Peripheral cutter heads are utilized to machine bevel and cylindrical gears and basic milling operations on universal mills or five-axis machines. However, in the new cutter system discussed below, all other surfaces can be made with open tolerances.

INTRODUCTION

Peripheral cutter heads are used for the machining of cylindrical and bevel gears as well as for general milling operations on universal mills or five-axis machines. Most peripheral milling cutters are solid cutters, consisting of one piece of mostly high-speed steel. Other peripheral cutter designs utilize carbide inserts, which are mounted or brazed into pockets on one or both sides along the outside diameter disk shaped cutter. The base material in carbide inserts is case-hardened steel. Carbide inserts mounted or brazed onto the outer circumferential surface are also a commonly used design.

If a milling action has to happen on the sides of a disk shaped cutting tool, the depth-of-cut can depend on the radial length of the cutting edges. Since standard carbide inserts are only available with a cutting edge length of mostly less than 20mm, it is common in such cutters to stagger two or more inserts radially with a certain overlap to allow cutting depths deeper than 20mm. If a large cutting depth is required without the need of a chip width that matches the cutting depth, it is possible to work the way into a recess, notch, or tooth slot in several passes if the cutter profile behind the cutting edges has a low profile and clears the already-machined surface.

In order to provide deep cuts with long cutting edges, it is also possible to utilize stick blades, which are radially oriented. Figure 1 shows an example of a peripheral cutter head for the manufacture of Coniflex straight bevel gears. Depending on the stick out of the blade tips versus the outer diameter of the cutter disk, and the angle of the cutting edges versus the axis of rotation, it is possible to achieve cutting edges which are 50mm and longer, considering readily available carbide stick dimensions.

Stick blades can be re-sharpened, depending on their length, anywhere between 30 and 150 times. This, combined with the fact that the profile grinding can realize individually customized blade angles, makes the stick blade system principally very attractive for the use in peripheral cutters. However, the application of stick blades was prohibited in the past because the sticks had to be clamped firmly at two or more sides. Blade clamping commonly requires rigid surroundings of the blade slot, with provisions for clamping the stick using a clamp block and a clamp screw. Rigid surroundings, clamp block, and clamp screw in a peripheral cutter require space in direction of the cutter axis. Prior designs of peripheral stick blade cutters show an abrupt width increase behind the end of the cutting edge toward the cutter center. Cutting depths larger than the length of the cutting edge (notches, recesses or gear teeth) can therefore not be realized with today's peripheral stick blade cutters. The problem of the front hub is displayed in Figure 2.

ELIMINATING CUTTING DEPTH LIMITATIONS

The Pentac®SlimLine development relates to a low profile peripheral cutter with stick blades. In order to avoid large wall thicknesses required to accommodate individual clamp blocks and clamp screws for each stick blade, a flex disk is utilized in order to clamp all blades with one or several clamp screws at or around the center of the cutter disk. In order to accommodate the individual size
variations within the tolerances of real stick blades as well as tolerances in the cutter seating surfaces, the flex disk is slotted between each blade seat in order to provide a blade-clamping web, which acts like a deflection beam. Figure 3 shows a three-dimensional CAD model of the system.

Each web covers one particular stick blade at the opposite side of the blade seating surface. The center hub of the flex disk has a length, such that it doesn’t contact the locating surface on the cutter head body if the disk is placed in position to hold the blades. The screws, which are positioned in the hub wall, have to be torqued such that the initial gap $\Delta h$ between the face of the hub and the locating face on the cutter body is reduced to zero (see Figure 4). $\Delta h$ consists of two components $\Delta h_1$ and $\Delta h_2$.

Each web has two contacting pads, which have the function of a clamp block in a conventional stick blade cutter head. The contacting pad closer to the cutting edge of the stick blade has an initial contact, when the flex disk is placed in its position. At this stage of cutter building, the second contacting pad (closer to the end of the blade which is opposite to the cutting edge) has a gap to the blade clamping surface of $\Delta d$. While the hub screws are torqued, the gap $\Delta d$ will be closed, while the gap between the lower hub face and the locating surface reduces from $\Delta h$ to $\Delta h-\Delta h_1 = \Delta h_2$. The flex disk is manufactured from a linear elastic material such as through hardened spring steel. The gap reduction $\Delta d$ is calculated such that the contacting force of the upper pad builds up to a predetermined amount (e.g. 9000N). The continuation of the hub screw torquing will entirely close the gap $\Delta h_2$ between the lower hub face and the locating face on the cutter body. $\Delta h_2$ is calculated such that the linear elastic characteristic of the flex disk material will build up an additional clamping force (e.g. 4500N). The second part of the blade clamping action might influence the clamping force of the upper pad to a small extend (e.g. lower it), which can be compensated in the initial gap calculation of $\Delta d$. The hub screws in the flex disk have to be torqued together in a sequence e.g. applying a cross pattern. While the torquing sequence is applied, the gap $\Delta h$ is closed in one step, without regard to the first and second clamping force on the upper and lower pad.

It is possible to place the blades in their slots (contacting the seating surfaces). Position the flex disk in its place with the clamp screw holes lined up with the corresponding tapped holes in the cutter body, and only rotate the screws to a hand-tightened fit first. In this condition, it is possible to slide the blade sticks axially to a

![Figure 3. Low profile cutter](image_url)
pre-determined position and assure that the tips of all blades have the same distance to the cutter center. After this axial location of the stick blades, the hub screws can be torqued to a specified torque. This will close the gap $\Delta h$ and secure the clamp screws from loosening during the use of the cutter in a cutting operation.

Even if the described cutter-building sequence is performed very carefully, the stick blades will have the tendency to shift in axial direction by small amounts. The result is a so-called radial cutter runout or tip runout. A last step in cutter building is therefore the cutter truing. After the radial blade tip locations are measured, the blades have to be moved axially by small amounts to a corrected position, which is called truing. In conventional peripheral stick blade cutters, each blade is secured with one or two clamp screws. This gives the ability to un-torque a single clamp screw and slide an individual blade in its corrected position, without influencing any of the other blades. The radial repositioning of a single blade without influencing the secure clamping of any of the other blades clamped by the flex disk is not possible by loosening one or more of the flex disk hub screws. If one hub screw is loosened, none of the blades will be freed up and allow axial movement. If several adjacent hub screws are loosened, several blades might be freed up and even undergo some small movements only by the relaxing of the clamping pads. The newly developed method reverses the conventional way of freeing up one single blade by loosening the one or two clamp screws of the particular blade. The un-clamp principle utilizes jack screws from the back of the cutter body, each of which is oriented on the side of a blade opposite to the clamping web, where the clamping web is wider than the stick blade and provides enough surface area for a firm and defined contact between the tip of the jack screw and the web (see Figure 5). In order to move an individual blade axially small or large amounts (even to replace it with a different blade) the jack screw is torqued from the back just enough to loosen the particular blade. Then the blade can be freely moved to the desired position and the jack screw is

**Figure 4. Two point clamping principal**

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released, which will clamp the particular blade securely in the desired position.

The cutter body design, in combination with the flex disk and un-clamp principle, solves the problem of creating a slim line peripheral cutter head, which has clearance behind the extension of the cutting edges, towards the center of the cutter head. The SlimLine cutter might be equipped with one kind of blades (cutting edges only on the top side or the bottom side of the cutter) or with an alternate blade arrangement (one blade with cutting edge on the top side, the following blade with cutting edge on the bottom side and so on). In case of alternate blades, it is important that the cutting edge tangents, extended towards the center of the cutter, clears the cutter body (at the back or bottom side) and the flex disk (at the top of front side) in order to allow for the milling notches or slots, which are deeper than the length of the cutting edges.

**APPLICATION RESULTS**

If SlimLine cutters are used for power skiving of internal ring gears, the main forces from removing chips on the blades are directed in the axial direction of the cutter disk. The prismatic seating surfaces against which the stick blades are pressed by the clamping force from the flex disk are adjacent to the cutting force. Micro movements during the cutting process are prevented due to this positive seating arrangement. The blade seating accuracy is high because of the long blade contacting area in the precision ground prismatic surfaces. The long seating contact will average out small inaccuracies that might be present in the blades sticks. If the average contact between the blade and the cutter seating surface is about 60%, then the cutting dynamic and the deflection from the blade and the cutter will initiate a certain alteration of the contacting percentage and also cause microscopically small changes in the contacting areas. This specific dynamic behavior generates a desirable dampening between the blade sticks and the cutter body. High seating stiffness in connection with a slim and elastic cutter disk presents the risk of cutter chatter. The combination of a SlimLine cutter design with the application of the Pentac blade seating principle presents the combination of high-seating stiffness with dampening against cutting chatter. Figure 6 shows to the left the power skiving cutting results of an internal ring gear with a conventional stick blade cutter with front hub and individual clamp blocks. The ripple along the flank lead is not the result from a classical chatter, which would be a vibration with a resonance frequency. It merely is the reaction of the blades and the cutter body to the pulsing cutting forces with a proportional deflection. The right side lead charts in Figure 6 are typical cutting results obtained with the new cutter system.

Smooth power-skived surfaces, like the once represented by the right side chart in Figure 6 are typical cutting results obtained with the new cutter system.

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**Figure 5. Cross-sectional view of low profile cutter**

**Figure 6: Cutting results: Left, conventional cutter, right, SlimLine cutter**

**Figure 7a. Ten slot Pentac®SlimLine for Power Skiving, front view and close up**

**Figure 7b. Ten slot Pentac®SlimLine for Power Skiving, front view and close up**

**Figure 8. Twenty slot Pentac®SlimLine cutter for Power Skiving**

**Figure 9. Twenty slot Pentac®SlimLine cutter for Straight bevel gear cutting**

**Figure 10. Twenty slot Pentac®SlimLine cutter for straight bevel gear cutting**
An interesting application of the SlimLine cutter system in the world of angular gear transmissions is the cutting of face gears. The new face gear cutting process “Coniface” also requires a peripheral cutting tool similar to the machining of straight bevel gears. The involute profile of the face gear blades and the high cutter inclination towards the flat front of the face gears at the beginning of the generating process often caused interferences between the front hub of the cutter head and the face of the parts. The slim silhouette at the front of the new cutter system allows inclinations between cutter and work, which are even above the capabilities of bevel gear cutting machines. SlimLine cutters applied to the manufacture of face gears gives the ability to possibly use a pure generating process for the slot rolling and even allows to freely apply top relief sections, which, in the past had been limited by the risk of interferences between the cutter and the front face of the part.

**UNIVERSAL USE AND EASE OF MANUFACTURING**

A serious question during the design phases of the new cutter system was how to mount this new disk cutter to the manufacturing machine. All prototype designs used the Gleason cutter spindle taper identical to the backside of all face cutter heads used for bevel and hypoid gear cutting. When the first SlimLine cutters were to be used on a cylindrical cutting machine platform, the connecting features typical for shaping machines had been designed on the backside of several SlimLine cutters. Designers and process engineers avoided the risk of a stiffness reduction as well as the run-out potential, which is the common side effect of tool component staggering. The SlimLine cutter in Figure 9 features a flat seating surface with a short tapered bore for precise centering and stiff connection to an adaptor. The adaptor can be exchanged to bolt the SlimLine cutter to a bevel gear-machine-cutting spindle or to a dedicated cylindrical gear Power Skiving machine. The distance to the machine spindle face and the diameter can be freely accommodated by selecting a specific adaptor out of a universal adaptor set.

In contrast to well thought-out functional elements of the SlimLine cutter system it is a remarkable fact, that only the connecting surfaces of the cutter to the machine tool and the two prismatic seating surfaces have to be machined with high precision. All other surfaces can be manufactured with open tolerances because they don’t have any influence to the functionality of this new cutter system.

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