

New Cutting Tool Developments in Gear Shaping Technology

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The advent of CNC technology as applied to gear shaping machines has, in the last 10 years, led to an astonishing improvement in both productivity and quality. As is usual when developments such as this take place, the technology of the machine tool suddenly jumps ahead of that of the cutting tool, and the machine is then capable of producing faster than the cutting tool can withstand.

The cutting tool technology was improved considerably some years ago with the advent of titanium nitride (TiN) coatings for gear cutting tools, and tool life increased dramatically, together with the ability of the tool to be used for cutting with increased speeds and

feeds. The TiN coating technique also meant that tool life could be improved irrespective of whether the machine tool on which it was used was old or new, although the best results are obviously obtained when operating under optimum conditions with up-to-date machines.

The tool life improvement of a coated tool relative to an uncoated one obviously varies with the application, but values up to five to eight times the life, with only half the tool wear per sharpening, have been experienced in many cases. What also became quickly apparent was that the very best results were obtained when the cutter was new and its cutting face was still TiN-coated. Once the cutter has been used and sharpened, the coating no longer exists on the front face of the tool, and only the coating on the flanks remains. This reduces the 5:1 advantage to the order of 2 or 3:1.

Fig.1 shows the same part produced at the same feed and speed by cutters treated in three different ways. From this example we see that the coated tools produced between two to four times the number of parts for half the amount of tool wear. The tool wear can take place on both the front cutting face and the side flanks of the tool, wear on the latter being caused primarily by interference on the relief or return stroke of the cutter and by trapping of the chips between the flanks of the tool and the gear. The wear on the front face is usually a form of cratering caused by the high loading combined with the

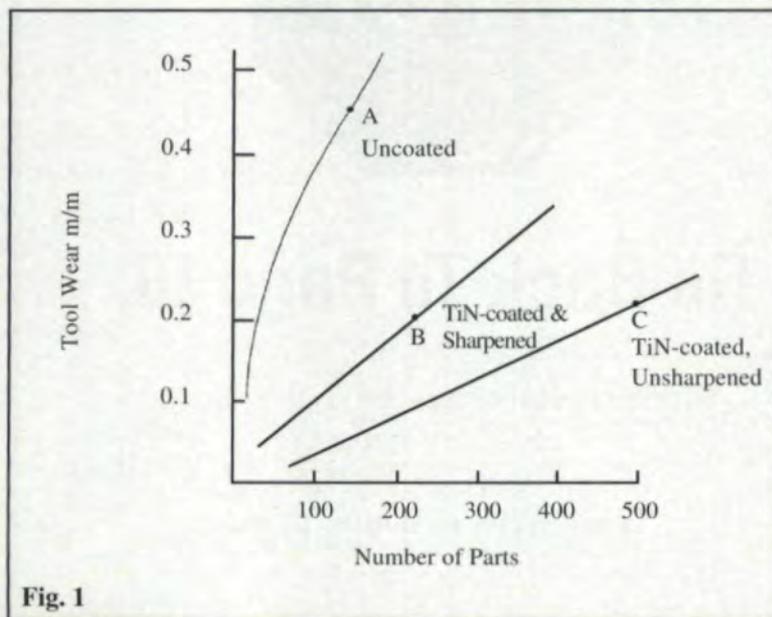


Fig. 1

high temperature of the chips produced.

This is, of course, an oversimplification, but draws attention to the two types of tool wear which occur. The high lubricity and surface hardness of the TiN coating handles both these factors very well, but once the coating is removed from the front face of the cutter, the cratering tendency returns more quickly.

Wafer Cutters

The next step in the improvements in cutting tool technology took place a few years later with the development of what is now called the wafer cutter. This technology has led to a further improvement in tool life for suitable applications.

Fig. 2 shows a typical wafer cutter assembly consisting of the wafer cutter blade itself (typically 0.025" to 0.050" thick), together with the clamp and backup ring. In the case shown, the entire assembly is mounted on an adapter as used in quick-change tooling.

The wafer is centrally mounted by means of the clamping ring and is fixed by several screws to the support ring. This ring is produced with teeth which give maximum support to the teeth of the wafer blade. The rake angle of the cutter face is formed by deflecting the blade back against the support ring, the face of which is formed with the required angle. A keyway is provided so that as each wafer blade is replaced, a tooth can be placed in the same alignment. Of course, it also resists the torque applied by the heavy cutting.

The wafer is in effect a disposable blade, which is used until the wear factor is unacceptable or the part quality deteriorates outside the acceptable limits, and then the blade is thrown away; i.e., it is not resharpened.

One of the big advantages of this technique is that the wafer is TiN-coated all over and, therefore, the optimum face is always presented to the workpiece. From the user's point of view, the most important factor is the blade quality, which is entirely the responsibility of the cutting tool supplier. It can be optimized in design and produced to the tool supplier's quality standards without the issue of loss of accuracy through poor sharpening arising. Sharpening inaccuracies are now eliminated, together with the sharpening costs.

On conventional gear shaper cutters, the cutter reduces in diameter after it is sharpened

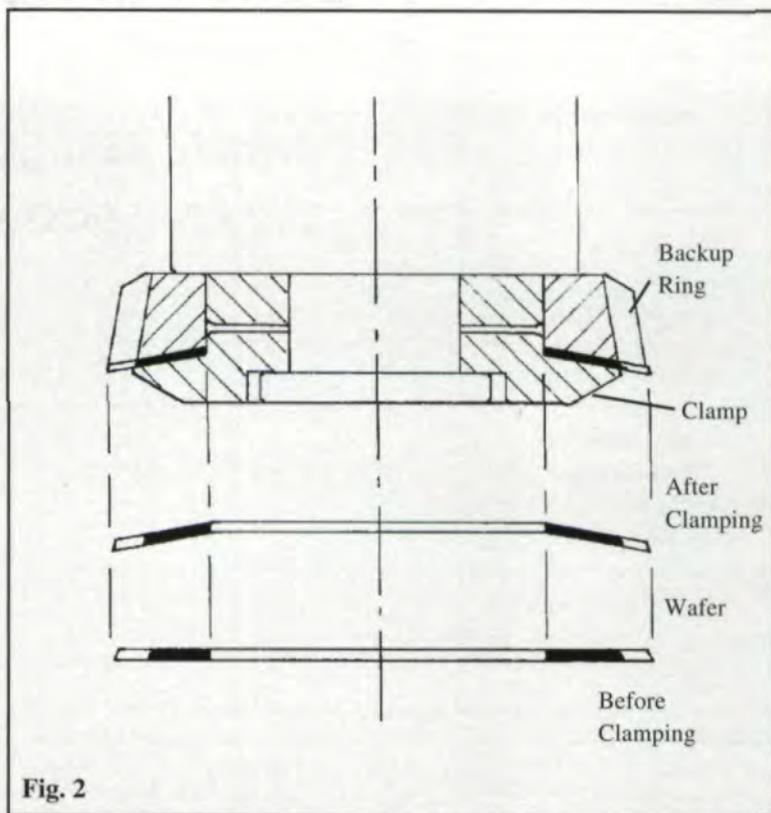


Fig. 2

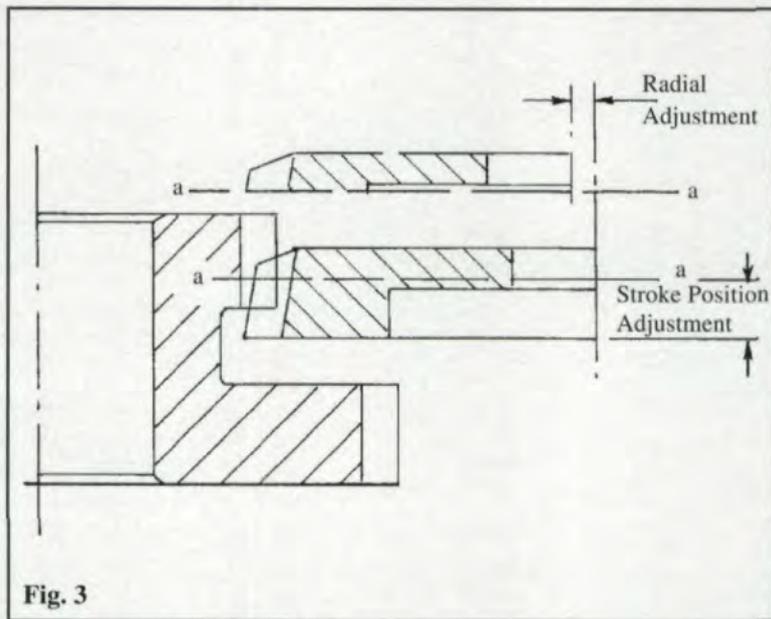


Fig. 3

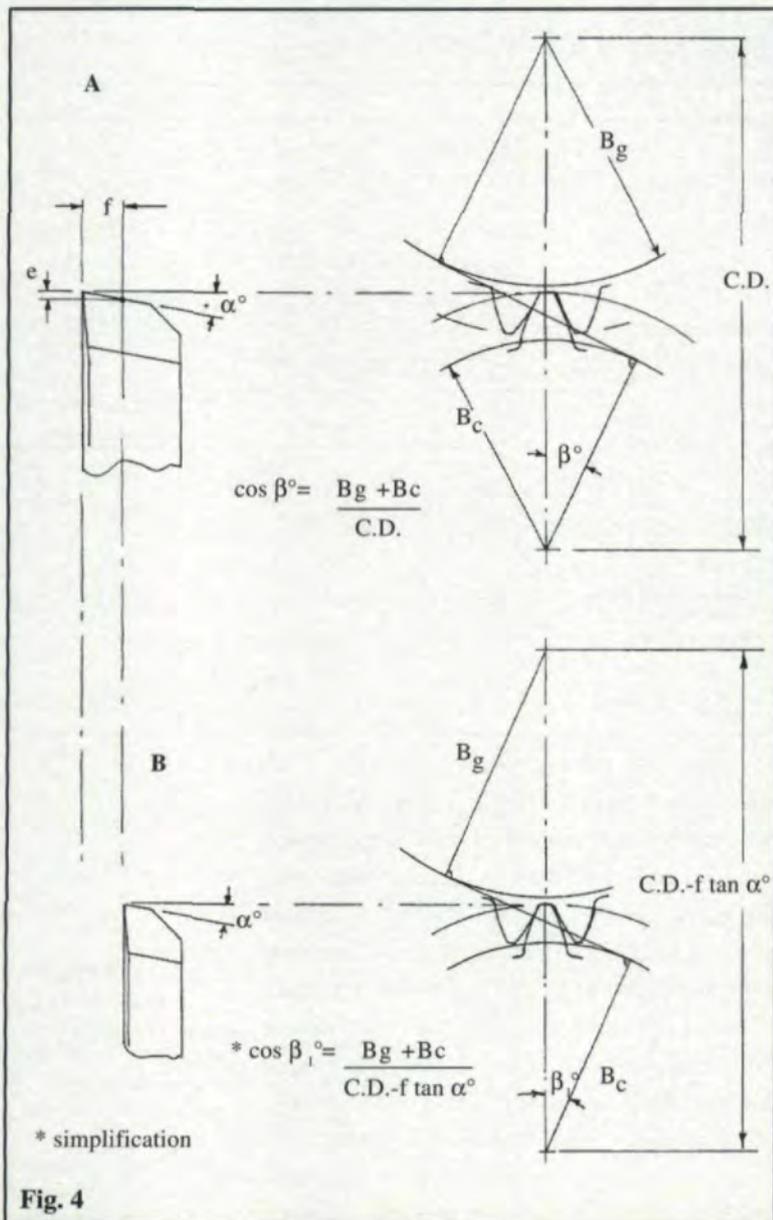
and, therefore, the machine tool has to be reset, since now it is necessary to adjust the center distance between the cutter and the workpiece and the position of the cutting edge relative to the gear face. (See Fig. 3.) The setup time on any machine is non-productive, and anything that can be done to reduce this element is worth considering. Obviously CNC facilities reduce setup time enormously, but the wafer technique can be applied to any shaping machine and show savings even if CNC is not available.

Wafer cutters are manufactured to a consistent size, therefore they can be replaced when

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Table I		
Gear Material: 20 Mo Cr 4 E 32 Teeth, 10 Face Width	Type of Cutter	
	Standard	Wafer
Module	2.116	2.116
Pressure Angle	30°	30°
Number of teeth	66	66
Cutter Material TiN-Coated	(PM) S6-5-3-8	S6-5-2
N° of Parts Produced		
Before Sharpening	1400	7000
After Sharpening	700	



worn out without changing the machine settings. A saving is thus experienced in both the time taken to change the tool and reset the machine and the time needed to qualify the part. The part size has to be requalified after a change in machine size, and this can be costly if inspection is a bottleneck. When using the wafer concept, no change in machine setting is necessary.

A typical example of the improvement in the tool life of wafer tools compared to standard type cutters is shown in Table I, where we see that when the standard coated tool was new, it achieved 1,400 parts, while after sharpening it only achieved 700 parts: whereas the wafer produced 7,000 parts, which in this instance gives an advantage of some five to 10:1.

One of the other advantages of the wafer cutter not readily obvious is the fact that it can be designed to give the optimum rake angles and cutting conditions. To understand this, it is necessary to consider the basic geometry of a standard type gear shaper cutter in both its new and worn out condition. (See Fig. 4.)

We see that when the front face of the cutter is sharpened by f , the outside diameter reduces by $2f \tan \alpha$ for each sharpening. The cutter profile is generated from a base circle, which remains constant through the life of the cutter and ensures that the cutter will always produce a true involute profile on the gear throughout the cutter's life. (See Fig. 4a.)

However, other factors must also be considered. When the cutter reduces on diameter, it has to be moved in to a closer center distance with the gear being produced in order to maintain the correct tooth thickness. (Note: The formula $2f \tan \alpha$ given is a simplification merely to illustrate the point. To find the exact center distance, it is necessary to calculate the tight meshing centers as shown in Fig 4b.) The effect of this change in center distance is to change the meshing pressure angle between the cutter and the gear, and for many applications, this is of no importance, since the cutter still produces the correct profile.

However, there are times when the tool designer requires the flexibility to design the cutter to mesh with the gear at a higher or lower pressure angle. For example, we know that the weakest point of the cutter tooth is the tip, which tends to crater under load, and we also know that the condition can be improved by

providing a full tip radius on the tool. The larger the tip radius, the better for the tool life. This tip radius can be increased by designing the tool with a lower meshing pressure angle. (See Fig. 5a.) The same thing can be done with a conventional cutter, but since the meshing pressure angle changes as the cutter is sharpened back, the tip radius is not constant throughout its life and does not fully blend with the tooth flanks all through its life.

When we consider gears which have to be shaved after generating, it is essential that the protuberance on the tip of the cutter be provided in such a way that it undercuts the gear flank at the point where the tip of the shaving tool engages the gear flank. The tool designer has to choose a meshing pressure angle that will meet this condition both when the cutter is new and when worn out. This often necessitates a compromise. (See Fig. 5b.)

The same applies to tools which have to chamfer the tips of the gear in addition to providing the undercut for shaving, since the optimum meshing pressure angle for the chamfer position will not be the same as for the undercut position. This varies again as the tool changes in diameter and, therefore, further compromises have to be made. If the tool does not change in diameter, the position is eased, and the tool designer has more choice of the optimum conditions.

One further point concerns chip flow conditions. When the chip is being generated, the flow path for the chips is continually changing, and a position can be reached where the chip rolls off the leading cutting edge, but gets trapped on the trailing edge. This is where major damage to the tool flank can occur.

Fig. 6 shows successive cutter teeth (at high feed rate for clarity), and we see that there is an opening on the trailing flank where the chip cannot flow easily. The chips flow at high speed and under high pressure, and when extruding through small openings, they can become trapped and tend to weld and smear along the cutter tooth flanks.

To obtain the largest openings the meshing pressure angle must be increased, therefore, the tool designer is faced with a number of variables, and the position is eased if the meshing conditions of the cutter do not change throughout its life. The wafer cutter meets this

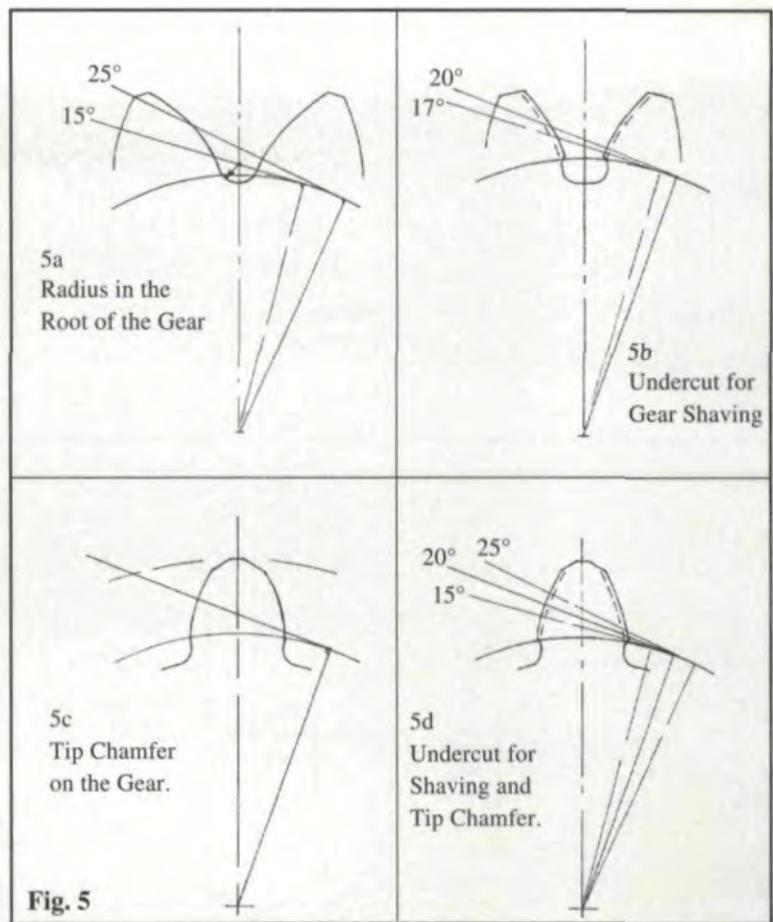


Fig. 5

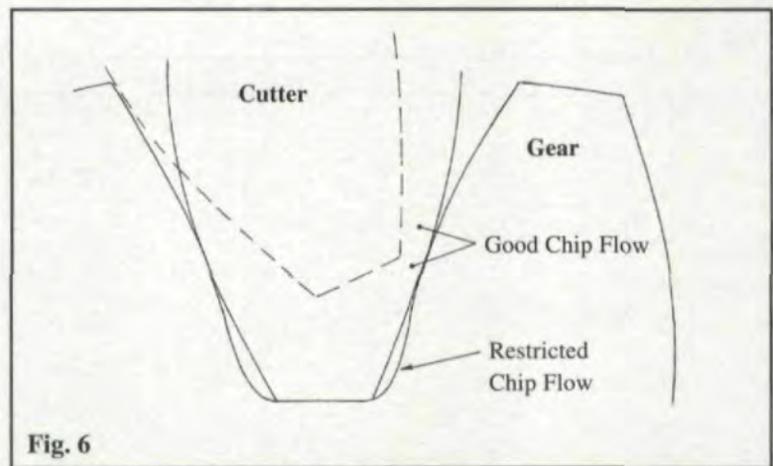


Fig. 6

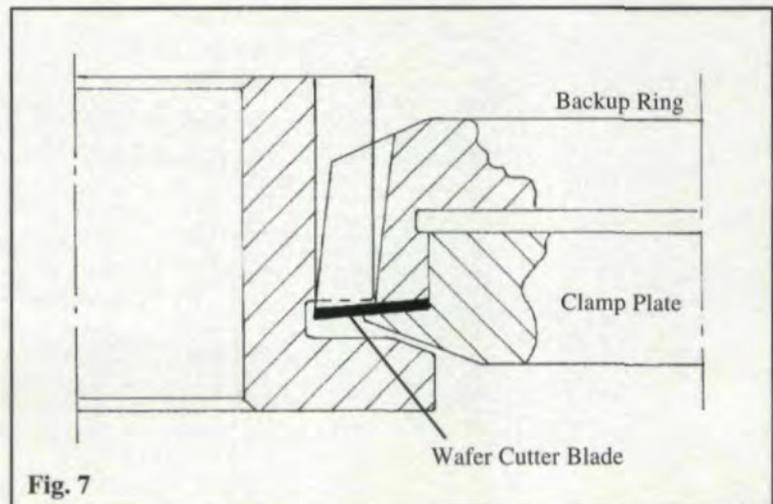


Fig. 7

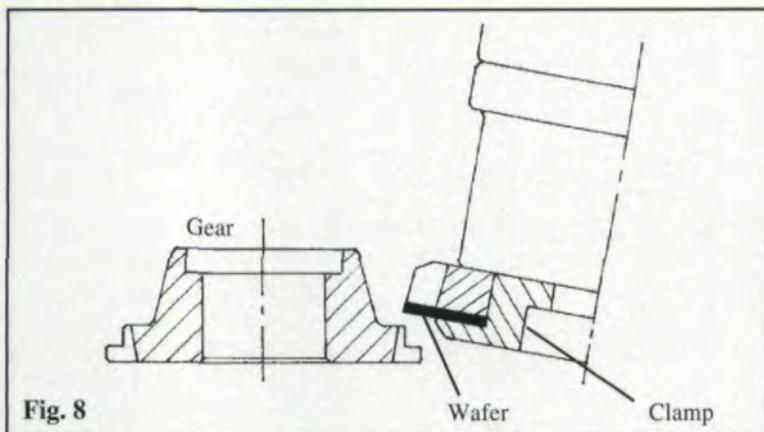


Fig. 8

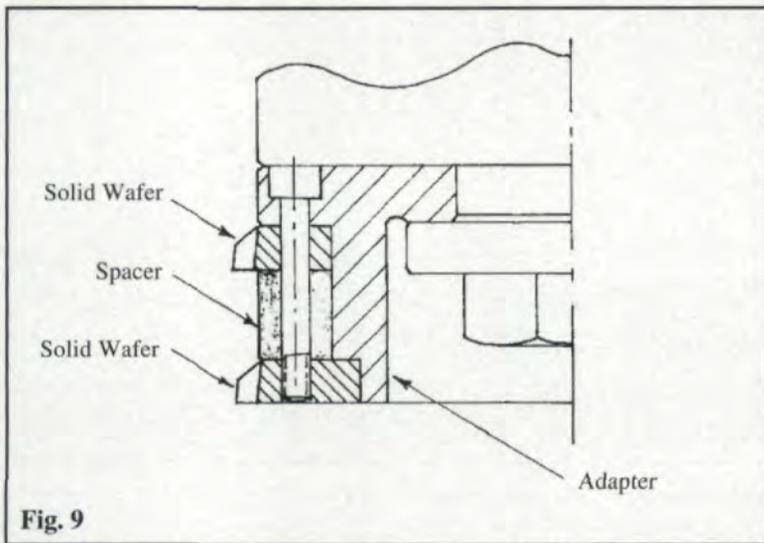


Fig. 9

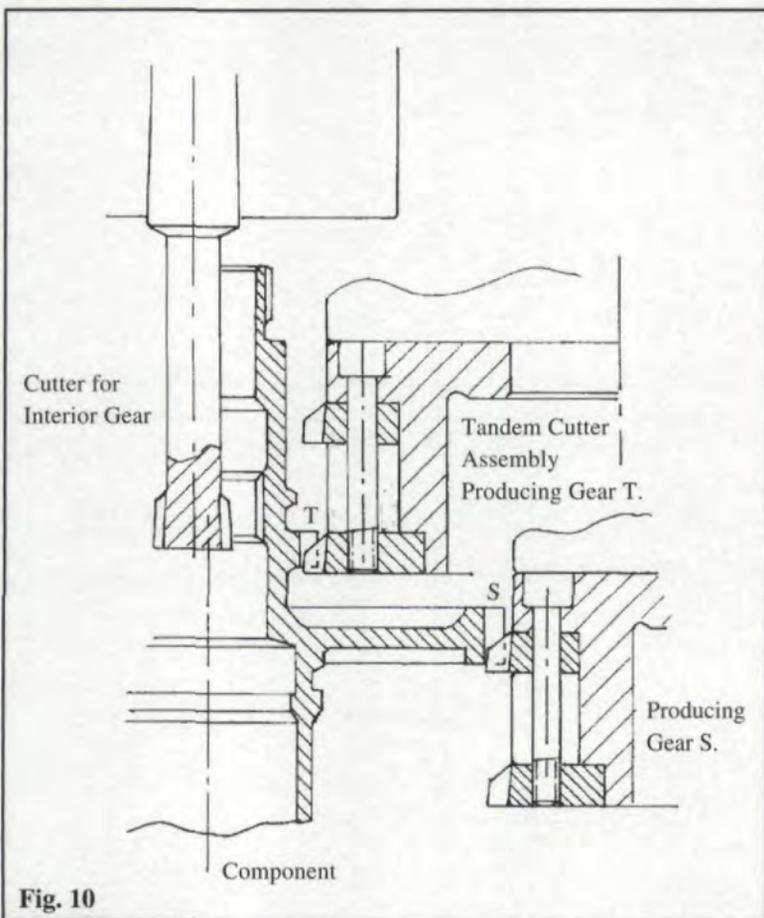


Fig. 10

condition since it is not sharpened after use.

Limitations

As with any process, the wafer technique has limitations, and these must be borne in mind when considering the application. At present, the wafer cutter is only suitable for spur gears, since it relies on the deflection of the blade to the support face to produce the rake angle, and it is not possible to achieve a helical orientation. Helical cutters can be produced to a limited degree if they are flat-faced sharpened, but this does not always offer a satisfactory solution, particularly on higher helix angles. One further point to consider is the fact that the front face of the wafer needs to be clamped, sometimes creating a fouling point as Fig. 7 illustrates.

An excellent application for the wafer cutter is the synchro-cone shown in Fig. 8, where the teeth are tapered and the axis of the work is inclined relative to the cutter. This part is produced in 26 seconds, the rotary feed being as high as 2.5 per stroke. The cutter produced some 10,500 parts in 77 hours.

Solid Wafer

The most recent development has been the solid wafer, which utilizes the same basic principle as the wafer cutter, but uses a wider blade and, consequently, does not need a front clamp plate. Fig. 9 shows a typical example where two cutters are mounted in tandem for a double cutting operation. This development enables helical gears to be produced, and the cutters may be ground with the cutting faces at right angles to the helix angle, as would be necessary for high-production cutting. This type of tool is particularly useful for multi-cutter setups where two or more cutters are used on the same adapter to perform several operations at one setup.

As with the wafer cutter, the solid wafer is not sharpened, but is used virtually to destruction, or until the workpiece is outside its acceptable limits. The blade is TiN-coated on all its faces.

Applications

Fig. 10 shows an excellent example of what can be done with a modern CNC gear shaping machine and solid type wafer cutter technology. The part in question is an aircraft gear, and the teeth T and S are produced at one clamping of the workpiece. Apart from the obvious saving in the handling time, the tech-

nique offers another advantage in that the two gears are now cut around exactly the same axis and are, therefore, concentric to each other.

The lower cutter produces the gear *T*, and the machine then automatically changes its program and resets. This can involve changing index, rotary feed, radial feed, crank speed, center distance, and stroke length if necessary.

The upper cutter now produces gear *S* to its required size, the two cutters having been measured for size prior to the start of the setup, and the data placed in the machine memory. The tools are not sharpened, but discarded when the wear factor can no longer be tolerated, and the replacement blades are clamped to the body of the adapter. Production continues with no change in machine setting.

A further example of the versatility of the solid wafer and CNC machine technology is shown in Fig. 11. The part in question is a long shaft with two gears having different numbers of teeth spaced either side of a flange or shoulder. The arrangement is such that the gears cannot be cut in the same direction. Under normal circumstances this would be a two-cutter setup job involving turning the part over and resetting the machine for up-cutting.

The wafer cutter itself is also an unusual application in that it consists of two segments, one arranged for up-cutting and the other segment for conventional down-cutting, but both segments being integral with each other on the same tool body. (See Fig. 12.)

The segment B has 70 teeth to produce the 35-tooth gear in two cuts, at which point the component will lie in the gap between the two segments. The segment A has 52 teeth to produce the 26-tooth gear in 2 cuts, but cutting in the opposite direction, the segment cutter being manufactured with cutting faces opposed to each other. The CNC machine automatically resets and changes its program so the index-stroke position and the cutting direction are changed automatically.

The two gears are produced at one clamping and are concentric to each other and give excellent control over the tooth size. The workpiece is large, heavy, and difficult to handle without mechanical aids; therefore, producing both gears in one clamping is big advantage.

Fig. 13 shows a second speed gear from an automobile gear box which has to be shaped

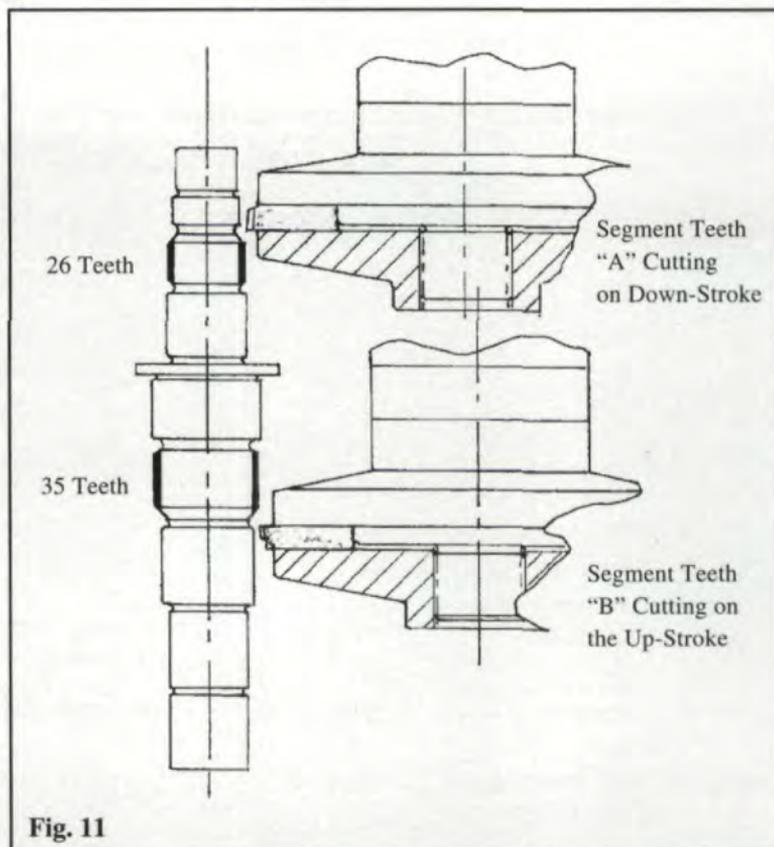


Fig. 11

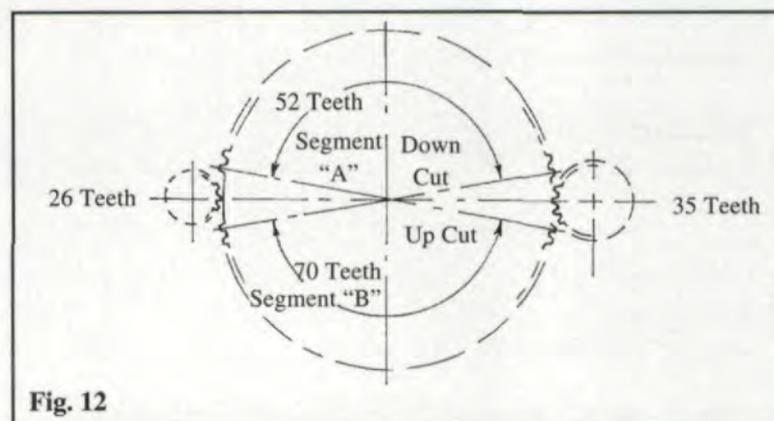


Fig. 12

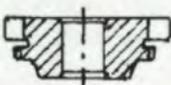
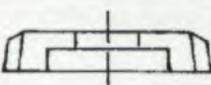
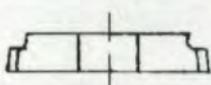
Component Data	Disc Type Cutter	Solid Wafer
 37 teeth 1-9 N. Mod 25° 30' Helix Angle 17.7 Face Width.	 TiN-coated disc after sharpening	 Solid wafer TiN-coated
Output per tool sharpening	250	2500
Number of teeth in the cutter	64	64
Useful length per tooth	2.83 mm	28.34 mm

Fig. 13

Table II - Cost Comparison

Conventional Shaper Cutter/Solid-Wafer		
	Shaper Cutter	Solid-Wafer
Module	1.9	1.9
Normal Pressure Angle	15°	15°
Number of Teeth <i>Z_o</i>	64	64
Helix Angle	25° 30'	25° 30'
Useful Width	14	—
Number of Resharpenings (Average)	32	—
Tool Price Per Unit	DM 1,600	DM 1,000
Costs Per Tool Per Sharpening	DM 50	DM 1,000
Costs Per Resharpening	DM 100	—
Wage Costs For Tool Changing	DM 15	DM 5
Total Costs Per Tool Per Sharpening	<u>DM 165</u>	<u>DM 1,005</u>
Cycle Time	1.14 min.	1.14 min.
Output (Number of Gears)	250	2,500
Tool Life Per Tool Sharpening	285 min.	2,850 min.
Time For Tool Cutting	15 min.	5 min.
Total Time per Sharpening	300 min.	2,855 min.
10 Shifts: 8 x 10h = 80 hours or 4800 minutes		
Number of Tool chucks Per 10 Shifts	<u>16</u>	<u>1.681</u>
Tool Costs Incl. Resharpening & Wage Costs For Tool Changing	<u>DM 165</u> <u>x 16</u> DM 2,640	<u>DM 1,005</u> <u>x 1.681</u> DM 1,689
Number of Gears Per 10 Shifts	4000	4202
Costs Per Unit	DM 0.66	DM 0.40

because of the adjacent shoulder formed by the sychro-teeth. It shows a comparison of results obtained by conventional and solid wafer cutters, both tools being TiN-coated. We see that the solid wafer cuts 10 times the length of tooth that a conventional cutter does.

This is further expanded in Table II, where the cost of producing the same gear by both types of cutter is compared. The example shown is currently being produced in Germany and from the figures quoted, we can see that the cost per gear is reduced by approximately one third. The time lost in tool sharpening and machine change-over time is dramatically reduced, since for the same cycle time and 80 hours of production, the standard cutter is changed 16 times, while the wafer cutter is only changed 1.681 times. The saving in downtime is therefore considerable.

Another factor which should be considered is the inventory level of the number of cutters required. The old rules of one cutter in use, one in sharpening, and one in the stores; i.e., a minimum of three, no longer need apply, since the sharpening operation is deleted. The stock level could be reduced by 30%

The application shown in Fig. 14 is a planetary gear from an automatic transmission, the data being

upper gear 1.99 Mod. 16 teeth 9.5 face width
lower gear 1.058 Mod. 31 teeth 22.0 face width

The tooth thickness for both parts is critical and the diameter over pins has to be held within 40µ (.0112") on diameter. Cutting with conventional cutters proved to be a problem, and the requirements of continuous automatic production and with continuous quality control could not be met for several reasons.

1) The pairing of the two cutters for size is done by the cutter manufacturer initially, but it must be maintained in production by the user.

2) Holding this size limitation throughout the life of the cutters places further restrictions on the choice of optimum meshing pressure angle.

3) The lower cutter does considerably more work than the upper cutter and reaches its critical wear point long before the upper cutter. This means that tool life has to be sacrificed unnecessarily on the upper cutter, since it has to be sharpened by more than the amount it is worn in order to maintain the relation-

ship between the two tools.

4) Inaccurate pairing of the cutters after sharpening in production causes lost "machine downtime" for qualifying parts.

The solid wafer solved this problem in the following manner:

The two cutters are mounted in tandem and ground to the exact size by the supplier, and since they are not to be sharpened when worn, they do not have to be requalified for size. Two lower cutters are manufactured for each upper cutter, since the rate of relative wear between the two tools is approximately 2:1. When the lower cutter is worn, then this cutter only is changed. By the time this second lower cutter is worn, the upper cutter is now also ready to be changed. All cutters are ground to a matched size by the tool supplier so that they are all readily interchangeable.

The tool life improved dramatically from 280 gears between sharpenings when using conventional tools, to 3,200 gears when using the solid wafer, approximately an 11:1 improvement. The machine now runs for approximately six working days without stopping for a tool change, and the quality of the gears produced is improved, thus the requirement of an automatic production process with continuous quality control has now been met.

Non-Involute Profiles

A further advantage of the wafer system is its ability to handle special profiles and non-involute forms. To appreciate the reason for this advantage over the conventional tool, it is necessary to consider the following:

Involute System. The advantage of this system is that the basic rack is simple and constant through the life of the tool. An involute shaper cutter will produce an involute gear of any number of teeth throughout its life.

Special Forms (Non-Involute Profiles). In this category the basic rack varies for each change of shape, change of number of teeth, and change of diameter of both workpiece and cutting tool.

Having appreciated the fact that the basic rack of the non-involute profile varies with each minor change in profile, diameter, and number of teeth, we next have to take into consideration the point made earlier in Fig. 4.

The meshing pressure angle on an involute tool changes as it is sharpened back, but the

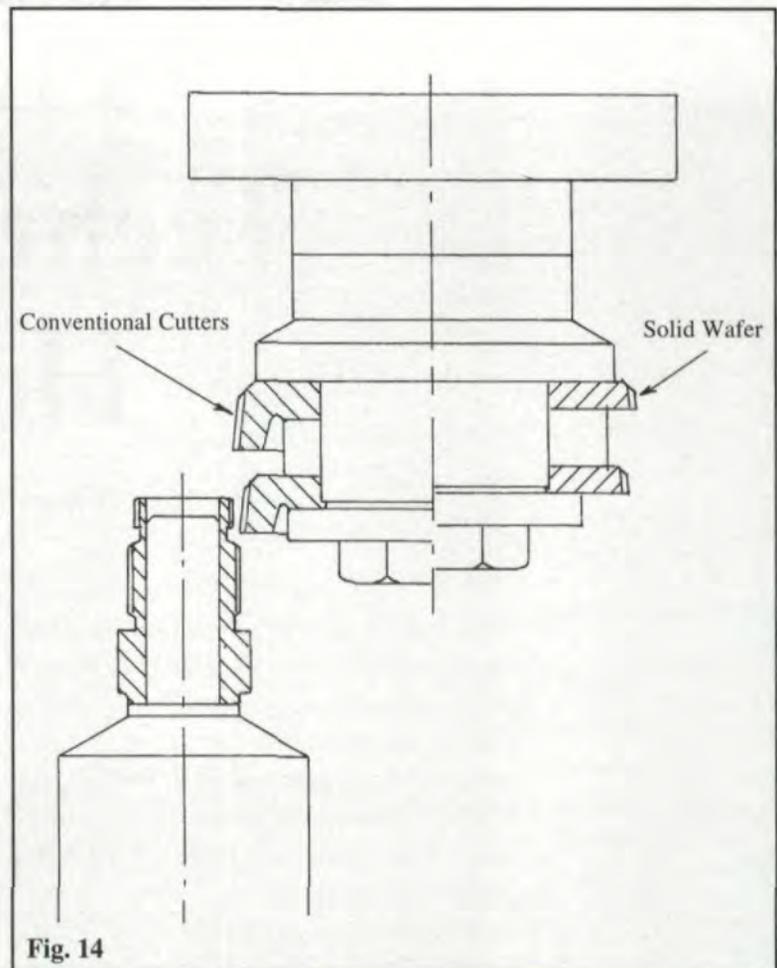


Fig. 14

basic rack remains constant; whereas with non-involute tools, the basic rack changes with the diameter of the cutter, and the profile is therefore different from the front to the back of the tool.

The tool supplier has to compromise when manufacturing conventional cutters for non-involute profiles and has to try to keep the change in the basic rack to a minimum. One way of doing this is to reduce the top rake angle of the cutter so that the change in diameter, when sharpened, is kept to a minimum, thus reducing the required change in profile shape. The wafer cutter, therefore, has the advantage that the diameter does not change because it is not sharpened, so it is only necessary to consider the basic rack at the one diameter. It is, therefore, necessary to reduce the top angle of the tool, and this allows the cutting rakes to be optimized. The quality of the profile of the cutter is also improved because it is only necessary to consider the form of the cutter at the one position. ■

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