation of the following program blocks:

1. Vertical wheel movement, which controls the grinding downfeed and the wheel reset prior to an index step.
2. Indexing.
3. Dressing.
4. Worktable Reciprocation.

The vertical movement of the wheel is being constantly monitored by an absolute optical encoder (65,000 position/turn) which updates the computer on wheel position, at a rate of 900 times per second.

This information is being processed by the computer and used to control a stepper motor which in turn moves the grinding wheel along a vertical axis. (Fig. 3)
The most significant elements in gear grinding are:

1. Number of teeth.
2. Depth of metal removal.
3. Linear wheel speed.
4. Rotational wheel speed.
5. Limits of rough and finish grinding.
6. Limits of wheel reset for rough and finish.
7. Type of grinding cycle selected.

All this information is required and is usually optimized after practical test on actual grinding.

When they are finalized, it is possible to permanently store them in "ROM" memory at each machine computer. Therefore, a complete library of selected cycles for all gears in current production is available at each machine.

When the operator is requested to set-up a specific machine, all he has to do is to enter the correct part number of the gear into the machine keyboard and the computer will search for the appropriate program and lock the machine to it. From that moment on every step is exclusively under full computer control.

A display is being updated at a rate of 20 times per second and will show the following significant information:

1. Grinding wheel rotational speed (R.P.M.)
2. Grinding wheel surface speed (F.P.M.)
3. Tooth number
4. Number of dressing
5. Vertical grinding wheel position
6. Alter size value
7. Part Number
8. Type of cycle selected

The "alter size" is a very useful feature that allows the operator to enter some variations on the value of the finish size of the gear without having to resort to long mechanical repositioning of the dresser, as previously requested.

Before starting the grinding process, the operator has a choice for selecting the most appropriate grinding cycle. Two different manual cycles, mostly used for set-up, and four automatic cycles are available. They differ mainly by the sequence of the steps performed.

The practical use of the computerized gear grinding system has been monitored over a period of several years and then a full program of retrofitting was launched.

Basically, the program was targeted to convert 12 gear grinders to the new configuration over a period of two years. The program has been successfully completed and the following benefits have been thoroughly achieved:

1. Machine productivity increased from 100% to 150%.
2. Operator skill requirements have been drastically reduced.
3. Scrap rates dropped from 18% to 2%.
4. Gear grinding is no longer an art but is a predictable process within expected time standards.
5. Machine downtime for maintenance is drastically reduced.
6. Operator is required to attend his machine for just 15% of the total grinding process, which considerably lowers the operator's stress level and will enable him to run more machines.
7. Lower investment required. All the retrofitted machines were over 15 years old and with a total cost of about $20,000 each, they have been converted to unique pieces of equipment, not readily available from the industrial market.

   It has been calculated that in order to buy the available but much less advanced equipment, B.H.T. would have invested about $6 million as compared to a total program cost of $250,000.

   The level of productivity of such equipment was not comparable with our computerized grinders.

After exhaustive simulations on a pilot machine, a further step, the loop wiring of all the computerized grinders, is now being implemented.

A terminal and a host computer will be located at the area supervisor's desk and will be capable of collecting any desired information from each machine.

Grinding cycle modifications can be entered at the terminal to each machine. Machine computers will then supply the host computer with all the pertinent data about the ongoing grinding process.

At the beginning of a set-up for a new part number at any machine, the operator will enter the gear part number and the production traveler number and the host computer will recognize the input to start the monitoring process for that specific machine.

The operator's name, machine number and starting time will be coded and stored. As soon as set-up is completed, the operator will load the first part for grinding and will enter the part serial number into the keyboard.

This will get the host computer to terminate the set-up survey and to start monitoring the actual grinding of the part. Therefore, a complete set of information will be available at the supervisor's terminal and as a hard copy from a printer.

The actual length of set-up, of the grinding process for each gear of the production traveler and also projections about the total time requested to complete the traveler will be available at any time of the process.

Additional information about the selected grinding cycle, any change to the cycle variables and the time of its introduction will also show deviations from standards.

Any machine downtime due to possible maintenance intervention will also be monitored along with the total time requested to fix the machine. A maintenance call will be performed at the terminal keyboard.

All the system data will be stored at the host computer and periodically transferred to main computer for further and more specific analysis by other organizations such as Industrial Engineering, Quality Assurance and Production Control.

Our programs for the near future are now directed toward these major developments:

1. Crown grinding
2. Helical grinding
3. N/C Dresser

Crown grinding will soon be possible by a simple expansion of our well tested technology.

So far only the wheel downfeed has been closely monitored and controlled as this axis control was the only one needed to implement spur gear grinding.

By the addition of a second axis controlling the working table position and velocity, it became possible to move the wheel along any curved path and therefore, the crown grinding will be a modular expansion of our system.

Any slope or form of crowning will be possible, eliminating some of the present limits to design.

Along the same line of thinking, it is obvious that the introduction of a third axis to control the workhead rotation, both in indexing and in continuous motion, when correlated with wheel downfeed and table position through computer control will produce a straightforward method of helical grinding.

The additional benefit will be the elimination of the mechanical index plate.

The third item in our list, the N/C dresser is probably the most needed change in all gear grinding technology.

To all those familiar with our present equipment problems related to the mechanical dresser, this is very obvious. To those who are not aware of it, we can state that the high cost of the set-up is a direct effect of the incredible sensitivity and lack of repeatability of this mechanical device.

On the other hand, the extreme accuracy of some of our involute profiles requires some sort of dresser to form the wheel. The N/C dresser has been in the design stage for several years because the available components could not supply the very demanding level of precision.

In fact, only recently we have reached the goal of moving a control axis with a resolution of less than 10 millionths.

Our usual type of microcomputer technology will be used in connecting the two axis requested. Therefore, a keyboard will replace cams and other mechanical devices and any involute profile change will require a mere push button action instead of hours of tedious shimming and adjusting.

The N/C dresser will be perfectly integrated in our existing hardware and software and will not require any additional computer.

A new concept of gear grinding has evolved and its final stage will result in the ultimate gear grinding machine.

I would like to emphasize the brilliant work of Mr. Chester Skrodzki and his dedicated efforts with the computer technology and the electronic development.

REFERENCES: F. Marcenaro: Computerized Gear Grinding Development. Presented at the 36th Annual Forum of the American Helicopter Society, Washington, D.C., May 1980.

TYPICAL BELL HELICOPTER TEXTRON BLUEPRINT REQUIREMENT

INTERNAL GEAR

• DIAMETRAL PITCH	12
• TOOTH TO TOOTH SPACING	.0002"
• ACCUMULATED SPACING	±.0008"
• INVOLUTE PROFILE	.0001"
• INVOLUTE WAVINESS	.0001"
• MATERIAL - M50 TOOL STEEL NITRITED	
• MAXIMUM STOCK REMOVAL	.005"
• NO GRINDING SCRATCHES TOLERATED	

TABLE 1.

COMPUTERIZED GEAR GRINDING

WHAT IS IT?

- A NEW CONCEPT IN GEAR GRINDING PLUS MICROCOMPUTER TECHNOLOGY

CAPABILITIES

- HIGHER PRODUCTIVITY
- SUBSTANTIAL SCRAP REDUCTION
- HIGHER GEAR QUALITY
- LOWER OPERATOR SKILL
- HIGH RELIABILITY

Figure 1.

MACHINE 2

OPERATOR: D. WHITE

P/N 206-040-118-1
S/N A20-32647

DATE: 10-11-82
START TIME: 8:45 AM
END TIME: 10:16 AM

TOOTH	CONTACT		
1	12.6		
2	12.7		
3	12.8		
4	12.7		
5	12.5		
6	12.8		
7	12.9	H	
8	13.1	H	MAX
9	13.0	H	
10	12.9		
11	12.6		
12	12.7		
13	12.8		
14	12.7		
15	12.5		
16	12.8		
17	12.6		
18	12.5		
19	12.4		
20	12.4		
21	12.3	L	
22	12.1	L	MIN
23	12.2	L	
24	12.4	L	
25	12.5		
26	12.4		
27	12.5		
28	12.6		

Figure 2.

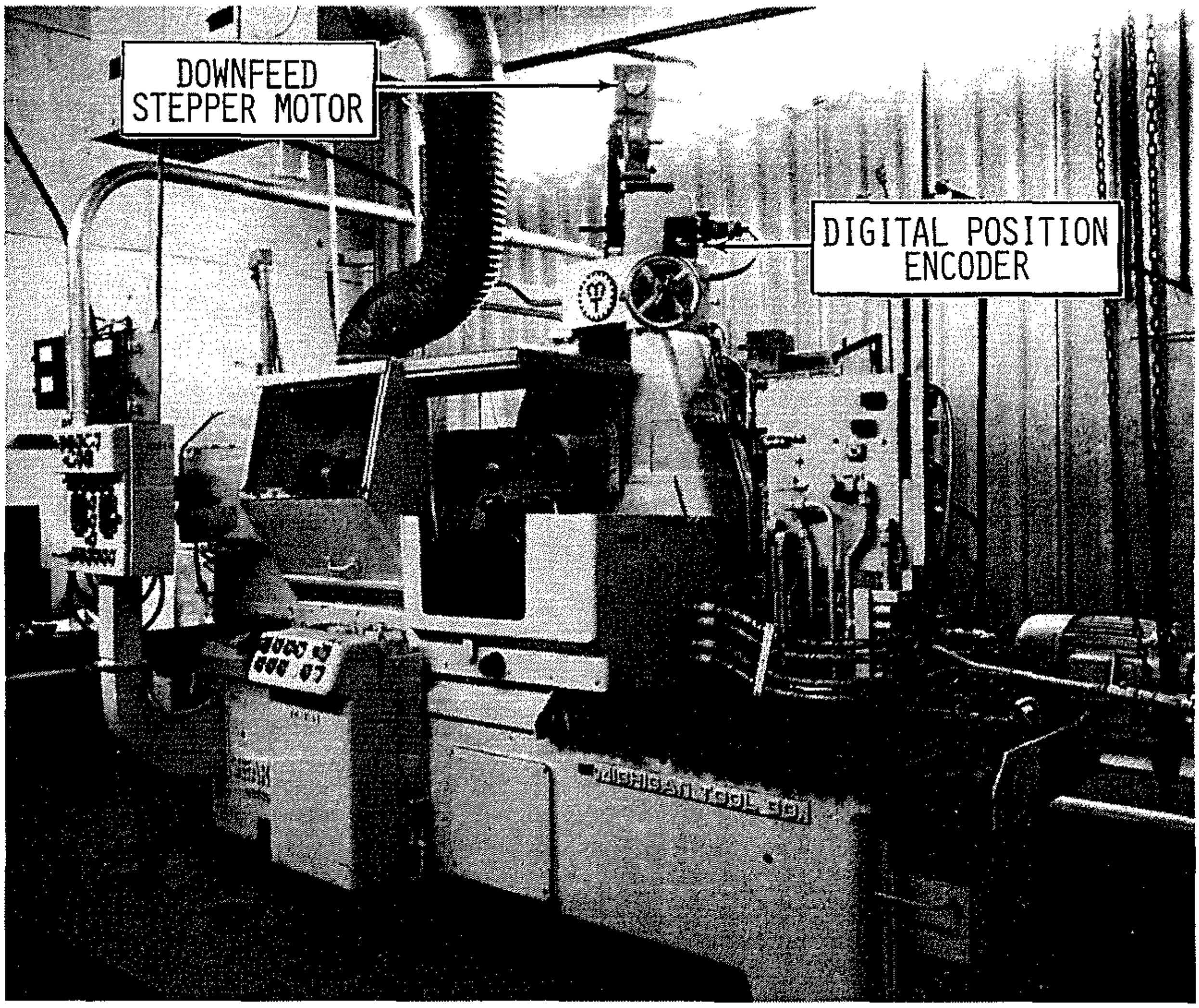

Figure 3.

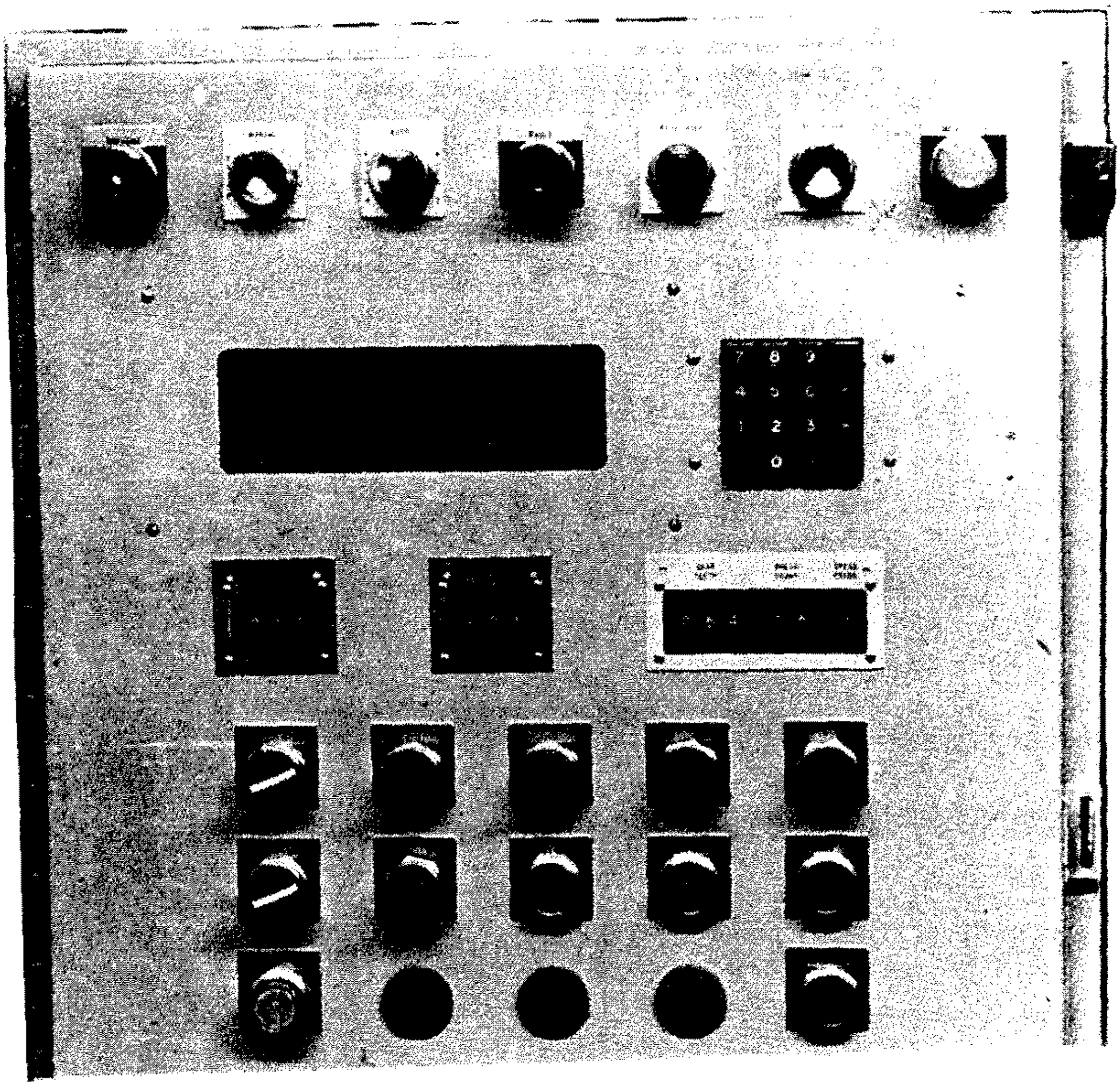

Figure 4.

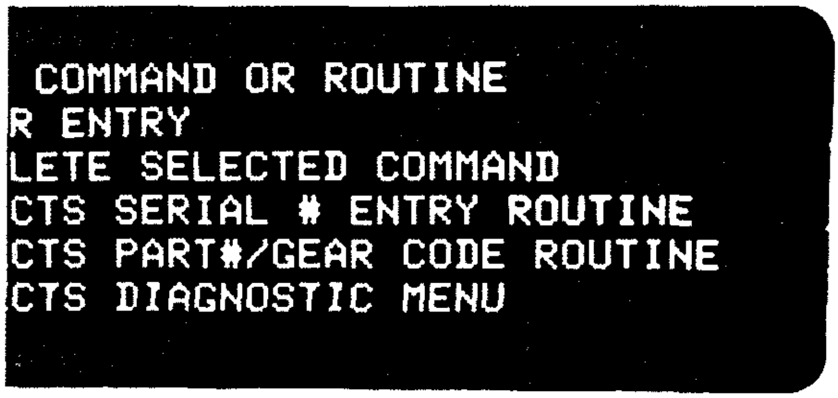

Figure 5.

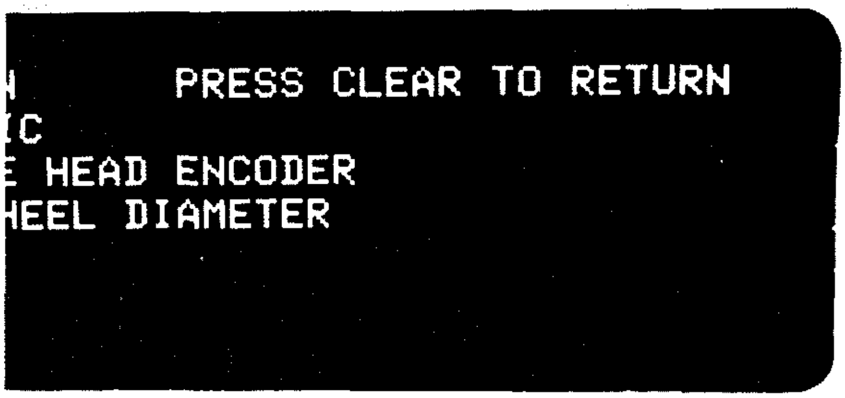

Figure 6.

```
ENTER PART NUMBER * * * CLEAR TO RETURN

PART# 205-040-178-003

SET GEAR CODE TO 001
```

Figure 7.

```
TOOTH...52      FPM...4930
DRESS...52      RPM...5280

ONE-PASS CYCLE   * * *   FIXED DRESS
```

Figure 8.

PRODUCTION

PART NUMBER	PARTS PER SHIFT Standard Machine	Computerized Machine
205-040-178	2	4
212-040-688	2	4
206-040-108	5	8
206-040-118	3	6
214-040-658	1	2

SCRAP

	%	%
205-040-178	16	3
212-040-688	17	3
206-040-108	5	5
206-040-118	14	3
214-040-658	39	7

Figure 9.