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Power Skiving of Cylindrical Gears on Different Machine Platforms

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[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

Abstract

Skiving is a cutting process which was first patented in 1910 [1] as an efficient process to manufacture internal ring gears. Like honing, Power Skiving uses the relative sliding motion between two “cylindrical gears” whose axes are inclined. The skiving cutter looks like a shaping cutter with a helix angle for example, 20° different than the helix angle of the cylindrical gear to be machined.

The skiving process is multiple times faster than shaping and more flexible than broaching, due to the continuous chip removal in skiving, but it presents a challenge to machines and tools. While the roll motion between the cutting edge and the gear slots occurs with the spindle RPM, the relative axial cutting motion is only about one third of the circumferential speed of the cutter. The cutting components of rolling and cutting which result in a “spiral peeling” are represented with the process designation skiving.

Because of the relatively low dynamic stiffness in the gear trains of mechanical machines as well as the fast wear of uncoated cutters, skiving of cylindrical gears never achieved a breakthrough against shaping or hobbing until recently. The latest machine tools with direct drive train and stiff electronic gear boxes present an optimal basis for the skiving process. Complex tool geometry and the latest coating technology were required to give the soft skiving of cylindrical gears a breakthrough. Gleason has developed a line of dedicated power skiving machines, which apply solid HSS cutters for small to medium modules.

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The Power Skiving machine setup definitions

The geometric setup of a skiving cutter relative to an internal ring gear is shown in Figure 1. The front view of the generating gear system is shown in the upper left graphic. The ring gear is oriented in the main coordinate system with its axis of rotation collinear to the Y_4 -axis. The cutter center (origin of R_w) is positioned out of the center of Y_4 in the X_4 - Z_4 plane by a radial distance vector Ex . The pitch circles of the cutter and the ring gear contact tangentially at the lowest point of the pitch circle. The top view, which shows the tool inclination angle or shaft angle Σ , is drawn below the front view. In case of a spur gear the stroke motion is directed in line with the Y -axis. The relative velocity required as cutting motion is generated with a shaft angle Σ around the X_4 -axis of the coordinate system shown in Figure 1. In case of a helical gear, the cutter inclination can be chosen independently from the helix angle. However, a helix angle of 20° or larger offers the possibility to be matched with the shaft angle Σ and use a simplified spur gear style shaper cutter for the skiving operation. Also in this case, the stroke motion is oriented in Y direction but an incremental rotation ω_2 , which depends on the stroke feed has to be added to ω_1 . The shaft angle Σ can also be defined differently than the helix angle and it will still require the same incremental ω_2 , but the tool front face orientation and side relief angles have to be calculated from the difference between helix angle and the shaft angle Σ . The side view to the right in Figure 1 shows a second possible tool inclination which is called the tilt angle. This tool tilt angle can be used to increase the effective relief angles between the blades and the slots, and it can also be utilized to eliminate interferences between the back side of a long spur gear style shaper cutter with minimum relief angles (see section "skiving tools"). Within limits, it is also possible to utilize the tilt angle for pressure angle corrections.

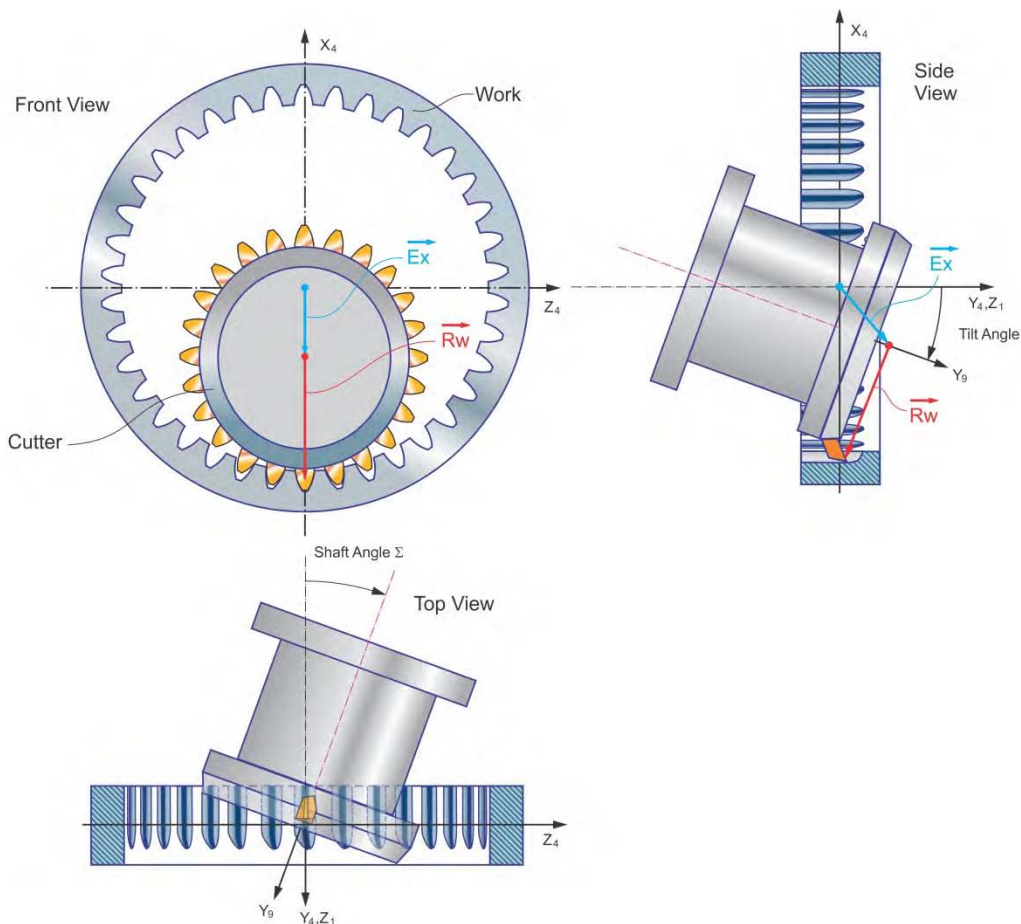


Figure 1. Basic geometry and kinematic of Power Skiving

The three dimensional side view in Figure 2 shows an internal helical gear with a shaft angle Σ between work and tool. The graphic shows the base angular velocities of the work ω_1 and the formula for its calculation. Figure 2 also includes the incremental angular velocity ω_2 and the formula to calculate it from the helix angle and the axial feed motion (stroke motion). The cutting velocity is calculated as the difference vector between the circumferential velocity vectors of work and tool in the cutting zone. Figure 3 shows a top view of the configuration between tool and work with the velocity vectors.

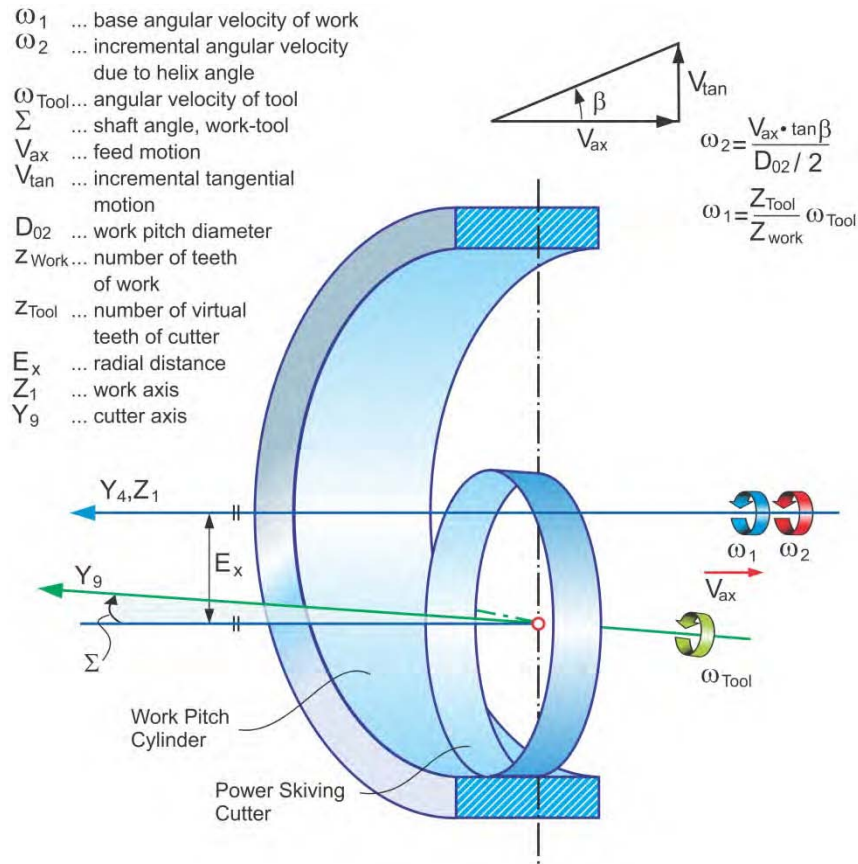


Figure 2. Pitch cylinders of work and tool

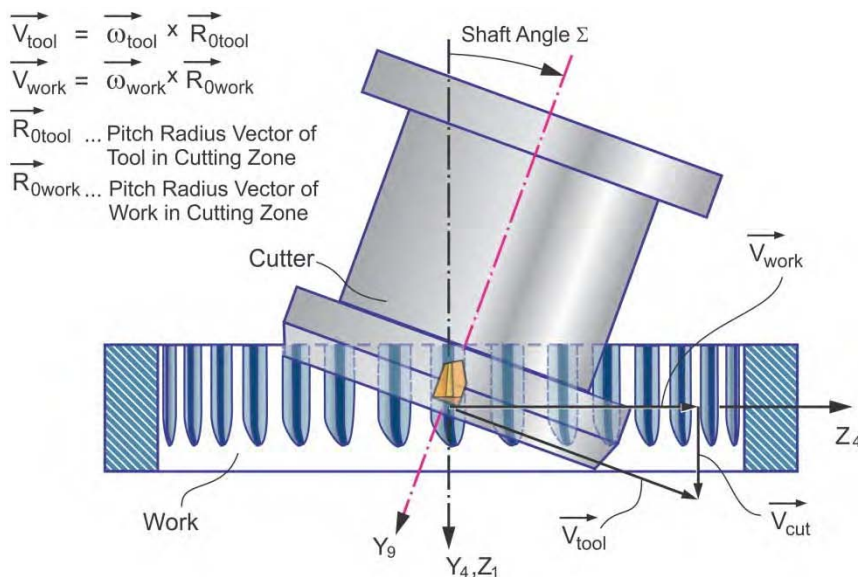


Figure 3. Calculation of cutting velocity

The reference profile of the tool is determined from the reference profile of the work applying the procedure shown in Figure 4. The reference profile of the work with pressure angles α_1 and α_2 and point width W_p is drawn as a trapezoidal channel, and it is cut with a plane under the shaft angle Σ (Figure 4, top, right side). The profile is defined by the intersecting lines between the plane and channel, and it represents the reference profile of the tool. This tool reference profile is used in order to generate the involute in the tool cutting front (Figure 4, bottom right side).

The machine setting calculation is shown in Figure 5 (top) on the example of a bevel gear cutting machine. The explanation of the formula symbols are:

X, Y, Z	Machine axis directions (Y is perpendicular to the drawing plane)
Σ	Shaft angle between cutter and work
CRT	Cutter reference height
B	Cutter swing angle
P_z	Pivot distance to spindle front in Z-direction if $B = 0^\circ$
P_x	Pivot distance to spindle center line in X-direction if $B = 0^\circ$
Z_1, Z_2	Components in Z-direction

Depending on the helix directions in work and cutter, the cutting takes place below or above the work gear center line in order to keep the B-axis angle below 90° . In case of no corrections, the crossing point between the cutter axis and the work axis lies in the cutter reference plane. The bottom section of Figure 5 shows the cutting blade definitions as reference.

Chip formation and optimization of chip load

Although the chip formation process of skiving appears different when compared to traditional gear cutting operations, understanding it a fundamental task in recognizing weaknesses or strength of the skiving process. Power Skiving has been called a combination of “cold forming” and cutting... Is not every metal removing process such a combination? The task of a successful process is an economical combination of speed, part quality, tool life (tool cost per part), and of course the investment in the machine tool.

The plane in Figure 6 which shows a segment of an internal ring gear to be skived, and it is defined along the face width at the point where the last generating occurs. The second cutting tooth from the left has just entered into a part of the slot which is already rolled out from the previous cutting action. The third cutting tooth is advanced towards the observer and just begins a generating cut (see top view of unrolled partial slots). The generating cut continues to cut tooth number six. The lowest scallop in the top view was generated between the second and sixth cutting blade position. Cutting blades seven and eight finish the form cut end section of the slot.

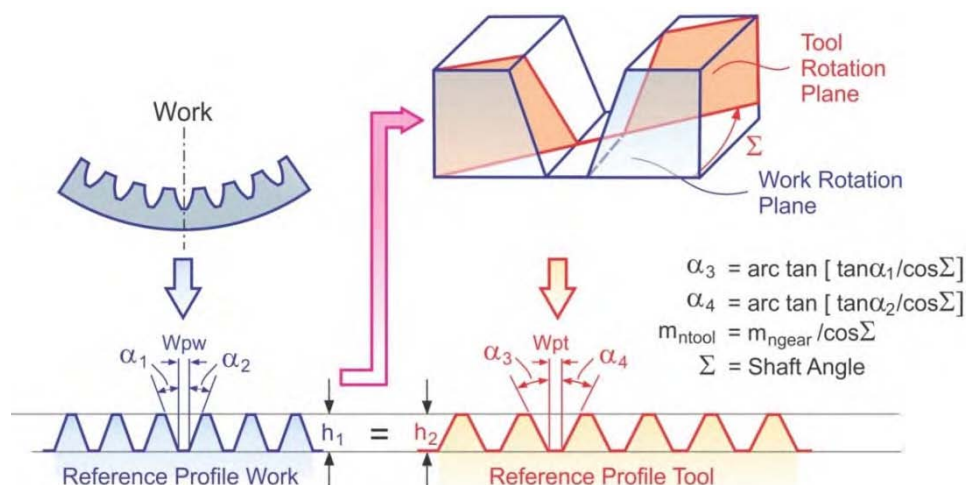
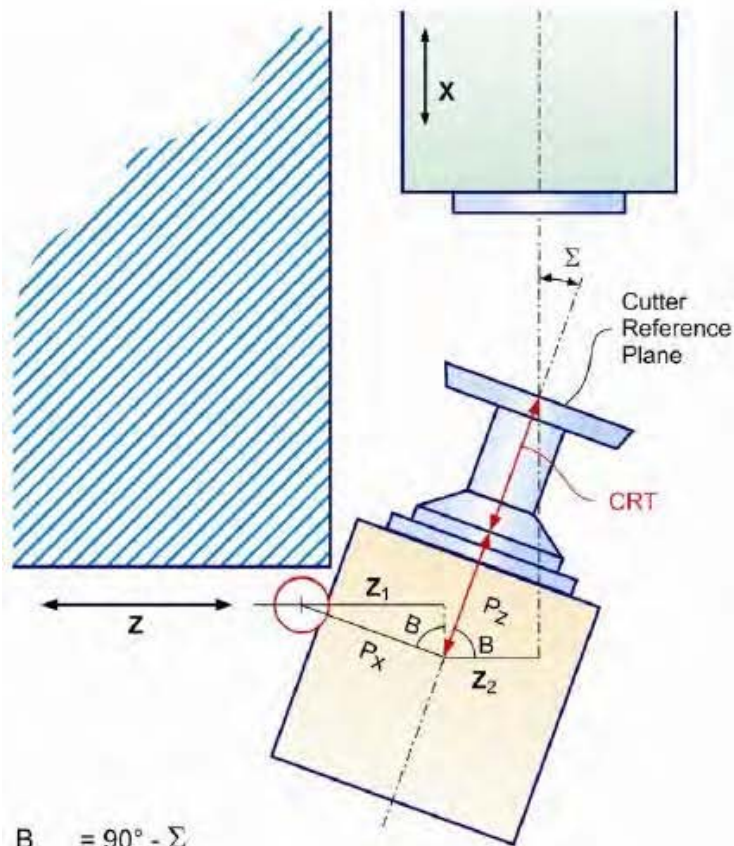


Figure 4. Procedure for the calculation of the tool reference profile



$$B = 90^\circ - \Sigma$$

$$Z_{\text{pos}} = Z_1 + Z_2 = (CRT + P_2) \cos B + P_1 \sin B$$

$$X_{\text{pos}} = \text{Arbor Height} + \text{Gear Width} + (CRT + P_2) \sin B$$

$$Y_{\text{pos}} = \text{Gear Pitch Radius} - \text{Cutter Pitch Radius}$$

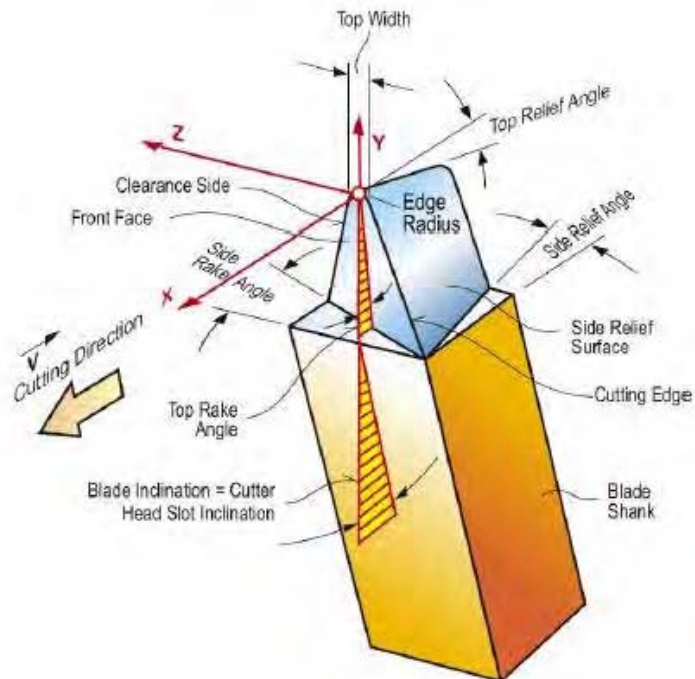


Figure 5. Calculation of machine settings (top) and cutting blade definitions (bottom)