BACK TO BASICS...

Gear Shaping Machines CNC Development

by
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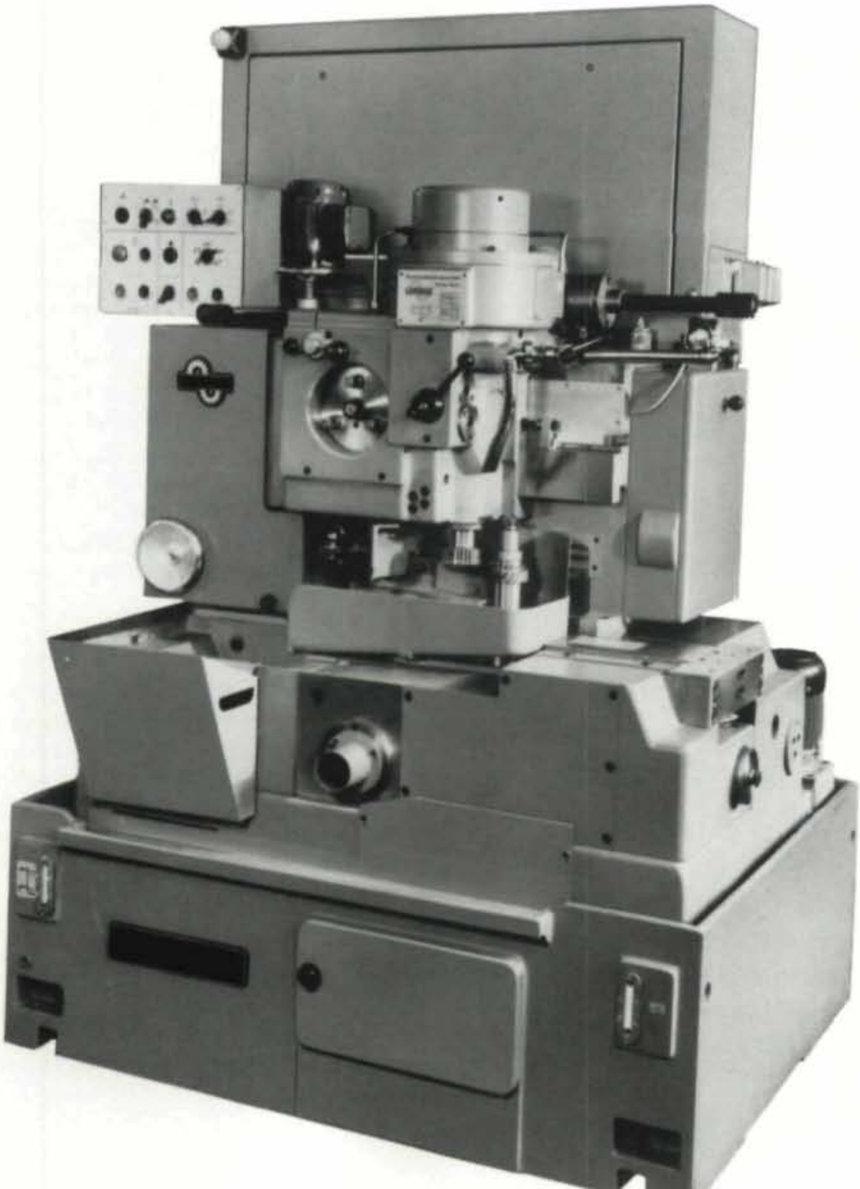

Up until approximately 1968-69, pinion cutter-type gear shaping machines had changed very little since their conception in the early 1900's. They were bridge-type cutter head machines, with a table relieving system to clear the cutter from the workpiece on the return, nonproductive stroke of the cutter spindle, see Fig. 1. The "modern shapers," introduced in 1968-69, went to a cutter spindle relieving action compared to the table relieving movement on the older style machines. Furthermore, the cutter spindle (and its moving housing) were mounted into a robust column, see Fig. 2.

Modern machines are at least two times heavier than old style machines of equal diameter. They are also two to three times more productive than the old style machines. This increase in productivity is directly attributed to the following:

- rigidity in the machine because of cutter spindle relief stroking drive train. This is a much smaller and constant mass to move, as compared to the larger mass of the table on the old style machine. That mass also varied depending on the size and weight of the gear being cut and the fixture.
- stroking rates in the range of 1,000 to 2,000 strokes per minute made possible by a cutter spindle relieving mechanism and hydrostatically mounted cutter spindle bearing and guides, Fig. 3.

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- larger cutter spindle diameters with proportionally increased horsepower of the main drive motor. Example: 20" maximum diameter capacity modern machine, with a 3.93" diameter cutter spindle and 20 horsepower, stroke drive motor; old style machine, cutter spindle diameter 3.34" and 5.7 horsepower motor driving the entire machine, i.e. cutter spindle stroking, rotary and radial feed change gears, see Fig. 4. Note: Maximum DP rating on this size machine went from 5 DP for the old style machine to 3 DP for the modern machine.
- overall weight of the machine increased by a factor of two to three times. Example: 6" maximum diameter capacity modern machine, 12,500 lbs.; old style machine, 4,900 lbs. This extra weight helps to absorb the higher cutting forces and reduces vibration.

While the first generation modern gear shaping machines were substantially more productive, they were still limited in flexibility as were the old style machines. For example:

1. A gear shaping machine with a two inch stroke has a very limited vertical height position (distance above the work table) in which that two inch stroke can occur, i.e. normally only three inches or less. This deficiency results in the need to supply the machine with a riser block (spacer mounted between the bed of the machine and column) to elevate the maximum stroke height to the same level as the tallest part to be cut. Consequently, shorter parts must be raised up in the special fixtures to this predetermined height. Obviously, riser blocks and built-up fixtures reduce the desired rigidity of the machine, and in turn, accuracy of the cut part and tool life. The cost for fixturing elements increases proportionately.
2. Quite frequently, shapers are used for cutting one gear in a cluster of gears, because one or two elements in the cluster must be shaped, i.e. cutter runout clearance is restricted. In addition to the shaped gear in the cluster, it would have been advantageous to shape another cluster in the same setup. However, because of

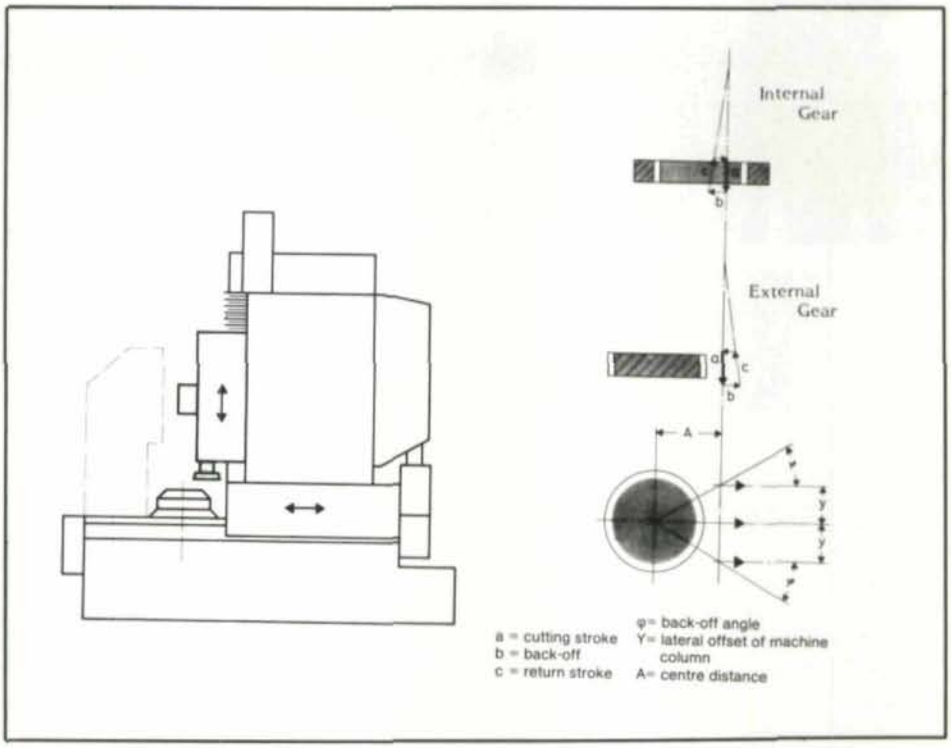

Fig. 2—"Modern" Gear Shapers — Cutter Spindle Back-Off System

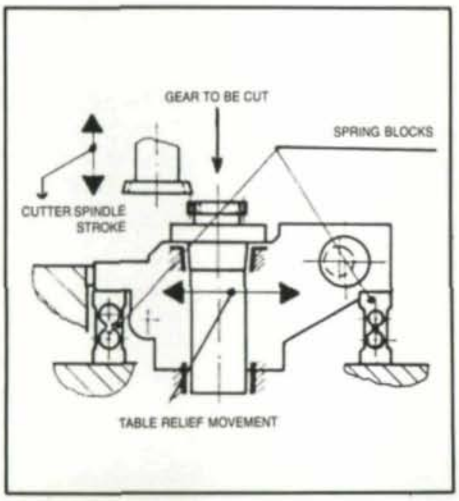

Fig. 1—"Old Style" Gear Shapers — Work Table Back-Off System.

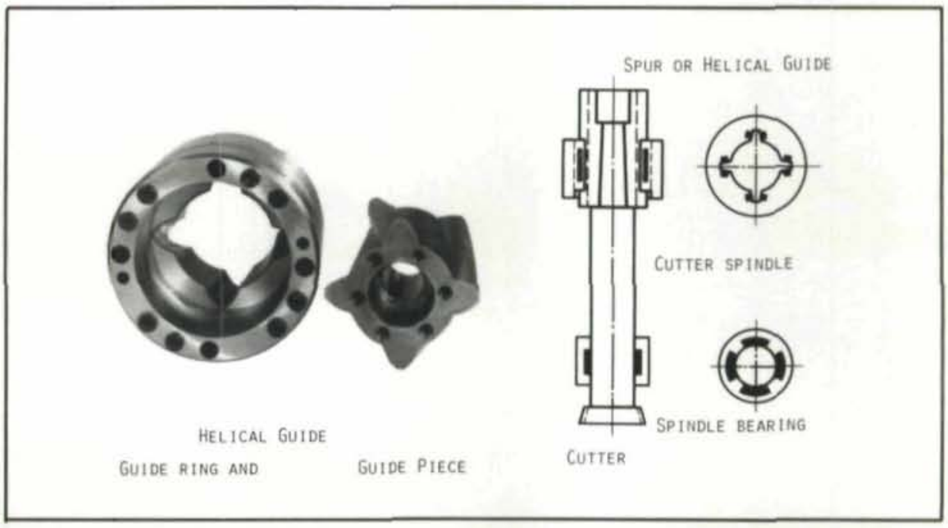

Fig. 3—Hydrostatic lubrication of cutter spindle guide and lower bearing

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FIND OUT WHAT THE NOISE IS ALL ABOUT.

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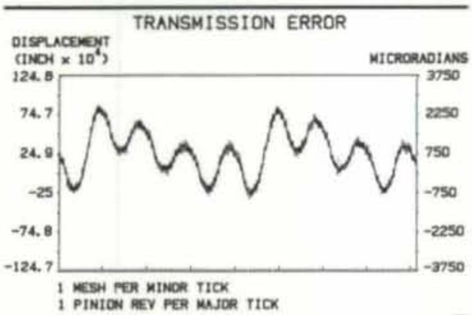

transmission error is what you need to predict noise levels of a gear set in operation, as well as to reduce process errors and the costly scrap and rework that go with it.

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	TOLERANCE	MEAS. ERROR	% OF TOLER
TOTAL TRANSMISSION ERROR	.0125	.0024	*
MAX TOOTH-TOOTH TRANS. ERROR	.003	.0004	*
AVG TOOTH-TOOTH TRANS. ERROR	.003	.0002	*
NUMBER OF BURRS OVER TOL	.005	0	*
MAX EFFECTIVE PROFILE VAR	.0015	.0001	*
AVG EFFECTIVE PROFILE VAR	.0005	.0001	**
COMB. ACCUMULATED PITCH VAR	.0015	.0029	REJECT
COMB. MAXIMUM PITCH VAR	.0034	.0005	*
COMB. MAXIMUM SPACING VAR	.0025	.0002	*

(RESULTS IN in)

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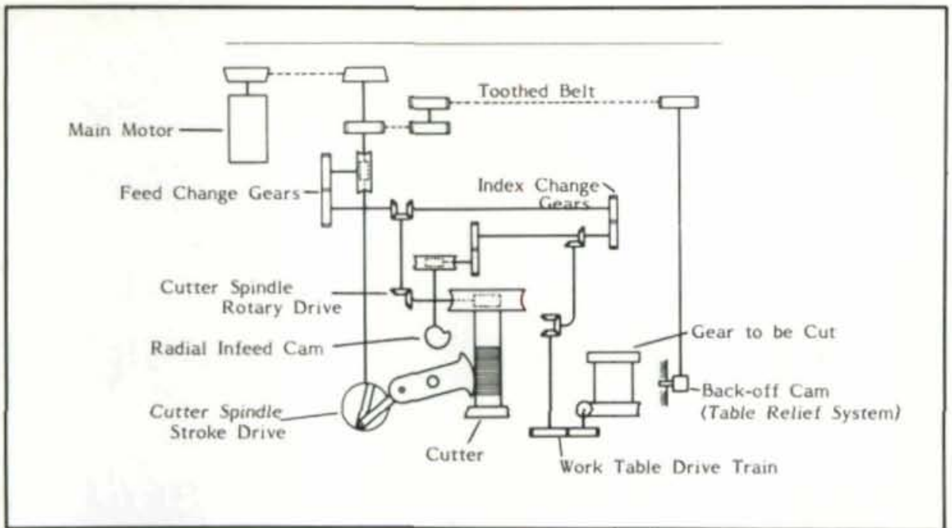


Fig. 4 – "Old Style" table relief machines with numerous drive trains necessitated by having a single drive motor.

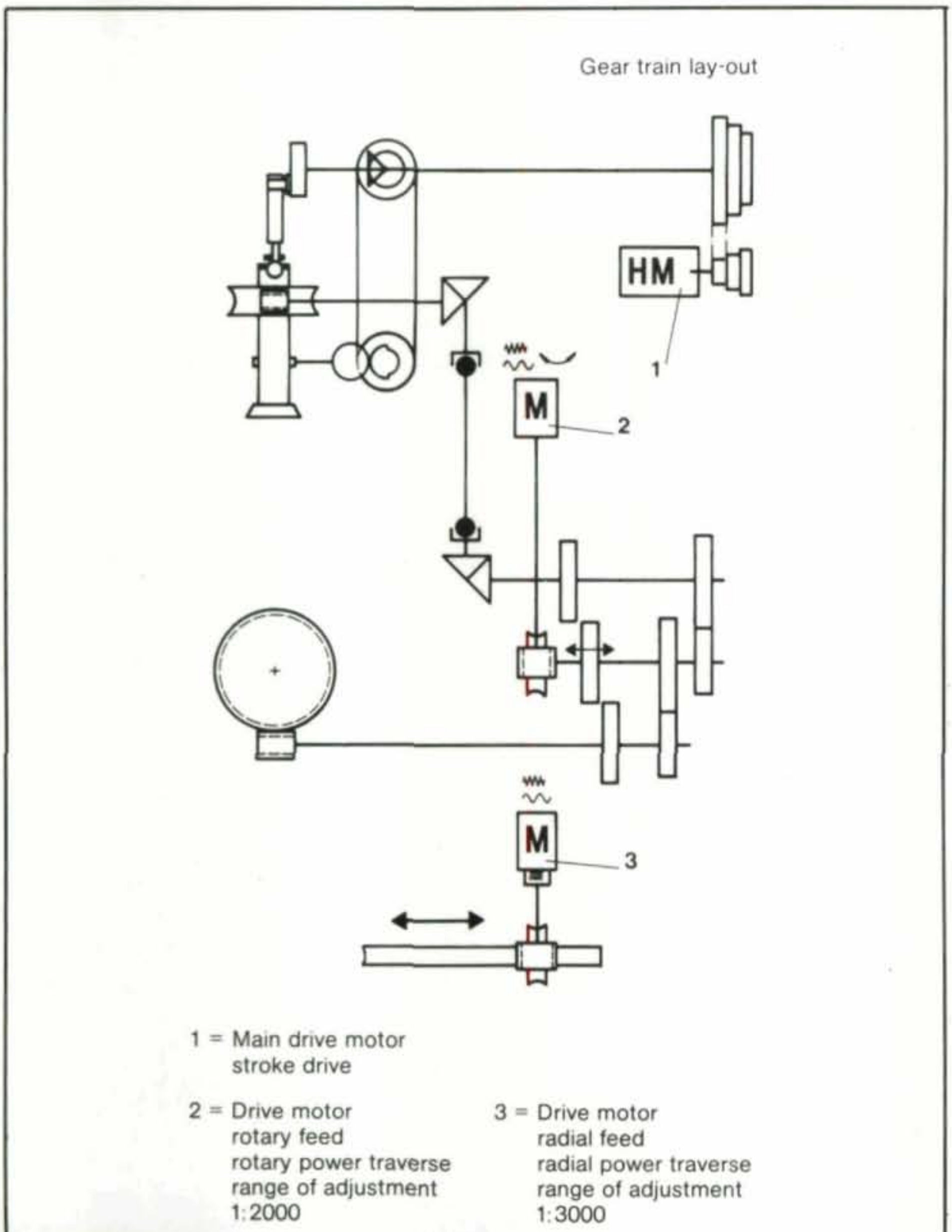


Fig. 5 – Second generation modern gear shaper with independent drive trains.

the different number of teeth, the required index ratios, and because of the fixed index change drive trains, this was not possible with the older style and first generation spindle relief machines. Also, the location of the second gear on the shaft made it difficult to reach, even with stacked cutter, i.e. two cutters mounted to the cutter spindle.

3. In the 1960's, the cutting tool was not the limitng factor in the cutting process. Light weight machines with numerous gear drive trains, see Fig.4, slow stroking rates and general lack of rigidity, made the machine the limiting factor; not the tool. The modern first generation spindle relief shapers in the early 1970's, using conventional M-2 tool steels, found the tool the limiting factor; not the machine. In the late 1970's and early 1980's, with the advent of powdered metal ASP 30 and 60, titanium-nitrided coated cutters, we found, in many cases, the machine to be the limiting factor once again. New infeed techniques had to be developed to realize the full potential of these new tools.

The second generation of the spindle relief machines added independent wide speed range, rotary and radial feed DC servo drives, Fig. 5. The third generation machines incorporated an automatic cutter clamping feature and a CNC controller which eliminated index change gear drive trains. These machine advances dealt with the previously mentioned limitations throught the following design features, see Fig. 6.

A. The machine is fitted with a vertical adjustable cutter head slide (Z axis) which allows vertical positioning of the entire head. In most cases, riser blocks and specially elevated work fixture are not necessary. For example, this 2.35" stroke length machine has an axial displacement of the cutter head slide (stroking position) of 5.9". Using NC techniques, the positioning of the cutter head slide is accurate to within a tolerance of .0008".

B. The C and D axes, which required rotary movement (index ratio) of the cutter spindle and rotary movement of the work table respectively, are controlled by CNC technique with rotary encoders. There are no index change gears in the machine. The resolution of the rotary encoders is 3.6 arc seconds. This design feature makes it possible to cut two or more gears in a cluster, having different index ratios, in a single setup. Depending on the gear data of the cluster gear, it might be necessary to use stack mounted cutters. The lead of both cutters must be the same. A CNC guide has not yet been developed, but experimental work is being done in this area. Fig. 7 shows two external gear clusters being shaped in a single setup. CNC shapers are also perfectly capable of cutting components having both internal gears (or splines) and external gears in a single setup.

C. Frequently, cluster gears have a timing requirement between a tooth on a gear in the cluster in relation to another tooth on a second gear in the cluster. The use of a CNC control system makes it possible to meet these demanding requirements. Fig. 8 illustrates such an alignment requirement. This automotive transmission component requires a tooth alignment accuracy between the two gears of .0008". The part has been cut on a CNC shaper, as illustrated in Fig. 1, achieving an alignment accuracy of .0004". This accuracy will be maintained in a production environment.

D. Down and up shaping of a component is made possible with CNC. The part configuration illustrated by Fig. 9 dictates that both the upper and the lower gear be shaped. To do this part in a single setup, down and up shaping is required. The center section of the component has an outer diameter larger than the root diameter of the two gears. There is also an alignment requirement of the teeth of the upper gear to the lower gear. That alignment can be easily obtained, because the part is cut in a single setup using keyed cutters. The relation of the cutter spindle backoff and cutting stroke direction is controlled by the CNC unit. When cutting the upper gear, the cutter relief occurs on the upward, nonproductive stroke. In the case of the

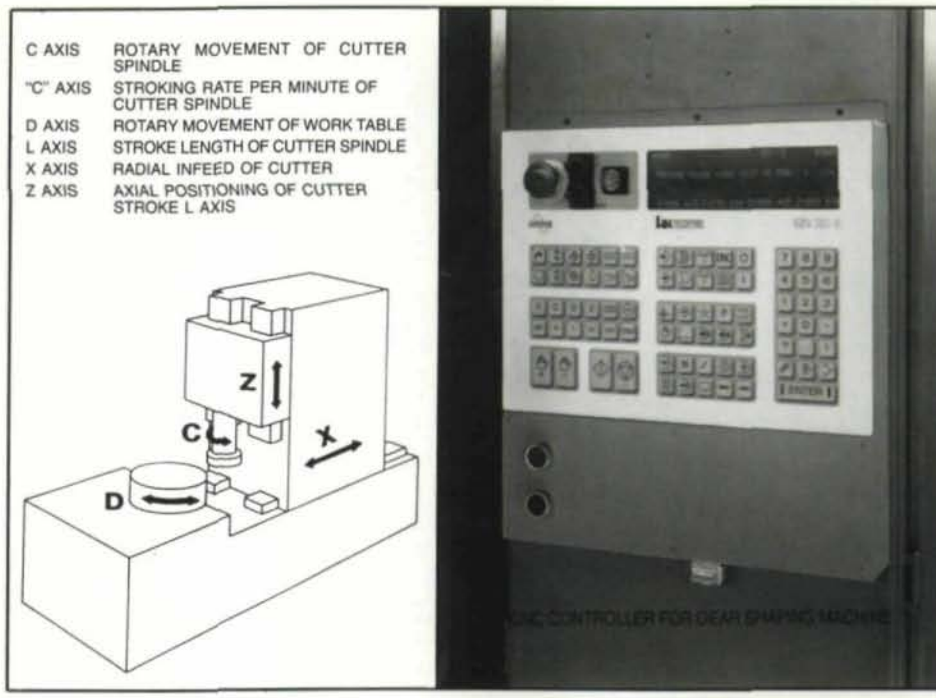


Fig. 6 – 6 Axes CNC gear shaping machine.

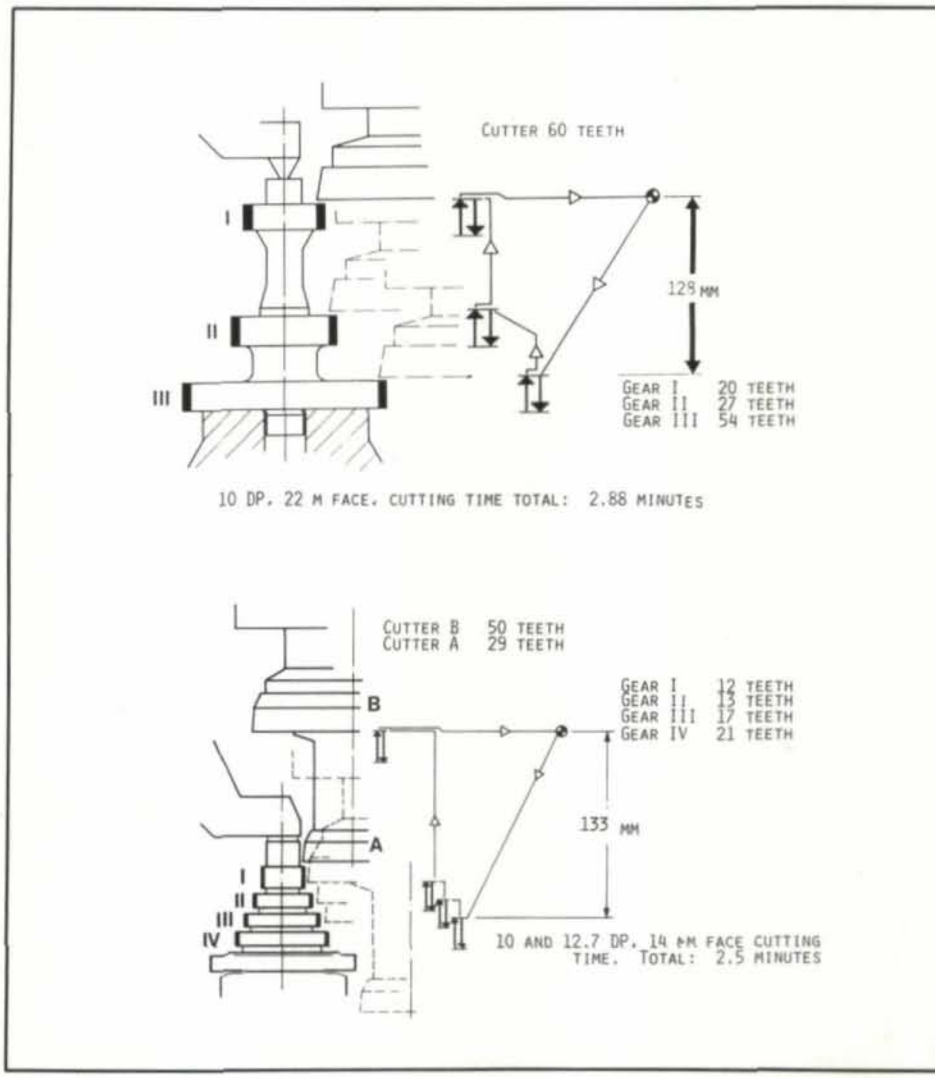


Fig. 7 – Spur cluster gear cutting in a single set-up.

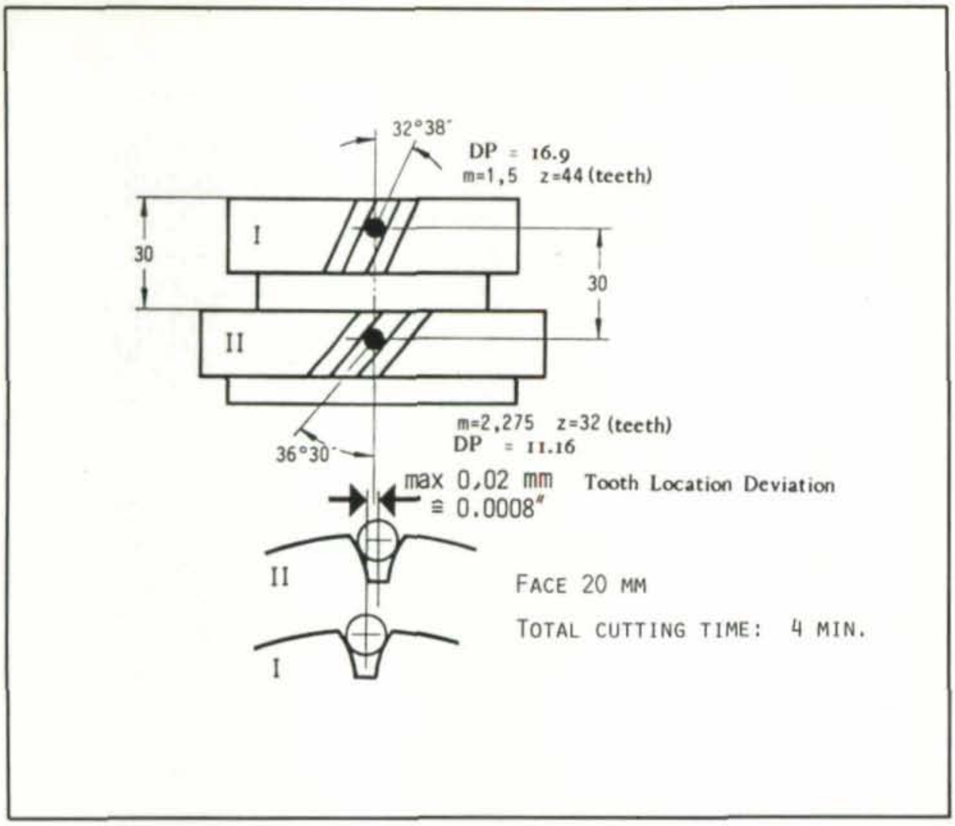
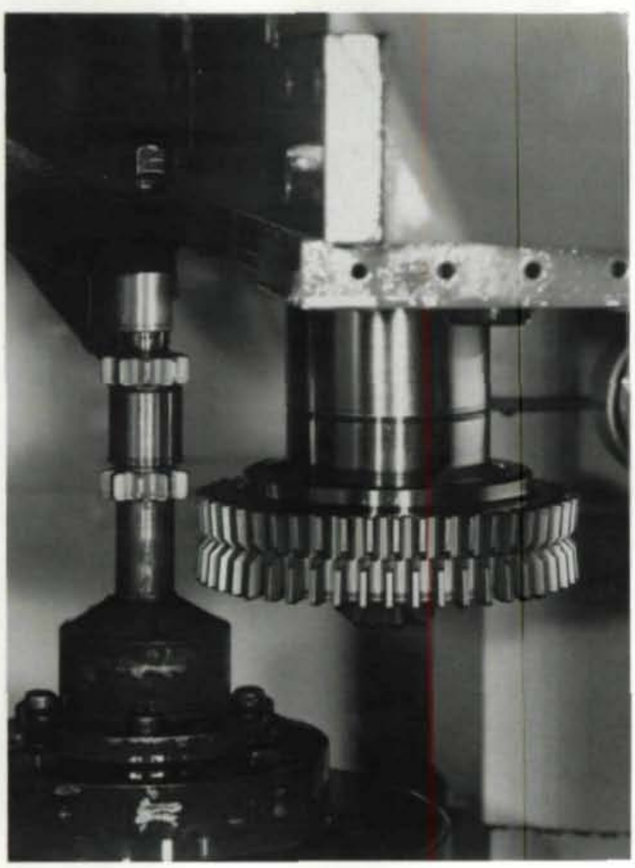


Fig. 8—Helical cluster gear cutting with a tooth location requirement.



8/10 DP, 1.2" pitch dia., .4" face, 9 teeth cutters
38 teeth, 6" dia. — total floor-to-floor cutting time
1.05 minutes

Fig. 9—Down and up shaping of a cluster gear in a single set-up.

lower gear, the cutter relief action occurs in the downward stroke.

E. A total CNC gear shaping machine has fully independent, short and rigid drive trains, i.e. radial feed, rotary feed and cutter spindle stroking (for kinematic drawing, see Fig. 10.) Independent drive trains with wide speed range DC servo motors, i.e. 1-3,000 RPM, permit a new cutting technique called CCP (Controlled Cutting Process). The conventional cutting technique produces a chip with a considerable difference in thickness from the leading to trailing flanks of the cutter, see Fig. 11. This type of chip formation leads to a "burning back" of the leading flanks, especially the leading flank tooth tip of the cutter. That cutter edge deterioration occurs long before the trailing flanks and tips show signs of wear. The CCP cutting process produces a chip with a uniform thickness and wear land from the leading to the trailing flanks of the cutter. The CCP technique uses extremely high rotary feeds and matching radial feeds to suit the workpiece and cutter geometry. This more uniform chip thickness formation increases cutter life by as much as 100% and reduces cutting time in the range of 50% to 100%. In addition, better gear quality is achieved with a superior surface finish. In quite a few cases, subsequent finishing operations such as shaving, can be eliminated. (See Table I)

F. The CNC controller allows for a programmable, constantly reducing radial infeed. Higher radial infeeds can be tolerated when the cutter first enters the workplace, i.e. the first cut. Chip loading is slight and increases progressively as the cutter works its way into the depth. As the chip load increases, the radial infeed is progressively reduced. The factors considered when calculating the reduction in radial infeed are diametral pitch, pressure angle, diameter of the workpiece, diameter of the cutter and whether the part is an internal or external gear.

G. Machine down time, whether it be in a transferline situation, a flexible

TABLE I

Two production examples of gear shaping to preshave conditions:

Workpiece			**Machine Setting**	**Conventional**		**CCP**	
				▽	▽▽	▽	▽▽
No. of Teeth:		46					
Normal module	4.2 DP	6 mm	Strokes per Minute ______	180	2 × 450	180	500
Helix Angle:		0°	Cutting Speed ______ m/min	33	2 × 82	33	91
Face Width:	1.96"	50 mm	Rotary Feed ___ mm/stroke	0.75	0.75/0.5	4.710	3.770
Material:		CK 45	Radial Feed ___ mm/stroke	0.05	0.05/0.01	0.006	0.005
Tensile strength:		190–210 Brinell	**Cutter life**	**approx. 15 parts**		**approx. 36 parts**	

Cutter life increased by more than 100 %

Workpiece			**Machine Setting**	**Conventional**		**CCP**	
				▽	▽▽	▽	▽▽
No. of Teeth:		46					
Normal module	4.2 DP	6 mm	Strokes per Minute ______	180	2 × 450	180	500
Helix Angle:		0°	Cutting Speed ______ m/min	33	2 × 82	33	91
Face Width:	1.96"	50 mm	Rotary Feed ___ mm/stroke	0.5	0.5/0.5	4.710	3.770
Material:		CK 45	Radial Feed ___ mm/stroke	0.03	0.03/0.005	0.006	0.005
Tensile strength:		190–210 Brinell	**Cutting Time ____ minutes**	**20.0**		**14.2**	

Approx. 30 % increase in output.

machining cell or a job shop, must be avoided. Semiautomatic and fully automatic cutter change techniques have been developed to help reduce idle items. Fig. 12A and 12B show how a shaper cutter, mounted to an adapter, is automatically clamped concentric to the cutter spindle. Concentricity is held to .0002" or better. This reduces cutter mounting radial runout error and the part's accumulated pitch errors as the result of that cutter runout. Cutter change, because of a new setup or tool wear, can be accomplished in a matter of seconds, Fig. 13A and 13B. The CNC controls are programmed prior to the cutter change, so that down time is kept to a minimum. An axial moving cutter head slide or cutter spindle (Z axis) is needed to automatically compensate for the new stroke height position. The infeed control (X axis) is needed to automatically compensate for cutter diameter change and the necessary infeed depth change. Cutting tools must be accurately measured after sharpening to obtain new X and Z axes tool off-set positions. A special measuring instrument is used to make these measurements. Such a measurement of the tool and electronic positioning of the X axis (infeed) slide to an accuracy of +/− .000040", assures the "holding of size," i.e. pin dimensions. It is not necessary to verify size by making an overpin dimension check after each tool change.

The addition of a CNC gauging unit at a station of an automatic part loading and unloading system enables the CNC shaper to function fully independent of operator attention. This in-process gauging and compensation unit carries out the following measurements and dictates required machine setting changes:

- measures gear runout error
- average center distance error
- a trend calculation – SPC (statistical process control for, let's say, 10 parts) is established from the measured values of the average center distance. A new X axis radial position is calculated from the analyzed data, and the CNC shaper control directs and sets the new X axis position. If tolerances are still exceeded, then a tool change can be

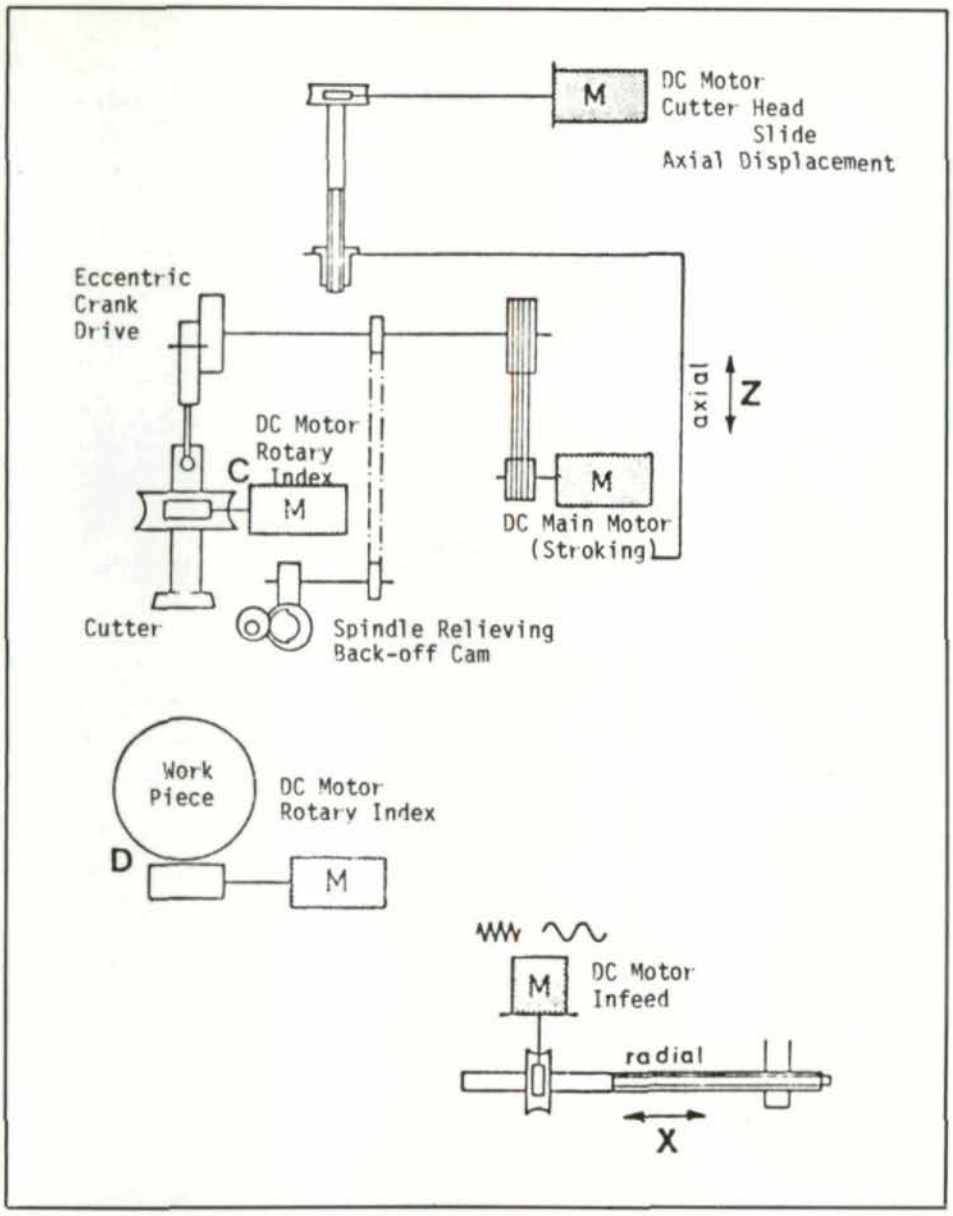


Fig. 10 – Kinematic drawing of gear drive train of a CNC gear shaper.

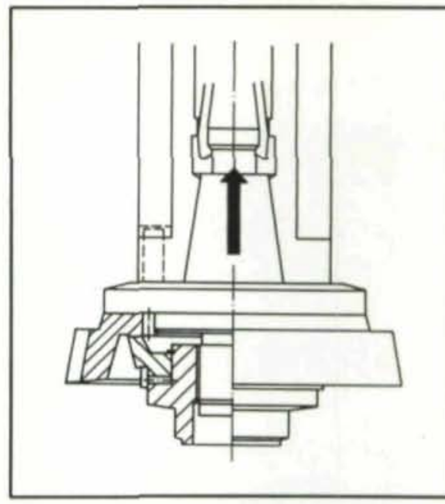


Fig. 12A – Automatic clamping of cutter and adapter to the cutter spindle.

Fig. 12B – Cutter adapter with ball cage for concentric location of cutter to cutter spindle.

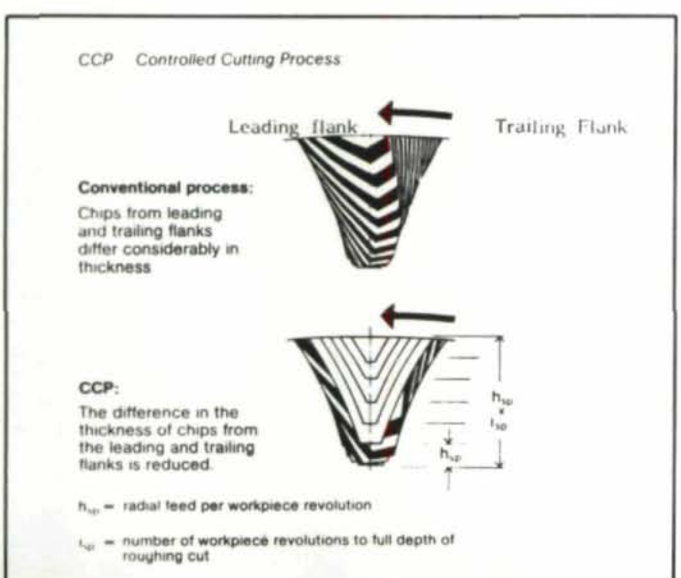


Fig. 11 – New Infeed Technique – CCP Controlled Cutting Process.

called for. If, after the tool change, the prescribed tolerance is still exceeded, the CNC controller can send out a fault signal requesting operator/setup man assistance.

Measurements are made by means of a ball-type probe plunged into a tooth gap. Initial calibration of the measuring head is done with a calibration master gear. Measuring time per tooth is about one second.

It is fashionable in manufacturing discussions today to use the abbreviation FMC (flexible manufacturing cells) and FMS (flexible machine systems). Those abbreviations are also commonly used with such comments as just-in-time manufacturing (inventory), zero setup time and autoloading of parts, fixtures

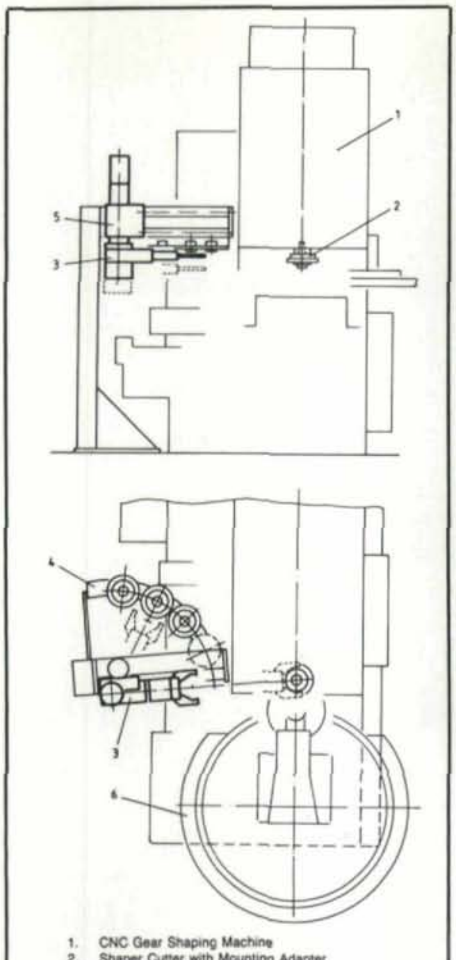
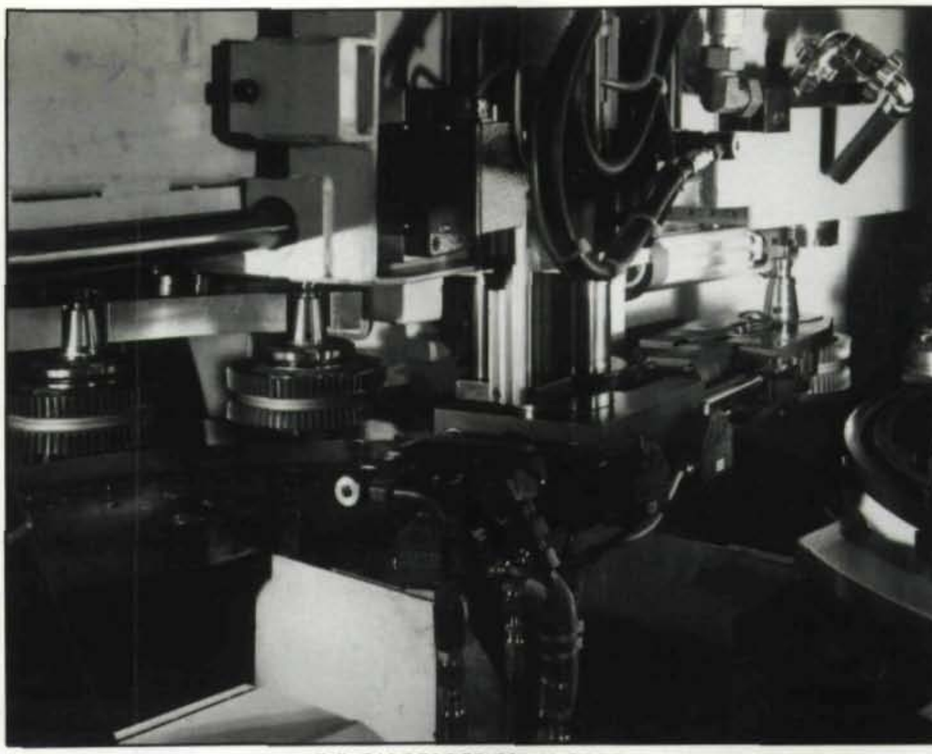


Fig. 13A & B – Automatic cutter changing unit with storage for 3 cutters.

and tools. The conventional first and second generation modern gear shaping machines are, most likely, not suitable for an FMS or FMC system. Many manufacturers say the state-of-the-art gear shaping machine is not ready for installation in an FMS or FMC manufacturing technique. Most certainly, the third generation spindle relief CNC gear shapers can, indeed, fulfill all design parameters needed for installation in an FMS and FMC applications, namely because of their special features, i.e.:

- zero setup time – automatic machine setup
- tool offset compensation
- fully automatic fixture change
- fully automatic tool change
- gear cutting flexibility – multiple gear cuttings per setup, i.e. cluster gears
- integration of a CNC post process gauging unit to the CNC control of the shaper



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