Innovative CNC Gear Shaping

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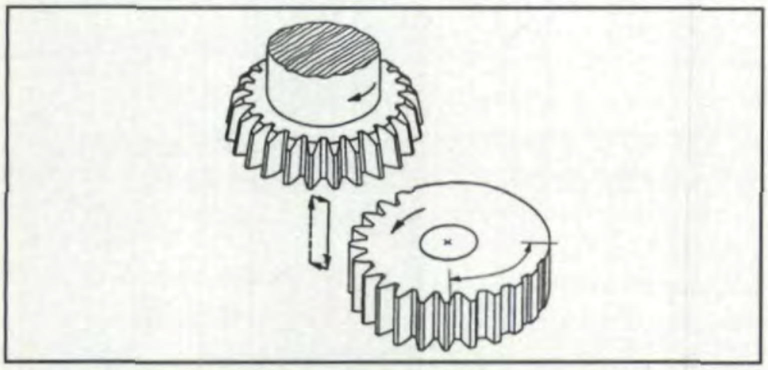


Fig. 1 — Working principle of shaping a spur gear.

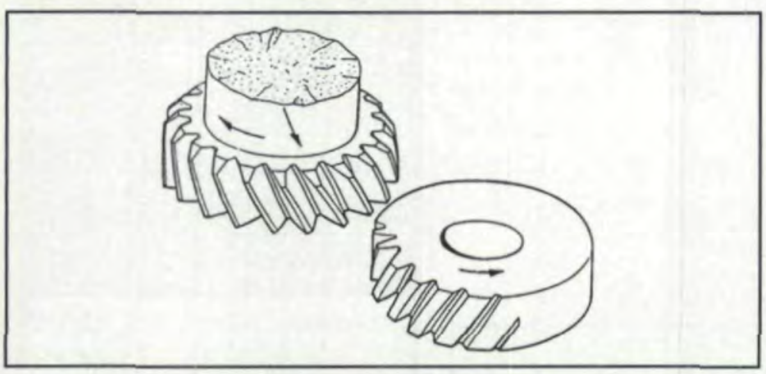


Fig. 2 — Working principle of shaping a helical gear.

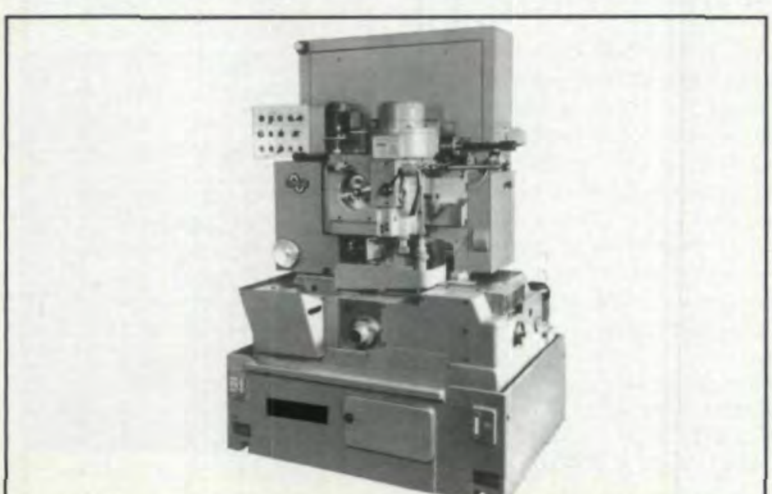


Fig. 3 — "Old style" gear shaper — work table back-off system.

Introduction

The Shaping Process — A Quick Review of the Working Principle. In the shaping process, cutter and workpiece represent a drive with parallel axes rotating in mesh (generating motion) according to the number of teeth in both cutter and workpiece (Fig. 1), while the cutter reciprocates for the metal removal action (cutting motion).

When shaping helical gears, an additional spiral motion is introduced to the cutter by the helical guide (Fig. 2). During the return stroke (relief stroke) the cutter is moved away from the workpiece to prevent flank contact or back-off motion.

These motions are basic functions of the shaping process. Efficient and flexible processing of small lot sizes requires additional automatically controlled functions and operations which will be discussed later.

Shaping methods. Any cutting action which a machine tool performs is based on a relative motion between tool and work. With gear shapers this relative motion is always the cutter stroke motion which is, depending on the application and shape of the cutter, complemented by the generating motion and radial infeed. In principle, three methods of shaping gears from a combination of these motions can be considered.

Conventional vs. CNC Machine Concept

"Old Style" vs. "Modern". "Old style" pinion cutter-type gear shaping machines changed very little from their conception in the early 1900s. 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 (Figs. 3-5). The "modern shapers," introduced in 1969, went to a cutter spindle relieving action instead of the table relieving movement on the older style machines. Furthermore, the cutter spindle (and its moving housing) were mounted into a robust column (Figs. 6-8).

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

1. Rigidity in the machine because of cutter spindle relief stroking drive train. This is a much smaller and constant mass to move than 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.

2. 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.

3. Larger cutting spindle diameters with proportionally increased horsepower of the main drive motor; for example, a 20" maximum diameter capacity modern machine may have a 3.93" diameter cutter spindle and a 22 horsepower, stroke drive motor, while an old style machine may have a cutter spindle diameter of 3.34" and a 5.7 horsepower motor driving the entire machine, i.e., the cutter spindle stroking and the rotary and radial feed change gears (Fig. 5). Note: Maximum DP rating on this size machine went from 5 DP for the old style machine to 3 DP for the modern machine.

4. Increase in overall weight of the machine by a factor of two to three times. For example, a 6" maximum diameter capacity modern machine weighs 17,000 lbs; the old style machine, 4,900 lbs. This extra weight helps to absorb the higher cutting forces and reduces vibration.

"Modern" Spindle Relief Type Gear Shaper with Change Gear Drive Train "First Generation". Figs. 7 and 8 illustrate the drive train of a modern conventional gear shaping machine with independent drives, i.e., AC main drive motor for stroke drive, AC servo drive motor for rotary feed and rotary power traverse and, finally, AC servo drive motor for radial infeed and radial power traverse. Notice that rotary feed and required rotational timing of the workpiece and cutter are handled by an index change gear drive train. Up until the 1980s and despite the introduction of CNC controls, the uniformity of the generating motions for rotary movement was maintained

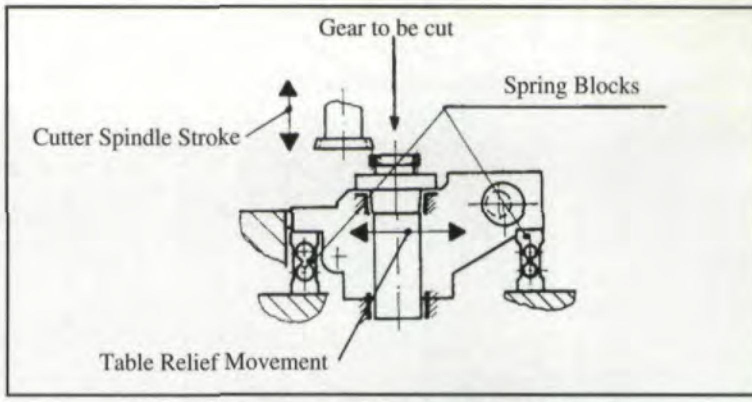


Fig. 4 — "Old style" gear shaper — work table back-off system.

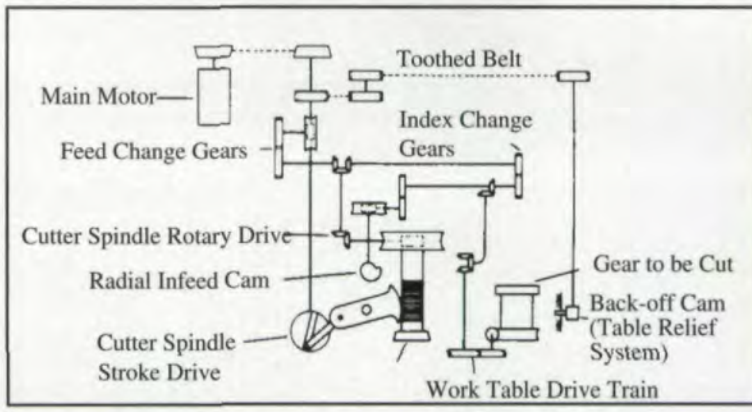
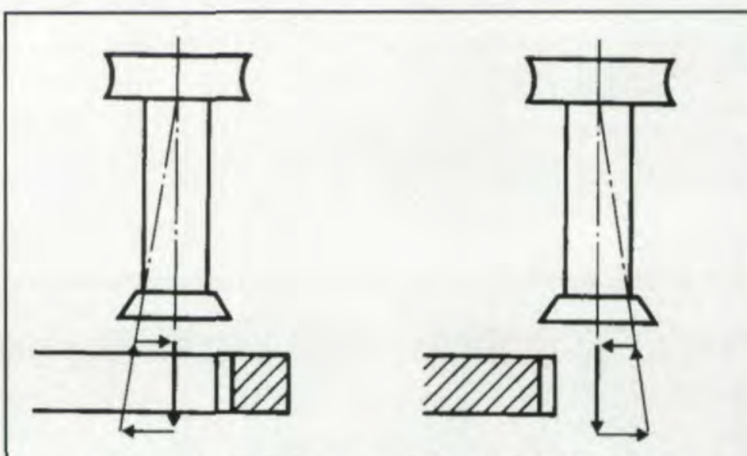


Fig. 5 — "Old Style" table relief machines with numerous drive trains necessitated by having a *single drive motor.*



• Adjustment of relief amount and change of relief direction.
• Relief amount setting adapted to the application.
• Change in relief direction in external/internal machining.

Fig. 6 — "Modern" spindle relief type gear shaper with change gear drive train ("first generation").

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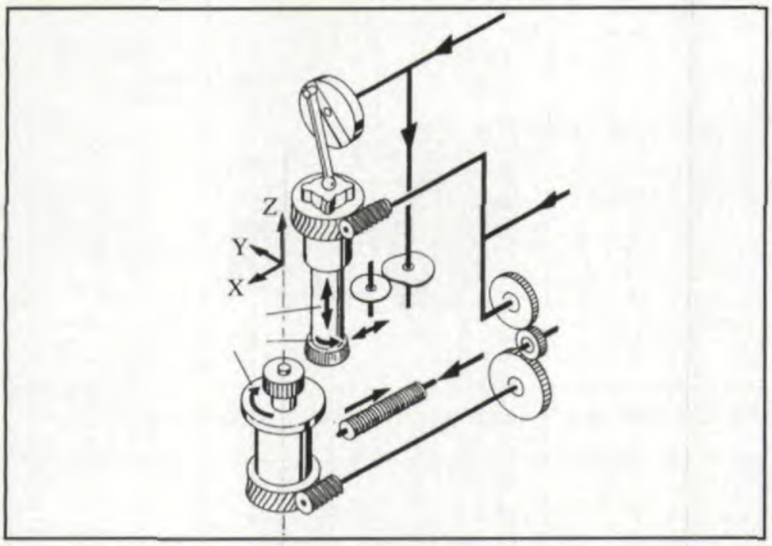


Fig. 7 — Mechanical link between cutter and work on a mechanical gear shaper.

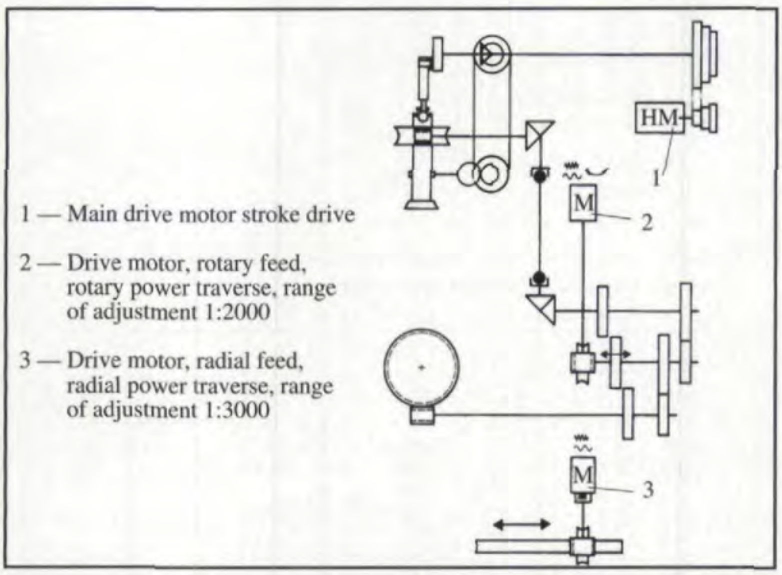


Fig. 8 — Three separate motors for stroke, rotary and radial movement.

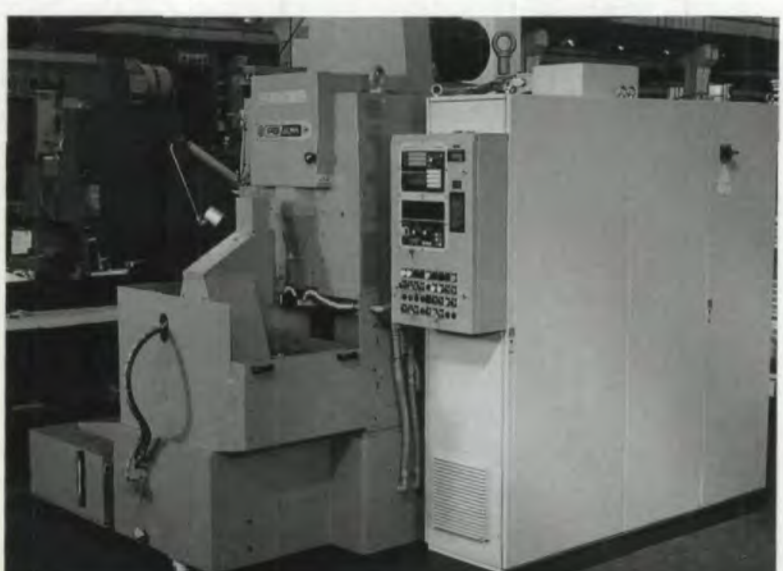


Fig. 9 — A conventional gear shaping machine with a maximum diameter capacity 7" and 2" face widths, stroking rates up to 1,800 strokes per minute.

almost solely by a mechanical drive train providing a positive link between these movements. The transmission ratio was varied by change gears.

CNC Development. Fig. 9 shows a non-CNC modern spindle relief gear shaping machine. Fig. 10 is the same machine, but with CNC control. There is little difference in the outer appearance other than the operator controls, however, the internal machine kinematics are quite different. CNC refers not only to programming of feeds and speeds, but more important, to the elimination of index change gear drive trains. In reality, little benefit can be realized by using a CNC control only to program feeds and speeds.

CNC Shaper "Electronic Gear Box". A "full" CNC gear shaping machine does not contain index change gear drive trains. The required index ratio and the timing relationship between the "C" axis cutter spindle and the "D" axis work table is controlled by CNC, i.e., the so-called electronic gear box. The same controller is used to specify the X axis radial infeed rates and the cutter spindle stroking rates per minute. Figs. 11 and 12 illustrate a five axis gear shaping machine. In addition to the X, C and D axes, we also see the Z axis, which is a vertical positioning of a given stroke length. "L" is a stroke length setting.

Flexibility and New Machine Design Concept

A Flexible Shaper. 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 — normally only three inches or less. Because of this, the machine needs to be supplied with a riser block (a spacer mounted between the bed of the machine and the 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 a special fixture 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.

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 run-through clearance is restricted. In addition to the shaped gear in the cluster, it would be advantageous to shape another gear in the cluster in the same setup. However, because of the different number of teeth, the required index ratios, and the fixed index change gear 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 cutters, i.e., two cutters mounted to the cutter spindle.

In the 1960s the cutting tool was not the limiting factor in the cutting process. Lightweight "old style" machines with numerous gear drive trains, slow stroking rates and general lack of rigidity made the machine, not the tool, the limiting factor. In the early 1970s, the modern first generation spindle relief shapers using conventional M-2 tool steels found the tool, not the machine, the limiting factor. In the late 1970s and early 1980s, 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 a CNC controller, which eliminated index change gear drive trains. These machine advances dealt with the previously mentioned limitations through the design features shown in Figs. 13 and 14.

The machine is fitted with a vertical adjustable cutter head slide (Z axis) (Fig. 13) which allows vertical positioning of the entire head. In most cases, riser blocks and specially elevated work fixtures are not necessary. For example, this 2.35" stroke length machine has an axial displacement of the cutter head slide (stroking position) of 6.7". Using NC techniques, the positioning of the cutter head slide is accurate to within a tolerance of .0008".

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 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

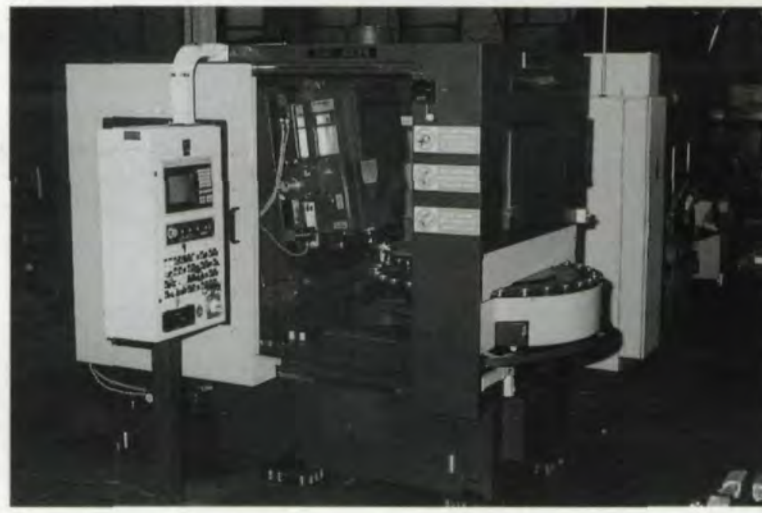


Fig. 10 — CNC gear shaper. Note the use of spring mount shock absorbers and tilt column for root taper cutting capability.

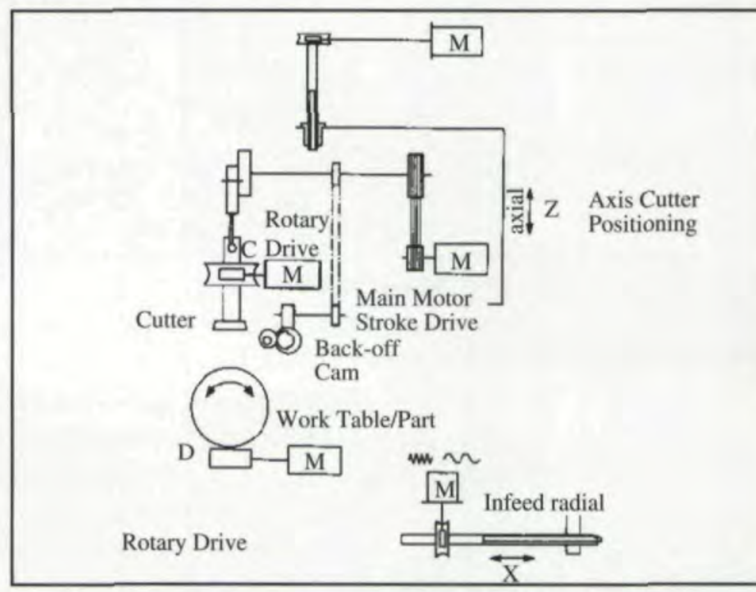


Fig. 11 — Kinematic drawing of drive train for a 4-axes CNC shaper. The servo drive motors (M) for X, D and C are AC brushless type for low maintenance. They also must have a wide speed range ratio, i.e., rotary axes C and D 1:4800 and X radial axis 1:1800 ratio.

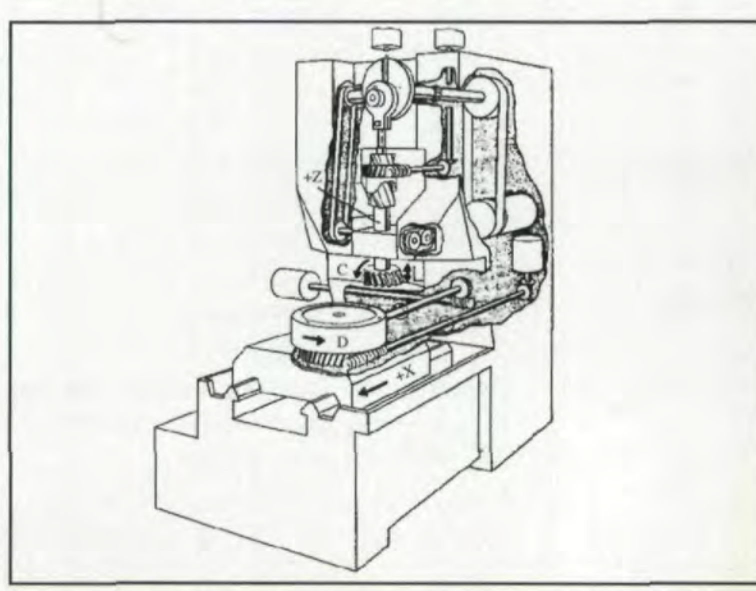


Fig. 12 — 5-axes CNC gear shaper.

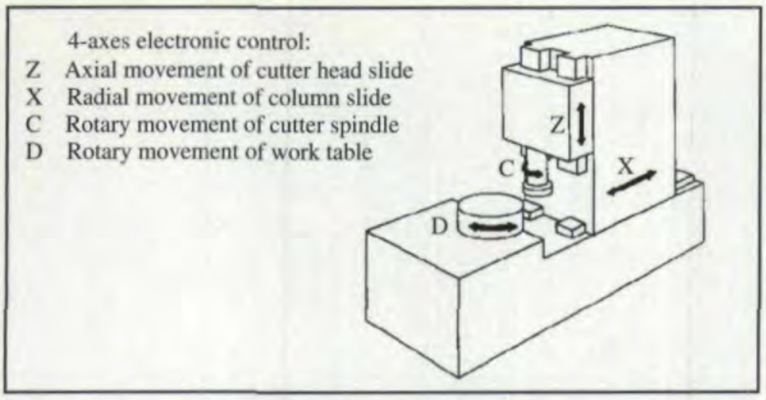


Fig. 13 — Cutter Head Slide CNC Shaper

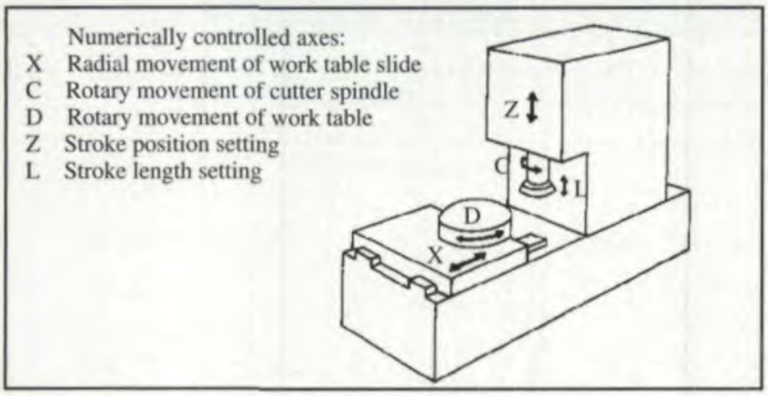


Fig. 14 — Conventional CNC Shaper

feature makes it possible to cut two or more cluster gears 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.

Example 1 in the appendix 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.

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. This example 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. 13, achieving an alignment accuracy of .0004". This accuracy will be maintained in a production environment.

Down-and-up shaping of a component is made possible with CNC. The part configuration illustrated by Example 2 in the appendix 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 upper gear of the component has an outer diameter larger than the root diameter of the lower gear. The teeth of the upper gear must also be aligned 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, non-productive stroke. In the case of the lower gear, the cutter relief action occurs in the downward stroke.

Innovative Design — An 8-Axes FMS-Ready Machine. Since the advent of CNC gear shaping machines in the early 1980s, hundreds have been sold worldwide. These machines, with their four and five axes, revolutionized gear shaping production in job shops and small batch production by increasing productivity by four to five times compared to older shapers. Even in mass production installations we have seen an increase in productivity of two to three times due to CNC cutting feed techniques and quick cutter changes.

However, these machines were not flexible manufacturing systems (FMS) or cell "ready." To meet this requirement, three additional axes and auto tool and pallet fixture loaders were needed. This was a real challenge for the builders of CNC shapers and their CNC control manufacturers, as the machine now has eight axes. Also, to be totally free of constraints, the Z axis stroke positioning range had to be as large as practically possible to accommodate various part configurations. Fig. 15 illustrates such a machine. Note the additional three axes:

O axis — quick return stroke; especially useful for gears with large face width;

A axis — the direction of the cutter spindle relief; internal versus external gears; and

B axis — a column tilt for cutting root tapered teeth.

Combining this machine capability with a pallet fixture and a 12-station tool loader results in a CNC gear shaping machine well suited for FMS installation. The flexibility of the large stroke positioning range (15.75") is equally important to special industries such as aircraft engine manufacturers and heavy construction equipment builders.

Feed Techniques to Match High Tech Machines

Optimizing the Generating Method. Four types of infeed can be distinguished (X, C and D axes):

1. Radial feed with rotary motion. (Fig. 16a). This is a traditional method, with radial infeed of cutter or workpiece to final depth with rotary motion of both cutter and workpiece. A comparatively short spiral length pattern, depending on the selection of the approximate feed rate (generating feed up to 1.0 mm (.04")/double stroke and radial feed of .02-.04 mm (.0008-.0016")/double stroke), results.

2. Radial feed without rotary motion. (Fig. 16b). Also a traditional approach, this method is recommended for:

a. Shaping internal teeth in order to avoid return stroke marks by the tool on workpieces with difficult tooth geometry;

b. Reducing feed times; and

c. Producing form cut profiles (single tooth indexing method).

Radial infeed is to final depth without rotary motion of workpiece and tool. It is used primarily to prevent collision when shaping internal gears and to save time by applying higher infeed rates (approximately .05-.10 mm (.002-.004")/double stroke), and meet special requirements.

3. Spiral method with constant radial feed. (Fig. 16c). This is used on a modern machine, but not necessarily one equipped with CNC. The chip volume increases with increasing cutting depth of the tool and

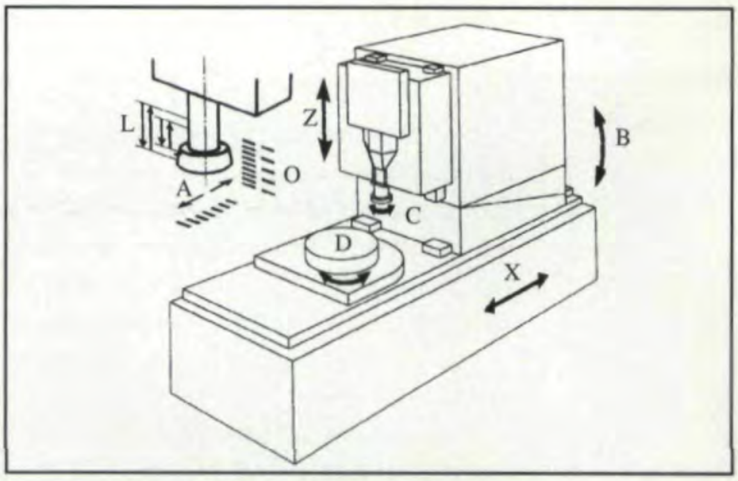


Fig. 15 — 8-axes CNC gear shaping machine.

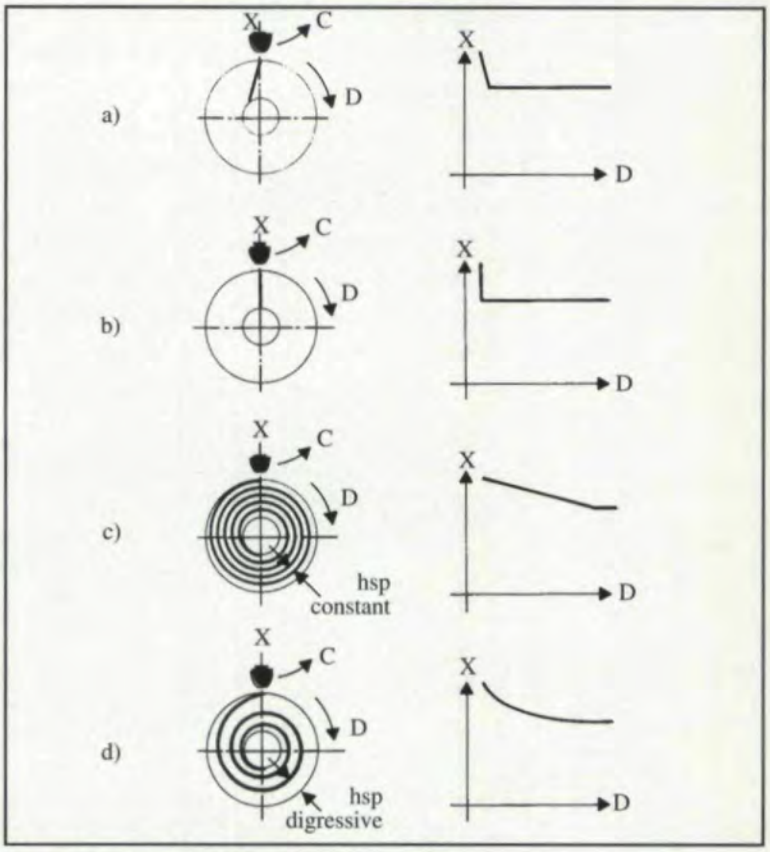


Fig. 16a — Radial feed with rotary motion.
Fig. 16b — Radial feed without rotary motion.
Fig. 16c — Spiral method with constant radial feed.
Fig. 16d — Spiral method with digressive radial feed.

Table 1 — Summary of cutting methods.

Method	Description	Types of Cutters
Generating	— Infeed without generating — Infeed with generating — Spiral infeed with either constant or variable radial feed	— disk-type cutters — hub-type cutters — shank cutter
Index generating	— Like generating, but no full work revolutions at constant feed (segment gears, special profiles which can be generated)	— cutter types as — segment cutter — single tooth form cutter
Single indexing	— No generating motion of workpiece during stroke action	— form cutter (primarily single tooth cutter)

uniform radial feed. This amounts to continuously increasing loads on the machine and the tools until the depth of the tooth is reached. Continuous uniform radial infeed is to final depth over several work revolutions. The desired large spiral length pattern results from appropriate feed rate combinations, depending on gear parameters (generating feeds up to 10 mm (.40")/double stroke and radial feeds of approximately .002-.030 mm (.000080-.0012")/double stroke).

4. Spiral method with digressive radial feed. (Fig. 16d). This is the newest technology and is only possible with CNC. Here, a decreasing rate of radial feed keeps the chip volume during the feeding process almost constant. The result is improved tool life and improved surface quality of the tooth flanks. In this method, travel is dependent on digressive feedrate pattern. The high requirements for proper control can fully realized only with CNC.

Cutting Forces and Torque Based on Feed Techniques. The controlled infeed of the spiral infeed method over as many as possible work revolutions is primarily used. Comparison tests with traditional infeed methods with or without generating at equal time for roughing show that the individual cutting edge is exposed to substantially reduced main cutting forces and torques (Fig. 17). This occurs because of better and more uniform chip formation, better chip flow and less chip deformation (Fig. 18). The desired effects are less cutter flank contact, less danger of rubbing on the return stroke, reduced temperature build-up at the cutting edge and less tendency for edge build-up.

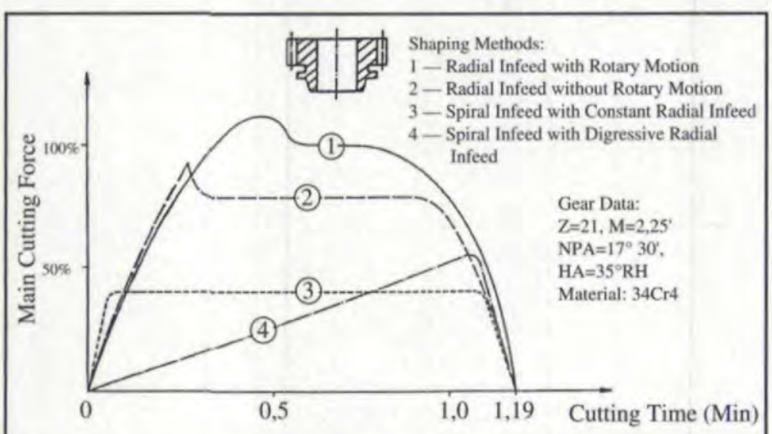


Fig. 17 — Main cutting force diagram roughing by the four infeed methods.

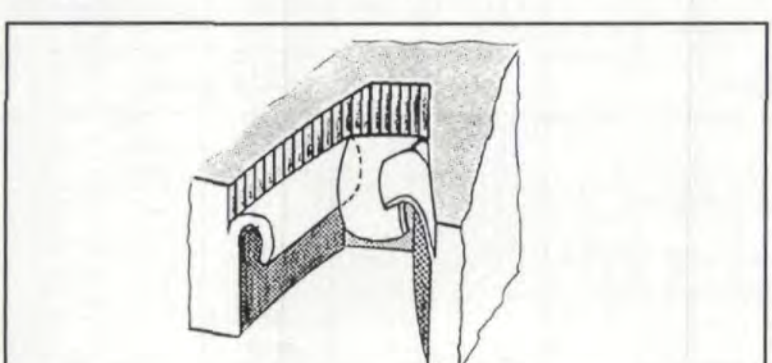


Fig. 18 — Chip formation, spiral digressive infeed method.

Spiral Digressive Infeed Cutting Technique. Applying the digressive infeed substantially increases the productive efficiency of gear shaping, assures short cutting times and provides effective tool utilization coupled with high accuracy. The process is applied to roughing operations with subsequent shaving, fine rolling, honing or grinding and to finish cutting operations such as are shown in Fig. 19, where both higher feed marks and enveloping cut formation, as with coupling gears, are acceptable or even desirable because of the improved lubrication effect (oil pockets). Key features of this infeed technique are:

1. Controlled Chip Removal

a. The spiral type infeed pattern is according to section.

b. Cutting data, such as numbers of strokes, generating feed, radial feed and cutting depth, are determined by computer control.

c. The bases for determining cutting data are the geometrical parameters of workpiece, tool, machine, material specifications and values obtained from trials.

2. High Speed Finish Shaping

a. This improves surface quality, particularly the formation of enveloping cuts for the desired subsequent operation.

b. This also yields extremely short finishing times as a result of the high generating feed rate, which can be up to fifteen times the rate of conventional finishing feeds, depending on the gear parameters.

3. Spring Cuts Without Infeed For Improving Quality

a. Typical tooth deviations (e.g., errors reproduced as a result of inaccuracies built into the cutter or as a result of improper cutter mounting) are averaged out.

b. The number of spring cuts depends on the relation of the number of teeth between cutter and workpiece and on the required gear quality.

Gears shaped by the digressive technique are comparable to hobbed gears in both surface and enveloping cut patterns. The same comparison applies to checking the gear, particularly to chart evaluations and to subsequent finish operations.

Actual production results have shown that selecting a machinable workpiece material and using TiN-coated cutters (especially face-coated) can have a positive effect on the surface quality of gears produced by the digressive technique.

This is not to say that one must always look for the easiest material to cut. For example, if an 8620 material is cut at a high rate (finishing at a surface cutting speed of 300 fpm), a 200 Brinell hardness would be preferable to the softer 150-160 Brinell. The softer material will tear and chip-weld to the flanks of the cutting, especially if the cutter's face is not TiN coated. This tearing and chip-welding will lower the obtainable AGMA finish-cut accuracy from a 10 to a 7 or 8.

Besides higher chip removal rates and reduced cutter wear through the digressive infeed technique, a subsequent finishing operation has generally better results than roughing by conventional shaping infeed methods. This occurs because of reduced gear runout and spacing errors, smaller required stock envelope and reduced chip volume.

These New Technologies Affect Cutting Times. The new feed techniques go hand in hand with the technology advancements made in the hardware, i.e., machine and cutting tools. The pendulum of the shaper cutting process no

Fig. 19 — Feed marks and enveloping cut formation.

Table 2 — Past to present cutting time review.

Gear Data	Typical Automotive Gear			Typical Truck/Agricultural Gear		
Diametral Pitch	12			5		
No. of Teeth	30			30		
Pitch Circle	2.88"			6.92"		
Pressure Angle	20°			20°		
Helix Angle	30°			30°		
Face Width	.8"			1.5"		
Material/Hardness	8620/220 BHN			8620/BHN		
Cutting Condition	Preshave			Preshave		
Quality AGMA	8/9			8/9		
Shaping Machine Data*	**Old**	**Modern**	**CNC**	**Old**	**Modern**	**CNC**
Infeed Method	Conv.	Conv.	Spiral Digress.	Conv.	Conv.	Spiral Digression
No. of Cuts	2	2	2 Feed Changes	3	3	3 Feed Changes
Strokes/Min.						
Cutting Speed, Ft./Min						160/99'
Roughing	335/115'	335/115'	360/121'	142/85'	150/92'	242/150'
Finishing	500/174'	670/232'	1000/360'	213/131'	150/92'	480/292'
Rotary Feed/Stroke						
Roughing	.0177"	.019"	.1007"	.0244"	.030"	.181"
Finishing	.0177"	.030"	.030"	.0244"	.030"	.072"
						.032"
Radial Infeed/Stroke	.0012"	.0012"	.020-.0008"	.0012"	.0012"	.020-.0008"
Roughing	.0004"	.0004"	.0002"	.0004"	.0004"	.0004"
Finishing						.0004"
Cycle Time, Minutes,						
Without Load & Unload	3.15	2.5	1.68	19.01	17.13	7.98
Pieces Per Sharpening						
Percentage	100%	190%	290%	100%	180%	340%

*Old — Table relief type machine (See Figs. 3-5).
Modern — Spindle relief type machine, but with change gears and independent drives (see Figs. 6-8).
CNC — Spindle relief type machine with large speed ranges and without change gears (see Figs. 11-12).

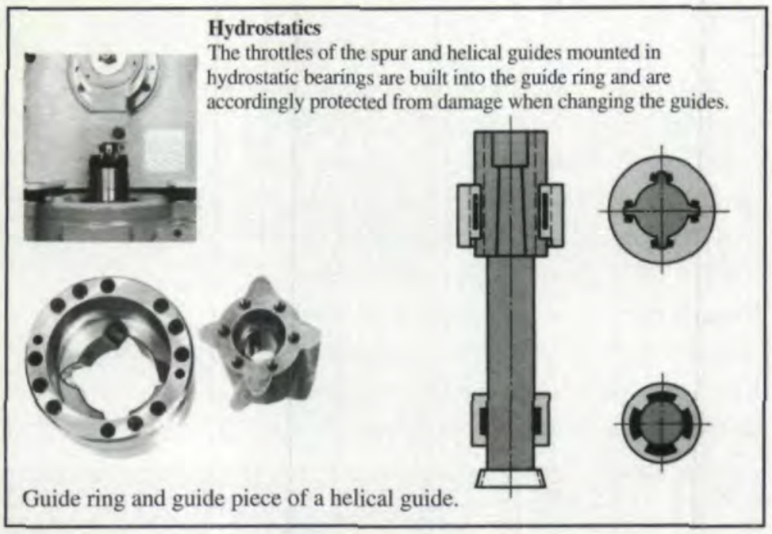


Fig. 20 — Hydrostatic lubrication of a helical or spur guide and cutter spindle.

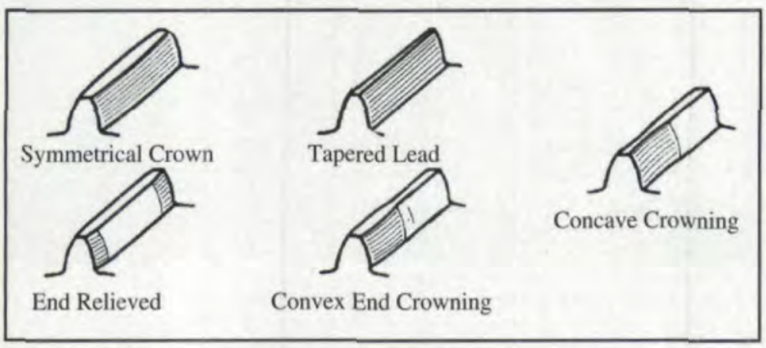


Fig. 21 — Types of longitudinal correction (lead correction) crowning, taper, etc.

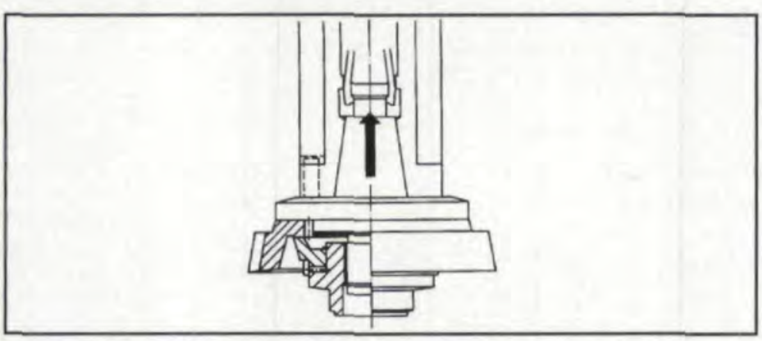


Fig. 22 — Automatic cutter clamping feature. The cutter and adapter are hydro-mechanically clamped into the cutter spindle.

Fig. 23 — Cutter adapters are automatically clamped concentric to the cutter spindle to an accuracy of .0001-.0002". Two cutters are mounted for cluster gear cutting.

longer swings in favor of the cutting tool vs. the machine or vice-versa. Cutting tool and machine are equal limiting factors.

Advancing Technology for Mechanical Components

Hydrostatic Guides. Gear shaping machines require spur and/or helical (lead) guides. Helical gears require helical guides that introduce to the cutter spindle an additional rotary motion during the working stroke. These mechanical guides are still required, but in almost all cases, the cutter spindle and guide are mounted hydrostatically (Fig. 20). This is a necessity based on the high stroking rate capabilities of some machines, i.e., 2,050 strokes per minute. This can lead to cutting speeds for finishing up to 492 surface feet per minute. Of course, work is being done on CNC guides, but none are currently available for quality production at high stroking rates.

Another element which is not CNC on the machines is lead correction, i.e., crowning capability. *Involute modifications are produced by modifying the cutter tooth form,* but crowning is achieved by moving the cutter spindle as it traverses the face of the gear. This movement is created by modification of the "back-off cam," which is part of the relieving mechanism for cutter relief. Cutter relief is the process of moving the cutter away from the gear so it does not contact the gear on the non-cutting return stroke. Of course, this applies only to "modern" spindle relief shapers.

Cutter Changing — Manual Quick Change and Fully Automatic Changes. See Figs 21-24 for illustrations of these features.

Worm and Worm Wheel Designs for Backlash Control. When the gear shaping process is evaluated for geometric capabilities, the following **general statements** can be made.

1. Lead errors are minimal with modern hydrostatic machines, i.e., AGMA 11-12 is an achievable quality. The hydrostatic mounting of guide and spindle maintains this capability.

2. Profile results are closely tied to shaper cutter tolerances, but are also related to cutter coatings, cutter clearance and rake angles and sharpening errors.

3. Part pitch line runout errors can be directly related to cutter mounting errors

and/or fixturing errors.

A Summary of the Benefits That Can Be Realized from a CNC Shaper:

1. The operator set-up is simplified because:

a. The operator does not have to mount index change gear,

b. The operator does not have to set cutter spindle stroke length and position;

c. The operator does not have to set infeed cams or micrometer switches for depth of cut;

d. The operator does not have to set speeds and feeds, which can be loaded by punch tape or DNC or recalled from the CNC controller memory;

e. The operator does not have to change direction of cutter relieving for upcutting or internal gear cutting to external gear cutting;

f. With the appropriate cutter measuring equipment the operator does not have to cut a trial piece to verify correct infeed setting for an overpin dimension check, i.e., cut a part to size;

g. On some machines the spindle back-off direction does not need to be changed.

2. Cluster gears can be cut in a single setup because of the Z axis stroke position and the absence of index change gears. If the DP differs from gear to gear, stacked cutters are applied.

3. Cluster gears with tooth location requirements can be cut in a single setup. C and D axes are independently controlled.

4. Keyways, single tooth form or other forms can be cut by the plunge cutting technique, i.e., no C or D axes rotation except for single tooth indexing. The X axis radial infeed is the only feed component used with this technique.

5. An internal spline or gear and external gear may be cut on the same blank. This requires the Z axis stroke positioning feature and stacked cutters with C and D axes index ratio change.

6. Cutter change down-time is reduced. The cutter can be electronically measured off the machine and new tool offset data entered through the CNC control while the machine is in production. Axes used are Z stroke position and X axis for new infeed depth stopping position ("final size"). Of course, this is done to compensate for tool height and diameter change due to cutter sharpening or new set-up.

7. Zero set-up time is important in connection with just-in-time inventory and flexible manufacturing cells and systems. A setup of only a few minutes can be presently obtained on gear shaping machines if the guide does not have to be changed and additional support equipment is purchased with the machine, i.e., automatic fixture and cutter change equipment.

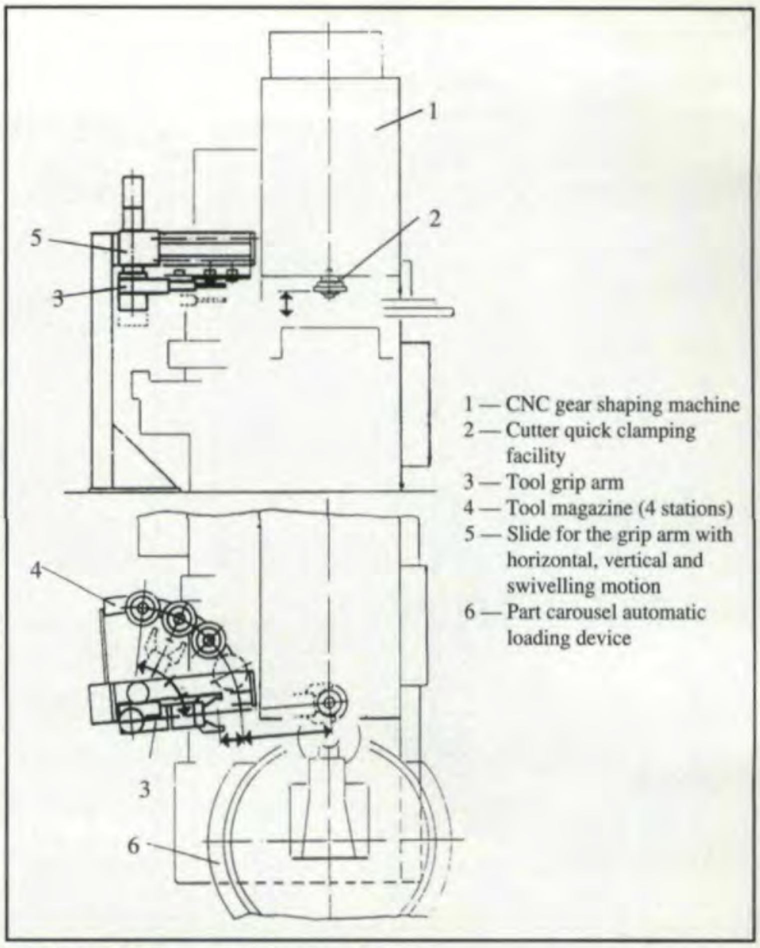


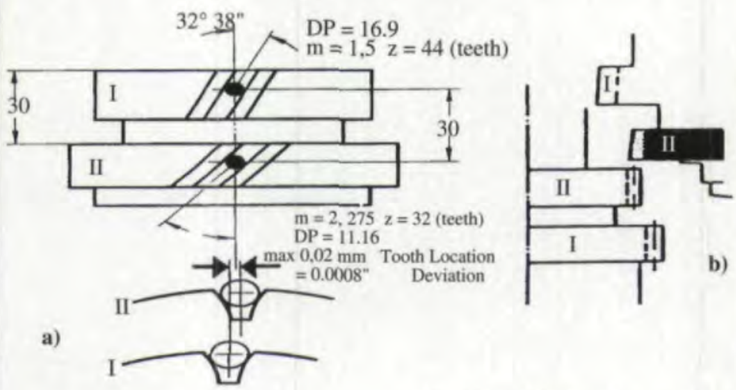
Fig. 24 — CNC gear shaping machine.

8. CNC gear shaping machines are more accurate than conventional shapers. X-axis infeed, feed per strokes and depth of cut (final size) are controlled by a linear electronic scale and AC servo drive. The accuracy of stopping at a preset infeed depth is plus or minus 40 microinches. Z-axis stroke length positioning is also controlled by a linear electronic scale to an accuracy of .0008". C and D axes are controlled individually by rotary encoders with a resolution of 3.6 arc seconds. These new shapers are capable of producing quality level AGMA 11 under production circumstances and optionally, AGMA 12.

9. The installation of a CNC gear shaping machine into a flexible manufacturing cell or system would dictate automatic tool changing capability.

Appendix: CNC Shaping Applications — The Real World

Example 1. Cutting a Helical Gear Cluster with a Tooth Alignment Requirement in a Single Setup. Figs. 25 a, b and c show a helical cluster gear with a tooth location requirement. This is an automotive transmission component. Gear I and gear II have

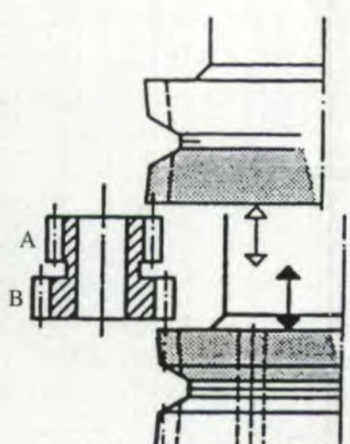


a)

Gear/Cutting Data	I	II
Number of Teeth	32	44
DP (Normal)	11.16	16.9
Face Width	.78"	.78"
Helix Angle RH	36°	32° 38'
Cutting Tool		
Number of Teeth	56	77
Strokes per Minute		
Rough/Finish	400/1000	400/1000
Cutting Speed/		
Surface ft. per Min		
Rough	138'	138'
Finish	344'	331'
Cutting Method	Generating	Digressive
Total Cutting Time	4 minutes,	5 seconds

c)

Fig. 25 — Helical cluster gear with a tooth location requirement.



Gear/Cutting Data	A	B
Number of Teeth	18	21
DP	10	10
Face Width	.70"	.61"
Material 8620	180-200 BHN	
Number of Teeth		
in Cutters	62	
Strokes Per Min./		
Cutting Speed		
Surface Ft. Per Min.		
Roughing	700/167'	700/167'
Finishing	1050/249'	1250/295'
Cutting Method	Down	Up
(Generating)	Digressive	Digressive
Total Cutting Time	1.2 min	

Fig. 26 — Cluster planetary pinion cutting down-and-up shaping in a single setup.

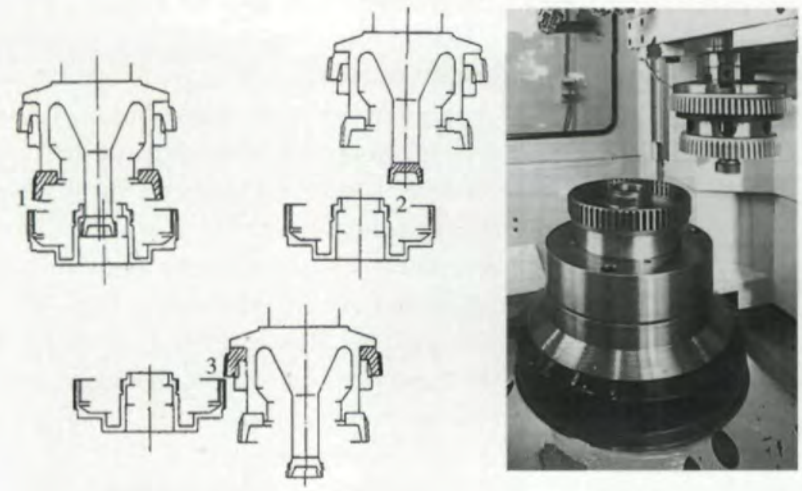
dissimilar helix angles, modules (diametral pitch) and number of teeth (Z). The required tooth location alignment accuracy is .0008". The part is cut on a CNC gear shaping machine to a preshave condition in a single setup. It is made of case-hardened material having a hardness at the time of cutting of about 190 BHN. Total cutting time for the component is 4 minutes, 5 seconds with an achieved alignment accuracy of .0004". The unusual condition here is that while there are two different helix angles, the lead of the cutters can be made the same and still retain the required helix angles by changing the diameter of the cutters. A single guide satisfies the lead requirement of both cutters.

Example 2 — Cluster Gear Cutting by the Down-and-Up Shaping Method in a Single Setup (Fig. 26). Note the back-to-back mounting of the cutters. When down-and-up cutting in a single setup, it is necessary to change the back-off direction, i.e., the relieving action of the cutter spindle. This is done automatically by the CNC controller during the repositioning of the cutters. Of course, when up-cutting, the pull stroke is a power stroke, not simply a return stroke, as when down-cutting.

Example 3 — Cutting of Three Gear Clusters with Three Cutters in a Single Setup. Three gear members (Fig. 27) are cut in a single setup. Two members have a tooth location requirement.

Example 4 — Cutting Gears by the Index Generating Method. "Index generating" implies alternating generating action between tool and workpiece at a given ratio with single indexing of workpiece and/or tool. This capability must be provided by the CNC control and requires that the electronic drive (i.e., the controlled motion between cutter and workpiece) can be temporarily opened and closed at any time and at any position without memory loss of travel increments.

Figs. 28 and 29 illustrate how this profile is produced. The pinion bore has straight-sided tooth profiles preventing the use of standard involute cutters. The profiles were broached in the past, but the many types of profiles resulted in exorbitant tool costs, and tool-related inaccuracies caused excessive pump noise levels. Precutting is done by single indexing



Gear/Cutting Data	1	2	3
Number of Teeth	60	70	64
DP	13.55	25.4	8.8
Face Width	.9"	1.1"	.47"
Material Cast Iron 200 BHN			
Number of Teeth in Cutters	56	42	68
Strokes Per Min./ Surface Ft. Per Min.			
Roughing	500/170'	500/170'	400/138'
Finishing	1100/374'	1100/374'	1100/374'
Gear Cutting Method		Generating Digressive	
Total Gear Cutting Time		4.25 minutes	

Fig. 27 — Planetary gear housing with three gearing elements being cut in a single setup (spurs).

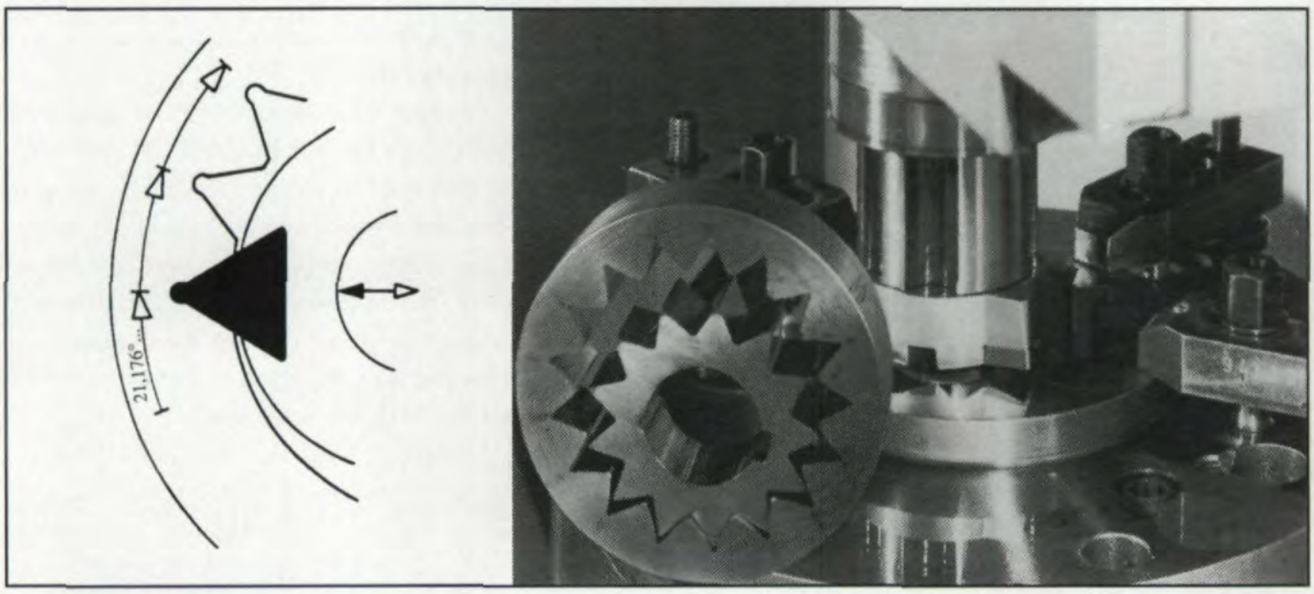
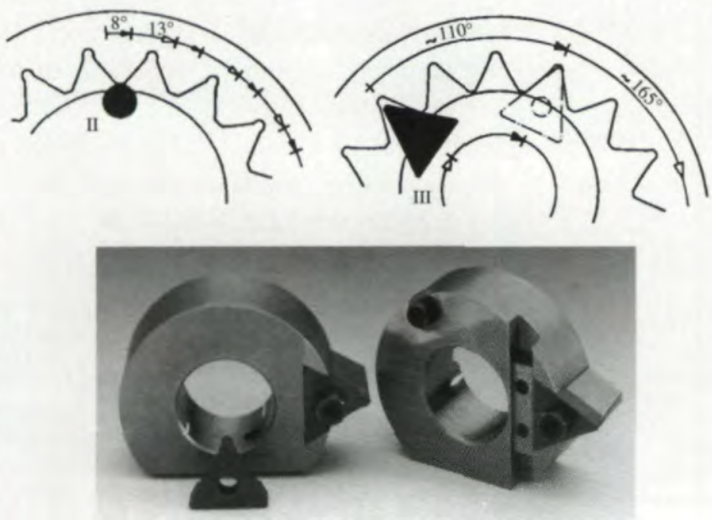


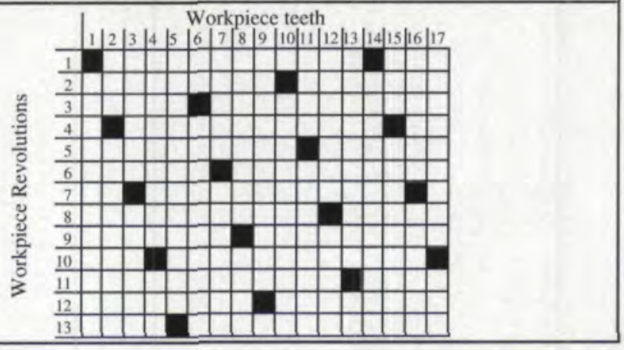
Fig. 28 — Preshaping the special internal profile of an oil pump gear by the single indexing method.

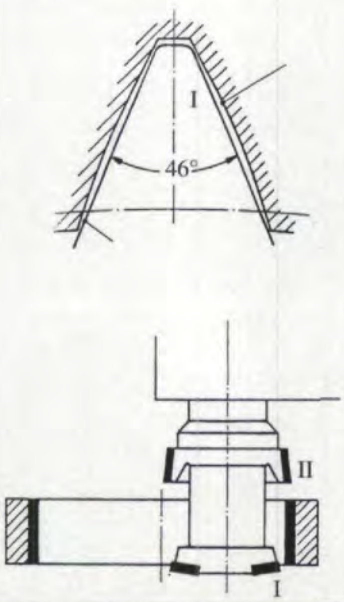


Gear/Cutting Data	Roughing	Tip Circle Shaping	Special Profile Finish Shaping
Number of Teeth/ Gaps	17	17	17
Profile Dimensions	.12" x .59" x .47"	.137"	.12" x .59" x .47"
Face Width		1.65"	
Cutting Tool		Indexable Carbide	
Strokes Per Min./ Surface Ft. Per Min.	350/173'	760/377'	Same
Cutting Method	Indexing	Indexing/Generating	
Cutting Time	2.5 Minutes	5.1 Minutes	

Fig. 29 — Finish-shaping the special internal profile of an oil gear by index generating.

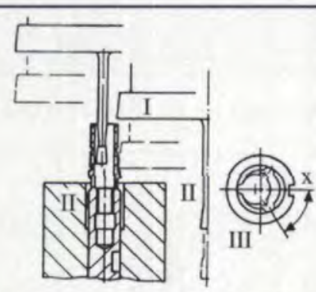
Table 3 — Finish Shaping Machining Sequence for a 17-Tooth Workpiece With a Single Tooth Cutter





Gear/Cutting Data	Roughing	Finishing
Number of teeth/slots	60	60
DP	—	5
Profile dimensions	.08" x .43" x .41"	—
Face Width	2.36"	
Cutting Tool	Reversible carbide insert	Disc type
Strokes per Minute	450	450
Cutting Speed/ Surface Ft. per Minute	325'	325'
Cutting Method	Indexing	Generating
Total Cutting Time	17.5 minutes	

Fig. 30 — Roughing and finishing an internal gear with a disc cutter in a single setup.



Gear/Cutting Data	External I	Internal II
Number of Teeth/ Gaps	26	3
DP-slots	32 DP	Semi-Round .05" Radius
Face Widths	1.54"	.9"
Number of Teeth in Cutter	190	3
Strokes Per Minute/ Surface Feet Per Minute:		
Roughing	80/36'	
Finishing	160/75'	
Cutting Method	Generating	Indexing
Total Cutting Time	6.5 Minutes	

Fig. 31 — Cutting an external spline and internal recessed slots with a tooth location requirement in a single setup. This is an aircraft engine component!

with an indexable carbide cutter insert of special profile design.

Finish operations start by first machining the major diameter. The spaces are skipped by rapid traverse. The major diameter is used for locating and clamping the part for subsequent machine operations. The next step is finishing the tooth space for index generating with an indexable carbide cutter. Its profile exactly represents a tooth of the pump pinion. The space is generated over 110° and then indexed 165° in rapid traverse. The machining sequence of the tooth spaces are indicated in Table 3.

Example 5 — Carbide Form Cutting, Roughing and Generating Finishing with a Disc Cutter in a Single Setup. This internal gear is roughed with an indexable carbide cutter insert and finished with a standard disc type cutter (Fig. 30).

Example 6 — Profiles in Recessed Bores That Cannot Be Broached. Fig. 31 illustrates the cutting of an external spline and internal recessed slots with a tooth location requirement. By cutting this part in a single setup, the required position relationship between the oil grooves and the external gear is no problem. The part, a difficult aircraft material, is shaped in 6.5 min.

Example 7 — Finish-Shaping of a Countershaft in a Single Setup. Fig. 32 illustrates two cutters tandemly mounted cutting four gears in a single setup. Each gear is cut in an individual machine cycle. Of course, feeds and speeds are changed automatically between each cutting cycle. The parts are finish-cut. They were previously finished in a shaving operation.

Example 8 — Multiple Machining Operations in One Cycle. Figs. 33 and 34 demonstrate the flexibility of an 8-axes gear shaping machine. Note the deburring technique in Fig. 34, operations 2a, 3a and 4a. ■

Reference:

Dr. Klaus Felton, "Effective Gear Shaping Principles," presented at American Pfauter Gear Process Dynamics Clinic, Sept., 1987.

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