CNC Gear Shaping

Dr. G. Sulzer
Liebherr Machine Tools
Germany

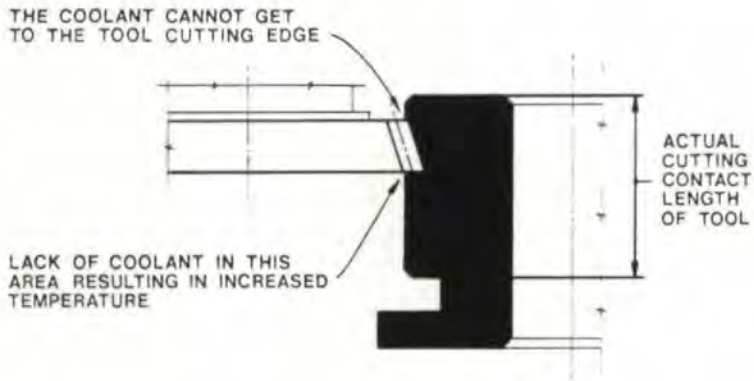

Fig. 1

Introduction

New Developments in Tools and Machines

Two major processes are used for cutting gears, hobbing and shaping. Because of it's universal application and it's high performance, hobbing is generally preferred. A hobbing machine is universal enough to produce worms, worm gears, spur and helical gears. By using Multistart hobs, the productivity of the machine can be increased considerably.

Normally shaping is only used when hobbing is impossible due to the form of the parts to be cut, i.e. internal gears and cluster gears with shoulders. Multistart cutters cannot be used. Nevertheless, the technological disadvantages can be reduced by advanced machine design and better cutter materials.

AUTHOR:

DR. G. SULZER *is Manager of Research & Development at LIEBHERR in West Germany. He earned his doctorate at the University of Aachen in Aachen, Germany where he has worked in the role of Manager Research Development for twelve years. He has been instrumental in the development of the Liebherr CNC machines.*

Tools

Sintered and tin coated high speed steels are generally established as cutter materials. Sintered high speed steel is particularly suited to shaping because of its durability when cutting at high temperatures, which arises more in shaping than in hobbing. Depending on the width of gear, a longer cut occurs and the access for coolant is limited during cutting.(Fig. 1 and Fig. 2)

The additional tin coating improves wear resistance on the tooth flanks. The time of contact between hob and workpiece is generally shorter than in shaping, and the access for coolant is much better.

To a limited extent, carbide cutters are also used but in the field of machining hardened gears only. Similar to skive hobbing, cutting speeds are increased by about 30% compared with soft machining.

The life of a tin coated cutter in it's original condition and after multiple resharpening, has been studied under practical conditions paying particular attention to filtration of the coolants. (Fig. 3) Using a filtered coolant, a life of up to 25 hours can be achieved between cutter regrinds. (Fig. 4) It is obvious that filtration of coolants is an important factor. Another factor is the condition of the tin coating itself. New cutters may vary a lot, but after several sharpenings, consistant life is obtained. At least 20 resharpenings per cutter are achieved and calculated cost should be based on the resharpened cutter rather than on a new tool.

Increasing the productivity of the shaping operation is one aim, another is increasing the flexibility of this method of machining. By using suitable tool shapes, shaping can be universal as well. Some applications are as follows:

Shaping a square using a pinion type cutter: other shapes can be obtained with the use of specially designed cutters. Shaping is then in competition with spark erosion and broaching as an operation.

Simultaneous shaping of three identical gears on one part reduces cutting time by one third.

The same principle obviously applies to two gears per part. (Fig. 5) When coarser pitches are shaped, the two cutters are displaced by half a pitch, thus giving more equal cutting forces. Using multiple cutters means that the tools have to be resharpened as pairs in order to give identical diameters.

Shaping Machines (Fig. 6)

Conventional shaping machines are driven by mechanical gear trains. A main motor drives the reciprocating motion of the cutter spindle, and a gear train driven from the stroke motion synchronizes a cam mechanism for relieving the cutter on its return stroke. The rotary motion of cutter and workpiece can be driven by a separate motor, but for the correct synchronization individual index gears have to be mounted.

Radial motion is produced by hydro or electromechanical drives and table positions are controlled by tripdogs and microswitches. Setting stroke position and stroke length is carried out manually and the same applies to the lateral offset

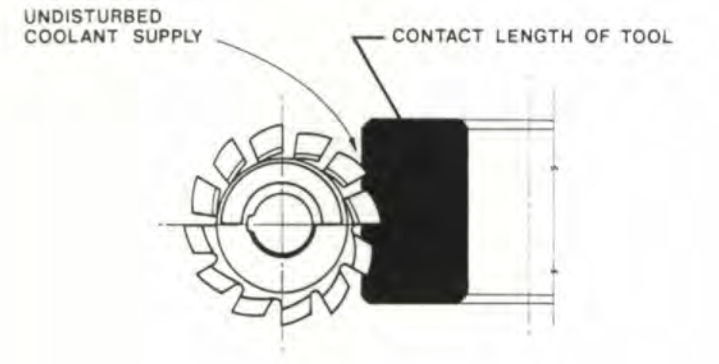

Fig. 2

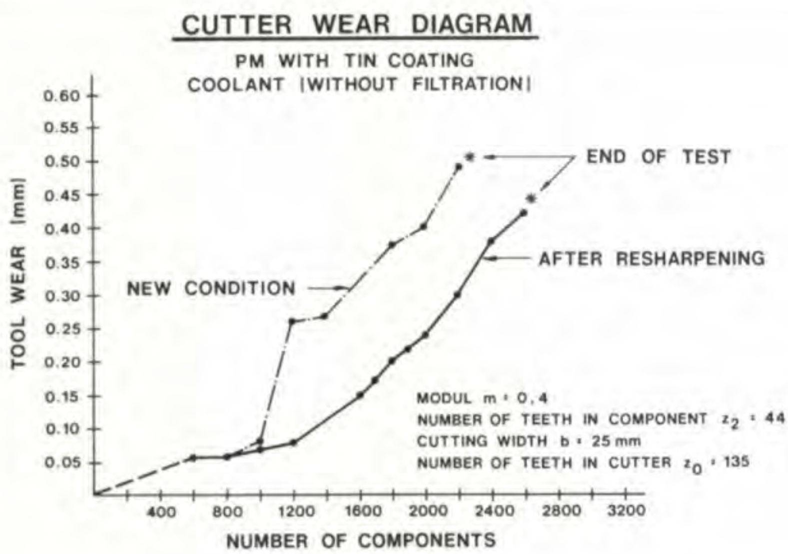

Fig. 3

between cutter and workpiece for preventing interference on cutter return stroke.

Linear path NC shaping machines are usually fitted with separate drives for the following:

Stroke motion
Rotation of tool and workpiece
Radial motion (X axis)
Stroke position (Z axis)

With this type of machine, it is still necessary to use index change gears in order to achieve the synchronization between cutter and work. Adjustment of stroke position and stroke length as well as cutter to worktable offset are adjusted manually as on the conventional machine.

Full CNC shaping machines feature separate drives for the following: (Fig. 7)

Stroke motion with depth center positioning (S axis)
Rotation of tool (D axis)
Rotation of workpiece (C axis)
Radial motion (X axis)
Stroke position (Z axis)
Stroke length (V axis)
Offset cutter stroke workpiece (Y axis)
Relief angle (taper) (B axis)

Through using NC on all axes, a CNC shaping machine gives the following advantages:

S Axis, stroke motion with dead center positioning

Cutter speed (number of strokes per minute) is programmable for any combination of infeeds, roughing, finishing or dwell operation. Therefore shortest cutting times are achieved without overloading the cutter. The dead center positioning feature assures safety when cutting internal gears (clearance between the cutter and workpiece during radial motions) and enhances stroke positioning in the set up mode.

D/C-axis, rotation of tool and workpiece

In normal applications, the axes D and C are performing a synchronizing motion between cutter and workpiece and controlling the generating feed programs. Mounting of index change gears is obsolete, feeds are programmable and dependent on the geometry and machinability of the parts to be cut. For balanced wear distribution on the flanks of the cutter, the direction of rotation can be changed automatically.

For special applications, each of the axes can be moved individually, such as for single index shaping of splines or keyways or angular positioning of the cutter to the workpiece. A combination of shaping by the generating method and subsequent single indexing (with a second cutter) in one operation is possible. Thus the range of applications is considerably extended.

X-axis, radial motion

Positional accuracy of the NC is approximately 0.005 mm. This means that safety clearances can be reduced to the outside diameter to be cut, and rapid traverses close to the outside diameter of the workpiece can be used. Tool offsets (difference in diameter) of the cutter to be used can be measured outside of the machine and an offset entered into the control while the machine is in operation. A combination of rotary and radial feeds allows any process such as pure radial infeed and extreme spiral infeeding to be

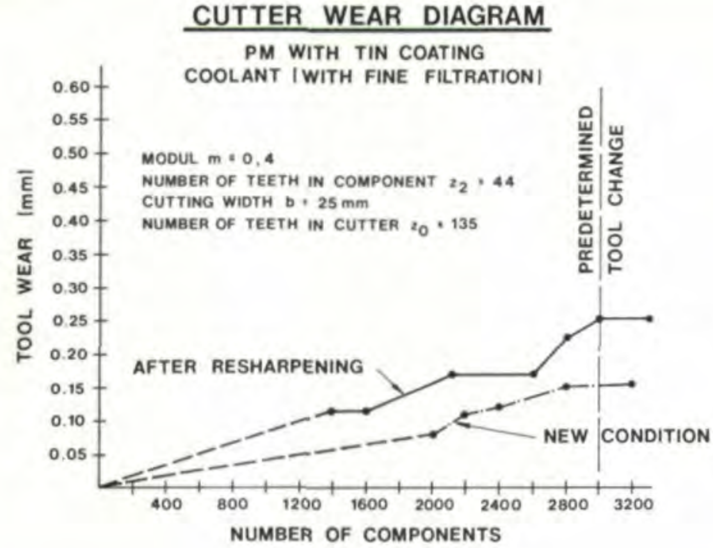

Fig. 4

Full CNC shaping machines feature separate drives for the following:

Stroke motion with depth centre positioning (S axis)
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Rotation of workpiece (C axis)
Radial motion (X axis)
Stroke length (V axis)
Offset cutter stroke workpiece (Y axis)
Relief angle (taper) (B axis)

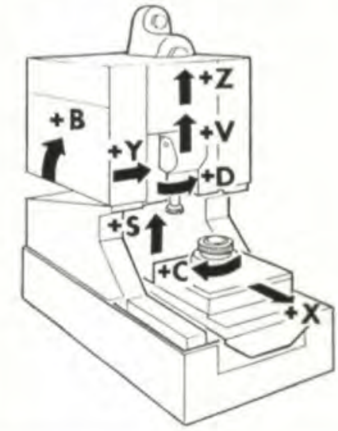


Fig. 7

Fig. 5

used. Optimum conditions for any combination of cutter and workpiece can be used.

Z-axis, stroke position

On conventional machines, it is necessary to set a stroke position after every tool change and sometimes during the machining cycle in the case of cluster gears (shaping two or more different gears in one operation), (Fig. 8 and Fig. 9) or with certain types of internal gears where the gear itself is lower than the upper face of the workpiece. Automatic stroke positioning by the NC saves a considerable amount of time and is more accurate and faster than manual setting.

Fig. 8

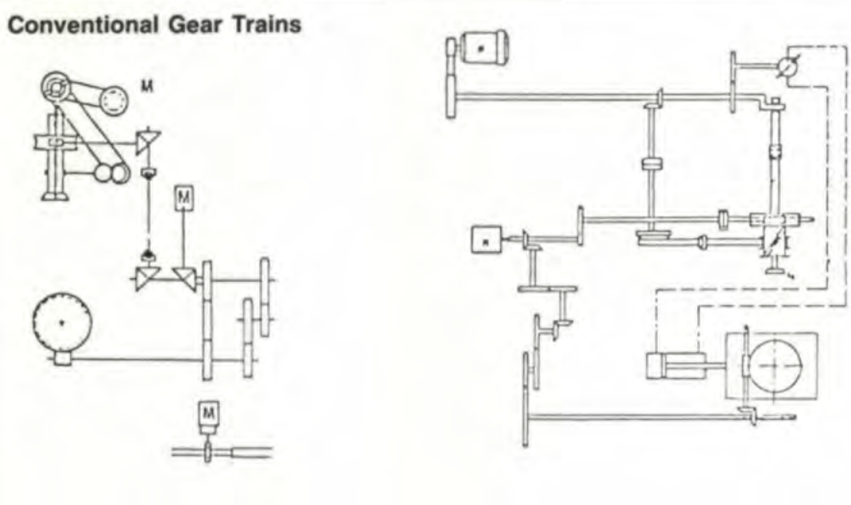


Fig. 6

V-axis, stroke length (Fig. 10)

Programming the stroke length reduces set up time. With advance control systems it is only necessary to enter the gear width pitch and helix angle; the stroke length itself is calculated and set by the control system. A major advantage of NC setting of the stroke length is with cluster gears with different face widths, (Fig. 11b) where for any gear, optimum stroke lengths can be applied. This is essential for economic production. (See Fig. 11a)

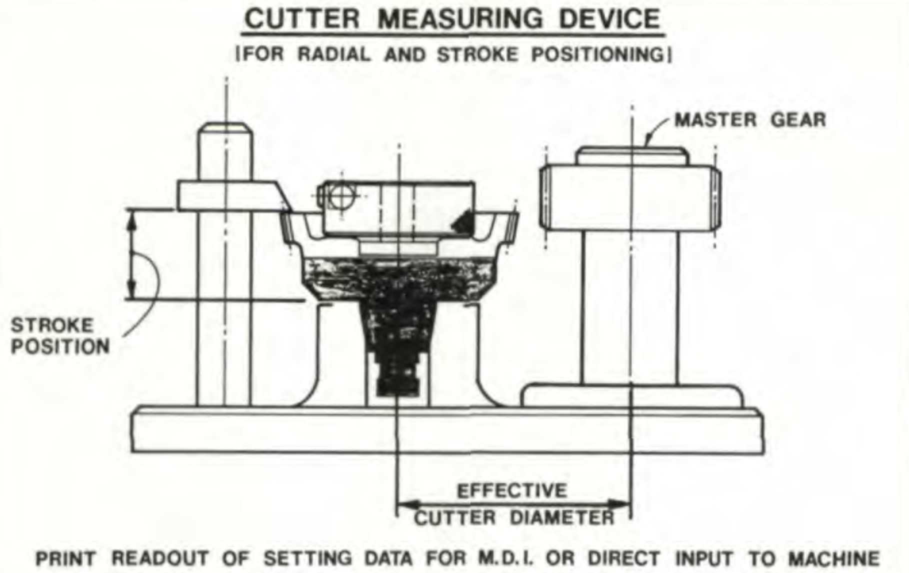


Fig. 9

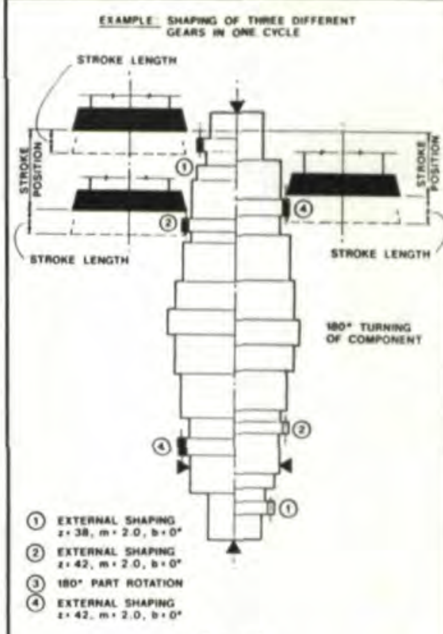


Fig. 11b

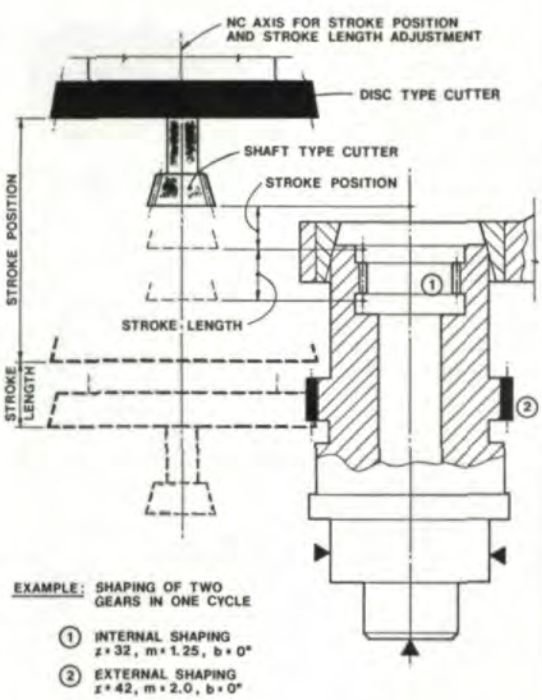


Fig. 10

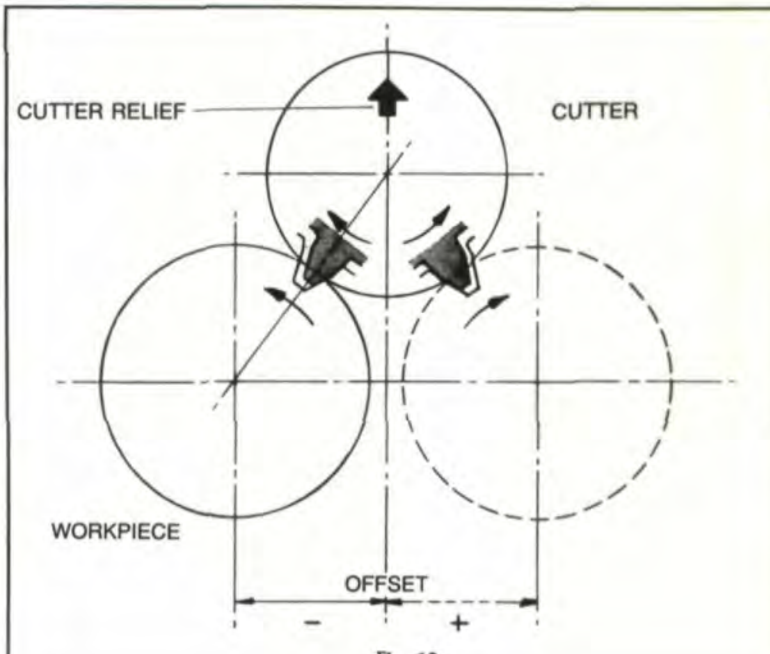


Fig. 12

EXAMPLE:

Gear 3	Gear 2	without CNC-stroke length:	
42 teeth, stroke 20 mm	42 teeth, stroke 15 mm		
with CNC-stroke length:		speed: 50 m/min	speed: 37 m/min
speed: 50 mm/min	speed: 50 mm/min	strokes: 800 per min	strokes: 800 per min
strokes: 800 per min	strokes: 1200 per min	time: 1.2 min	time: 1.2 min
time: 1.2 min	time: 1.2 min	**Savings with CNC:** 0.4 min per part = 33%	

Fig. 11a

Y-axis, offset cutter/workpiece (Fig. 12)

This axis provides the adjustment necessary for optimum cutter relief in order to prevent interference between tool and workpiece on the return stroke. This setting normally changes with every tool-workpiece combination and in some cases with the resharpening of the cutter. Setting via NC means a reduction in setting time, optimization of cutting conditions, and better tool life by changing

Fig. 13

the direction of rotation, which means reverse offsets between cutter and workpiece.

B-axis, relief angle (taper) (Fig. 13)

Angles can be programmed for any taper and for minor corrections in order to correct heat treatment distortions. General advantages of a full CNC shaping machine in production:
- ease of operation
- high accuracy
- maximum repeatability
- short cycle times
- easy servicing
- extended applications

Ease of operation

Fixed programs (canned cycles) are used for repetitive operations. These programs are fed with basic parameters only, which can be read directly from the part drawing and the tool specification. NC programming is not necessary, as entering the parameters is by a question and answer dialogue between machine control and the operator, and feasibility checks are carried out.

For special applications, which deviate from the canned cycles, tailored CNC programs can be written either by the user or the machine tool manufacturer. These programs and their parameters can easily be adapted to similar components. All programs and parameters can be stored in the controlled memory and recalled on request. Programming, as well as I/O operations can be carried out while the machine is working. Thus downtime is minimized and the safety of programming is enhanced.

High Accuracy

The closed loop between cutter and workpiece drive prevents any of the distortions known with conventional shaping machines which have long kinematic trains. This postively affects both lead and pitch accuracy, and the old dropped tooth condition is virtually eliminated.

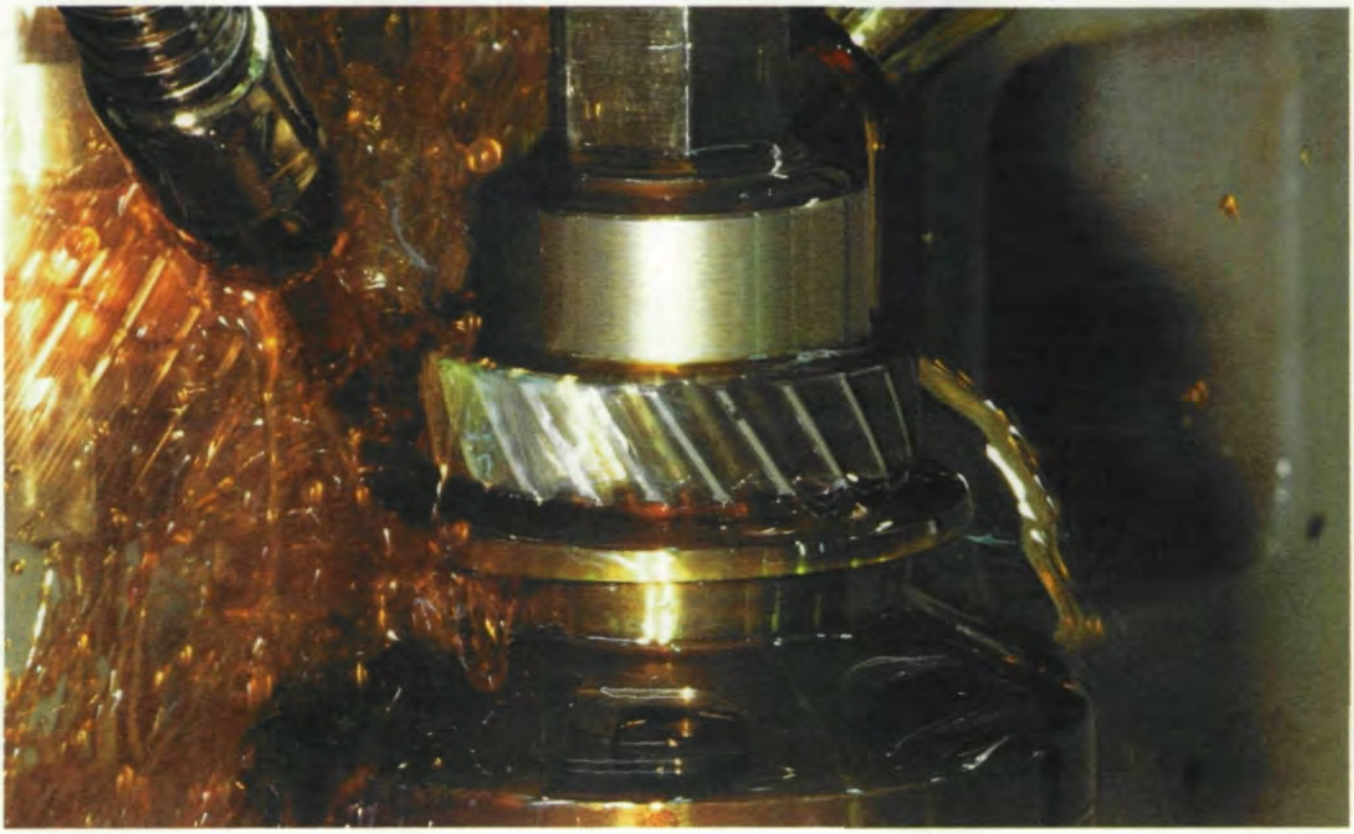
Maximum repeatability

Once optimum settings are established, they can be repeated identically on every batch of components. The closed loop control on the radial axis guarantees a constant size of all parts within one batch.

Short cycle times

The stored programs considerably reduce set up operations. The storage capacity (about 100 parts and their cut-

THE INNOVATIVE "SILENT SHAFT" GEAR SHAPER CUTS CYCLE TIME TO 1/2!



Mitsubishi has developed a new "silent shaft" mechanism that overcomes the vibrations encountered in high speed operations of gear shaping and lets you cut the cycle time in half. Two silent shafts rotating together with the crankshaft, cancels vibration on the SA25NC Gear Shaping Machine. This innovative mechanism permits speeds as high as 1,500 strokes per minute ... yet the vibration is one third of conventional machines.
Another feature of the SA25NC is the high rotary feed. The combination of the two features enables you to cut gears faster maintaining high accuracy and gives longer tool life to the cutter.
Simplified programming, reduced setup times and many, many more features to save you money. For more exciting information, contact our sales office in Bensenville, Illinois now!

Main Specifications

Max. dia. of work	
External gear	10" (4" cutter)
Internal gear	4.72" + cutter dia.
Max. D.P.	4DP
Max. work width	2.36"
Cutter stroke	300 ~ 1500str/min
Rotary feed (4" cutter)	0.0004"/str (at 300 str/min) 0.00008"/str (at 1500 str/min) 0.11 ~ 177.16 ipm
Table dia.	13"
Main motor power	7.5hp
Machine weight	11,000 lb.

CNC GEAR SHAPER

MITSUBISHI HEAVY INDUSTRIES, LTD.
5-1, Marunouchi 2-chome, Chiyoda-ku, Tokyo, Japan
Cable Address: HISHIJU TOKYO

Mitsubishi Heavy Industries America, Inc.
873 Supreme Drive, Bensenville, IL 60106 Phone; (312) 860-4220

Mitsubishi International Corporation
873 Supreme Drive, Bensenville, IL 60106 Phone: (312) 860-4222

CIRCLE A-8 ON READER REPLY CARD

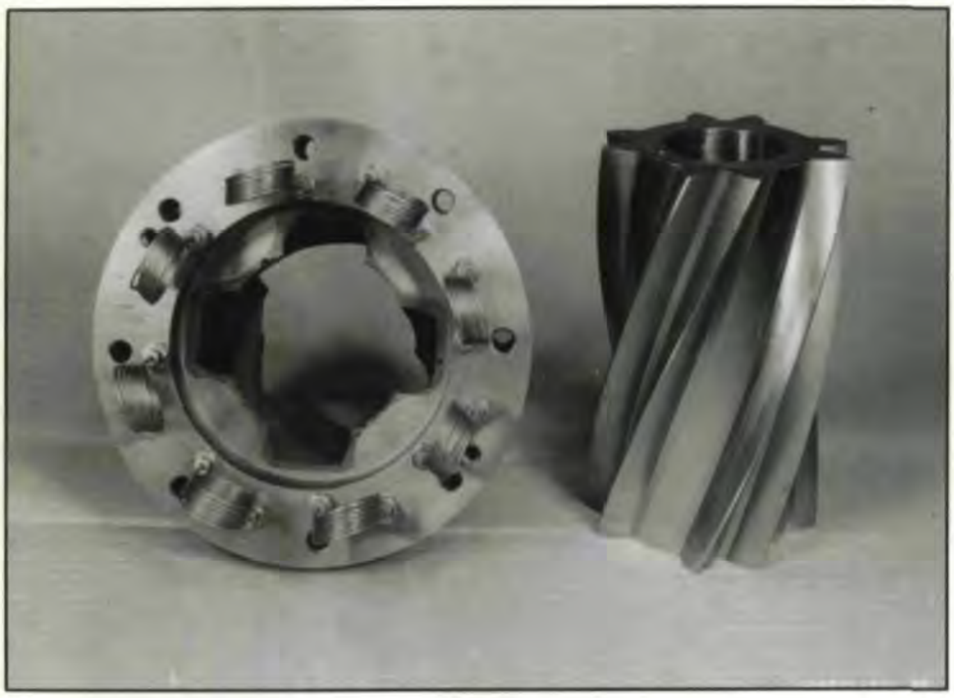


Fig. 14

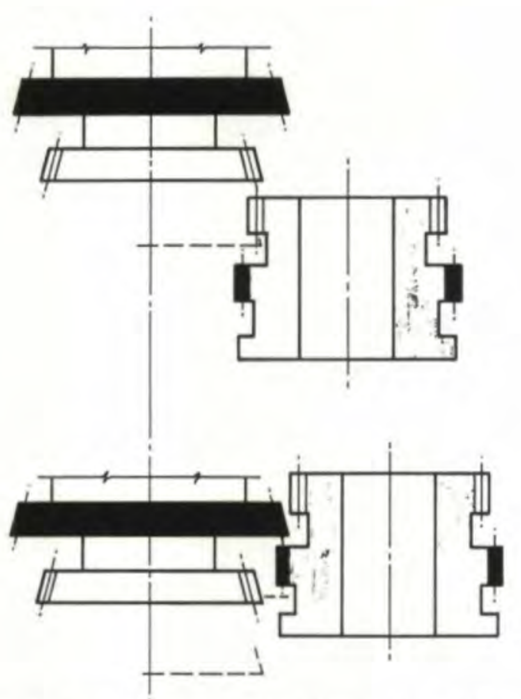


Fig. 15

ters) can be increased on request. Non productive times can be further reduced by using quick change systems for cutters and fixtures. Parallel programming increases uptime, and automation systems for part loading and unloading reduces idle time. Combining more than one operation in one loading of the workpiece also increases uptime and reduces idle time.

Cutting performance can be optimized by advanced programming and additionally by means of 3 override switches which control speed, radial feed and generating feed individually. If the number of strokes is changed, the generating feed per stroke remains unchanged so there is no risk of overloading the cutter.

Easy servicing by a machine diagnostic covering 100 potential faults gives plain language messages on the CRT display panel. According to the type or error, the system distinguishes between warnings and dangerous faults, and reacts accordingly. In the case of a fault which can cause damage, the machine is cut off automatically by the control system. Remote diagnosis through a modem and the normal telephone lines can be made by the machine tool manufacturer. Clear and quick diagnostics are the essential factor. Repairs can be easily made by the exchange of faulty control boards, encoders etc.

Extended applications

Full CNC shaping machines feature extended flexibility. Slots, keyways and other forms can be machined in almost any shape. Forms which cannot be shaped or hobbed can be manufactured by the single indexing method.

With the features offered by the CNC control, spare gears with the following specifications can be manufactured automatically.

Differing pitches
Differing numbers of teeth
Differing axial positions
Differing gear widths

The only limiting factor is still the lead of the cutter guide. (Fig. 14) This guide has to be changed for left hand and right hand helical gears and for spur gears; a combined operation of differing hand leads is not possible. This limitation does not apply to hobbing machines, as the NC controlled hob head swivel and the

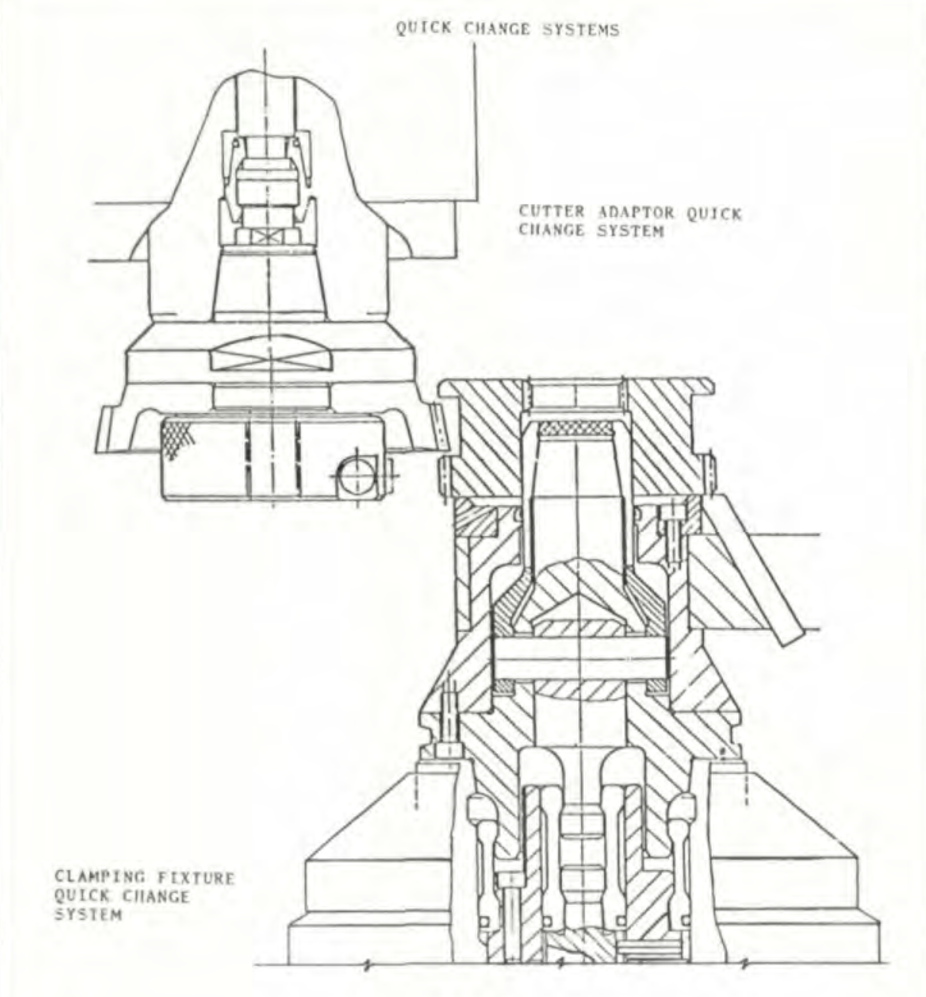


Fig. 16

NC differential can cope with any helix angle.

It is possible to shape different helix angles of the same hand with one guide. (Fig. 15) A large range of helix angles can be cut by using differing numbers of teeth on the cutters (different diameter). Currently, the possibilities of modern CNC shaping machines are not being fully exploited by gear designers.

Conclusions

Some of the technical possibilities of CNC gear shaping have been described. The decision about installing a full CNC shaping machine is however, based on economic factors. Determining factors are savings in set-up cycle times. The following table shows a comparison between the set-up times for a conventional and a full CNC machine: (Fig. 16)

Operation	Time (min)	
	conv	full CNC
Fixture change	20	5 1) (Fig. 19)
Cutter change	5	1 2)
Change index gears	10	-
Select program feeds speeds	1	- 3)
Set cutter/workpiece offset	8	- 4)
Set limit switches radial	3	-
Set cutting depth	1	-
Set stroke length	5	- 5)
Set stroke position	5	- 6)
Set relief angle (taper)	8	- 7)
Correct cutting depth after 1 gear		
	71 min	7 min

1) fixture quick change system
2) tool quick change system
3) parallel programming
4) Y-axis required
5) V-axis required
6) Z-axis required
7) B-axis required

This paper was presented at the SME "Gear Processing & Manufacturing Clinic," Nov. 1985.

E-3 ON READER REPLY CARD

COMPUTER SOLUTION . . .
(continued from page 30)

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E-1 ON READER REPLY CARD

VIEWPOINT
(continued from page 6)

I would like to point out an error in the November/December 1985, Gear Technology article "Finding Gear Teeth Ratios" which may be causing undue stress to some of your readers.

Equation number 4 on page 26 which is shown as:

$$Y_n = 1 - A_n Y_n - 1 + Y_n - 2$$

Should Be

$$Y_n = Y_n - 2 - A_n Y_n - 1$$

I found the article interesting and plan to use the program as a computerized method of selecting change gears for setting up hobbing machines.

Patrick J. Radle
Doerr Electric Corp.