Shaping Breakthrough: Eliminating Mechanical Guides to take time and cost out of helical gear production

Producing the desired helix angle, tooth trace modifications, and corrections due to heat treatment distortions has always been an expensive and time-consuming process for manufacturers using conventional gear shaping equipment because it involves the production of expensive mechanical guides. Gleason's new Electronic Guide (ES) shaping technology changes the paradigm.

In transmissions, gears continue to be one of the key machine elements for transferring torque and speed between the drive and the output. The requirement for reduced weight yet increased load on transmissions and the gears they contain places enormous demands on design and production.

Compared to other gear-cutting methods, shaping requires a comparatively short tool overtravel path, which provides the potential for reducing the space required for constructing transmissions by producing the gears to be shaped close to interfering shoulders / contours. Economical hobbing, on the other hand, requires among other things, a defined overtravel as a function of gear depth and hob diameter. This overtravel is several times larger than that of shaping, with the result that some gears can only be produced by the shaping method. Advanced tool designs and coatings allow long tool life and short cycle times to be achieved.

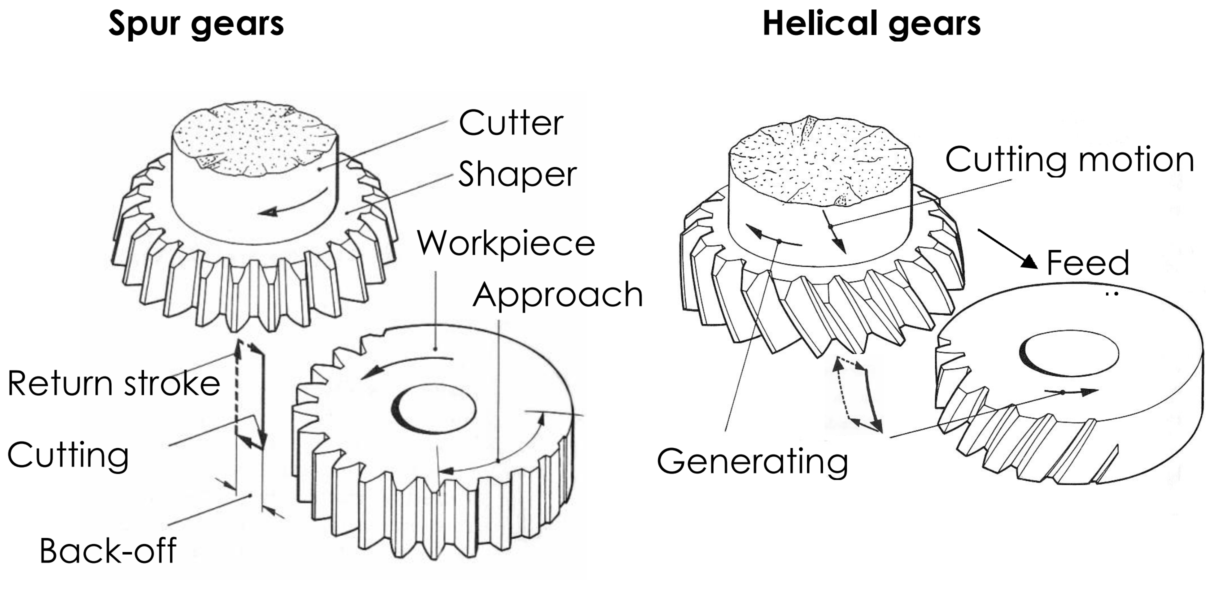


Figure 1
The principle of shaping

Shaping is a gear-generating process with a defined cutting edge. The tool and the workpiece form one transmission during shaping which rolls continuously and synchronously. During this process, radial feed is executed up to the required center distance between tool and workpiece. This rotational motion (generating the tooth profile shape) has a stroke movement (cutting motion) of the tool superimposed in the direction of the tool axis and this produces the required cutting on the flanks of the workpiece. The stroke movement is divided into the four areas: cutting stroke, backoff, return stroke and starting another cutting stroke. The cutting stroke creates a chip. Backoff increases the center distance between the gear blank and the tool to prevent the tool's cutting edge from rubbing with the workpiece on the return stroke. Return travel then brings the tool back to the current center distance for a new cutting stroke. The technical design of these four areas is affected by a cam, which is guided in the shaper head in synchronization with the stroke movement. In a mechanical shaper head, the stroke movement is created by the rotation of an eccentric driven by a CNC controlled spindle drive motor. The desired stroke length can be easily manually set or optionally CNC set.

When producing helical gears, an additional helical (twist) motion is superimposed on to the continuous generating motion of the tool. This helical motion has been traditionally produced by a mechanical helical guide. The helical guide creates the necessary addition rotational motion of the cutter spindle to generate a helix angle on the workpiece. The direction of this additional rotational motion super imposed on to the generating motion depends on the required hand of the helix angle (right or left) on the gear being shaped. The mechanical guide is constructed to reproduce the additional twisting motion of the tool based on the lead and hand of the shaper cutter. Consequently, it is pretty typical that each helical gear that requires a shaping operation needs a specific guide. There are exception of this situation when a designer understand the specifics of the gear shaping process and designs shaped gears with the possibility of having a “common lead guide”. The formal relationship shown bottom right in Figure 2 shows how the pitch diameter (d_0) of the tool with a fixed mechanical helical guide is dependent on the desired helix angle (β) of the workpiece. This creates a significant drawback, because for every helix angle, a special new helical guide is generally required which takes considerable time and expense to produce. In addition, changeover time for installation of each mechanical helical guide in the cutter spindle unit for every new and different gear takes an enormous amount of time, particularly when changing between workpieces with spur, left-hand and right-hand helical teeth.

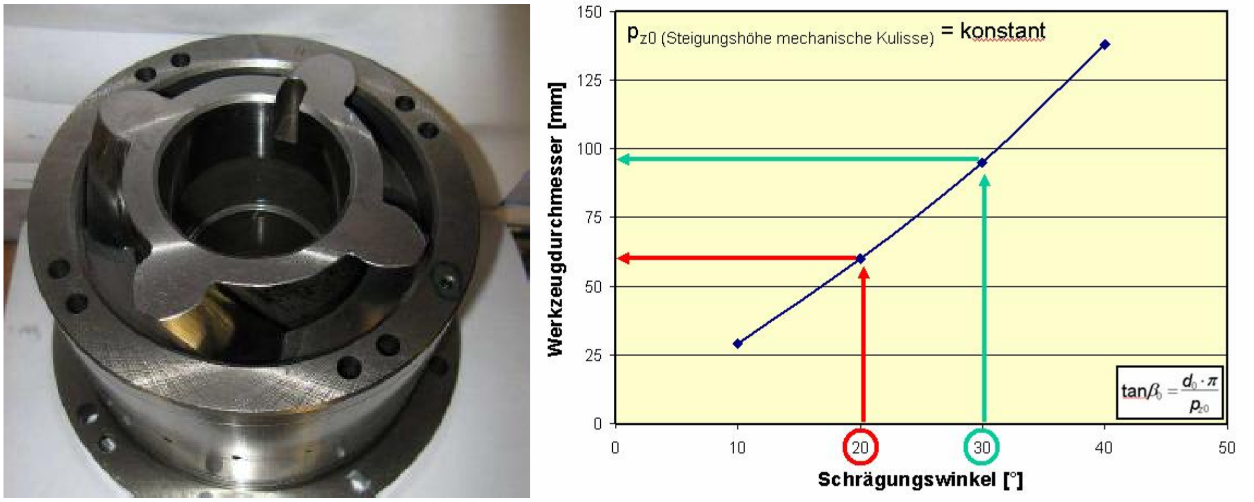


Figure 2
Left: mechanical helical guide for a helical gear
Right: example of the dependency of tool diameter on helix angle in a helical guide

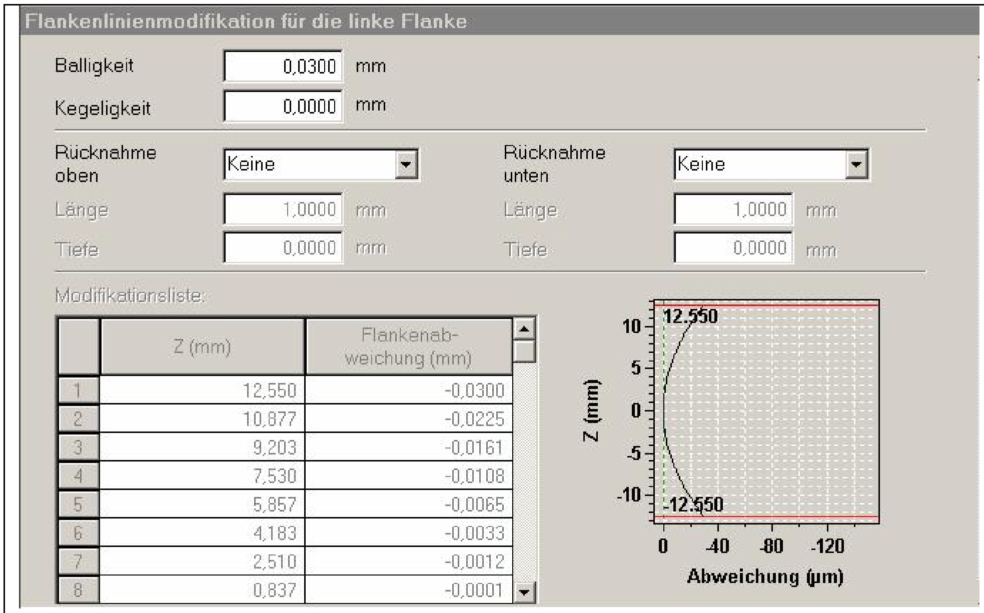
Shown on the left of Figure 2 is an example of a helical guide for a helical gear, whereas the right of the figure shows the strong influence of tool diameter related to the helix angle which results with a special helical guide. Once the tool has been specified and there is a fixed helical guide, it is also impossible to make any further changes, such as corrections due to heat treatment distortions when a part material or heat treat process is changed. This enormously restricts the flexibility of production and proportionally increasing the cost and time frame for the production of the different helical gear designs.

Then consider the action of forces on the gears when installed. Elastic deformation can have a significant and extremely detrimental effect on tip and edge contact. This can result in contact conditions deteriorating considerably, as well as causing increased wear and unacceptable noise in operation. To counteract these conditions, the gear designer uses convex designs of tooth trace, called crowning. Producing this correction requires a special radial change in center distance between the workpiece and tool over the facewidth of the gear. This radial displacement of the tool is effected by a special back-off cam. The special feature of this is that the profile of the backoff cam is altered so that the tool completes a slight change in center distance during the cutting stroke to create lead crowning on the gear. The drawback is that the amount of crowning depends on the cam and that other cams are required in the event of a change or switch between internal and external gears. This again increases costs and machine changeovers to meet the production of different gears requiring lead crows and special part specific crown cams.

To counteract the many drawbacks of a restricted helix angle and of inflexible lead crown modifications, Gleason has developed new technology that replaces the mechanical helical guide with high-performance, high torque servomotors, the latest NC controls, and proprietary software. This new ‘electronic’ helical guide combines a backlash-free generating drive of the tool with all the additional rotational movements of the tool, thus enormously increasing the efficiency of this new family of Gleason shaping machines (designated ES). Whereas previously with a mechanical helical guide the path of contact for the helical gear in question was mechanically specified by the helical guide, in the new design, the desired angle can be entered in the software dialog program on a flexible basis. This means that even small corrections to the helix angle, resulting from changing lead corrections due to heat treatment distortions are easily changed without the need to change the shaper cutter or helical guide. In addition, users have the option of producing several gears of differing helix angle and helix hand in one set-up.

A further benefit of the electronic helical guide is the ability to create lead crown corrections without the need of a special backoff cam. On the Gleason ES machines, a lead crown correction is a simple line input value in the CNC dialog program.

The lead crown is no longer developed by a radial change to the center distance between the tool and the workpiece, but by an additional variable rotation of the tool along the cutting tool stroke. However, this can only occur in a single-flank shaping process. This means that first the left-hand flanks and then the right-hand flanks are shaper cut. A further benefit of flexible modification can be considered to be that the root diameter of the workpiece is unaffected by the crowning process. In theory not changing, reducing the root diameter could produce a stronger tooth. With single-flank machining, therefore, the flexibility of the software-aided input means that it is possible to shape a taper lead and / or a lead end relief. Another possibility is to make entries using a table which allows every desired form of tooth trace (cf. Figure 3). A graphic visualization of the intended modifications is displayed for easy confirmation of the desired lead correction.



Flankenlinienmodifikation für die linke Flanke

Balligkeit 0,0300 mm

Kegeligkeit 0,0000 mm

Rücknahme oben Keine

Länge 1,0000 mm

Tiefe 0,0000 mm

Rücknahme unten Keine

Länge 1,0000 mm

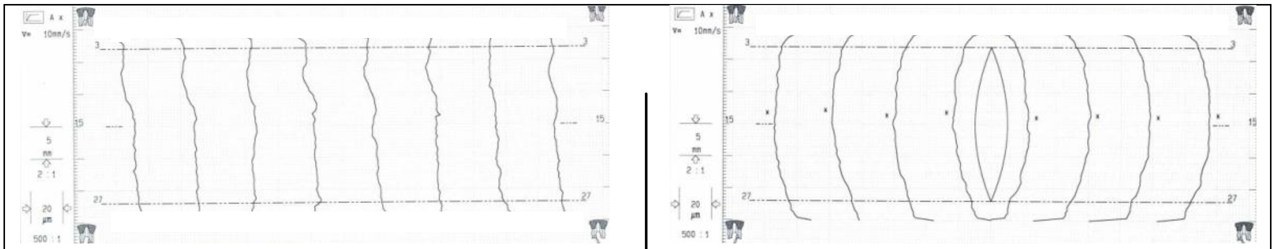
Tiefe 0,0000 mm

Modifikationsliste:

	Z (mm)	Flankenabweichung (mm)
1	12,550	-0,0300
2	10,877	-0,0225
3	9,203	-0,0161
4	7,530	-0,0108
5	5,857	-0,0065
6	4,183	-0,0033
7	2,510	-0,0012
8	0,837	-0,0001

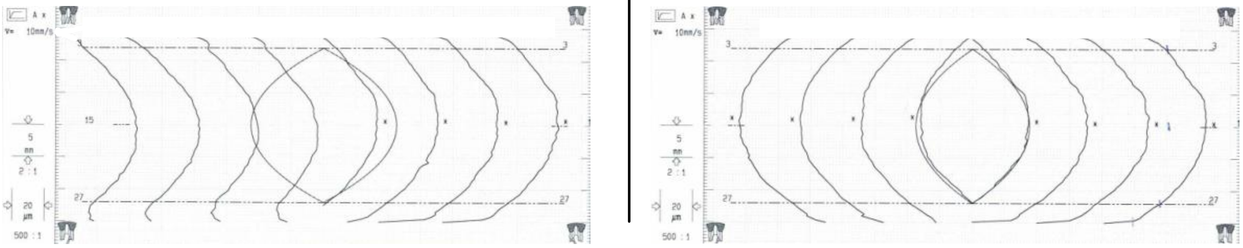
Figure 3
Dialog input for tooth trace modification (in this case: 30 µm crowning on left-hand flank)

Figure 4 shows some gear measuring results of the tooth traces of a test workpiece, produced consecutively using a shaping machine with electronic helical guide, without mechanical changes having to be made to the machine. Gear inspection charts generally represent the measuring of four teeth 90 degrees apart from each other. A straight vertical line means that no angular or form deviations were measured on a single tooth. An inclination of the straight line generally detects an angular deviation. Any other kind of deviation from a straight line reflects a combination of angular and form errors. Figure 4 illustrates diagrams of test workpieces with each differing in terms of tooth trace modification. No lead modification was selected in the top left example. The left-hand and right-hand flanks of the workpiece at top right were produced with convex crown of 0.015 mm. The diagram at the bottom right of the figure shows a crown amount of 0.030 mm. The workpiece bottom left has been shaped by differently-oriented crowning steps, something that is impossible on a conventional machine with a mechanical helical guide.



no modification

both flanks with 15 µm crowning



left flank with concave crowning
right flank with convex crowning

both flanks with 30 µm crowning

Figure 4
Different tooth trace modifications using electronic helical guide on a workpiece type with 2 mm module and 64 teeth

Substituting the mechanical helical guide with an electronic helical guide means that, overall, the latest-generation Gleason ES shaping machines can provide additional functions compared to the conventional mechanical helical guide, which are of significant interest in both job-shop and large-scale production. Using the electronic helical guide's capability of making lead modifications it is possible to create different lead modifications on the left flank from the right flank, i.e. independent of each other. These benefits can be used flexibly without incurring additional tooling costs such as special cams and helical guides and at the same time increasing the machine's up-time. It also enables users to respond quickly to a production requirement not having to wait months for expensive (in access of $15,000) helical guides and special lead crown capable backoff cams costing thousands of dollars!