Reverse Cutter Hand for Face Milling and Face Hobbing: Is a Left-Hand Cutter Required for a Left-Hand Face Mill Part?

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(*The following is another chapter from Dr. Hermann J. Stadtfeld's new book, Practical Gear Technology, part of an ongoing series of installments excerpted from the book. Designed for easy understanding and supported with helpful illustrations and graphic material, the e-book can be accessed for free at Gleason.com.*)

Introduction

Bevel and hypoid gear cutting in a single indexing face milling process is preferably conducted with a cutter hand (left-hand cutter vs. right-hand cutter) that matches the spiral direction of the part. For example, a right-hand gear is commonly cut with a right-hand cutter head. The reason is that the cutter head should rotate from toe to heel, which directs the axial cutting force component at the workholding, as shown (Fig. 1, red → axial cutting force component). In other words, if the cutter hand matches the hand of the bevel gear it cuts, then the cutting forces press the part against the workholding, thus securing its correct seating and its firm clamping.

If a manufacturer likes to limit the investment in cutter heads, because the batch sizes are low and pinion and gear cutting is conducted at different times on the same machine, then the cutter hand (of the single cutter which is purchased) should be chosen so that it matches the spiral direction of the ring gear. This decision is especially critical in the case of large-size Formate ring gears. In Formate cutting, the cutting forces are the highest compared to any other process because the blades cut the entire profile as well as the entire face width while they are moving through the slot. For the pinion, which is then cut with the opposite hand cutter, it has to be assured that the clamping is very secure. In addition, the plunge feed rates and the roll rates should be reduced to account for this less-than-optimal condition.

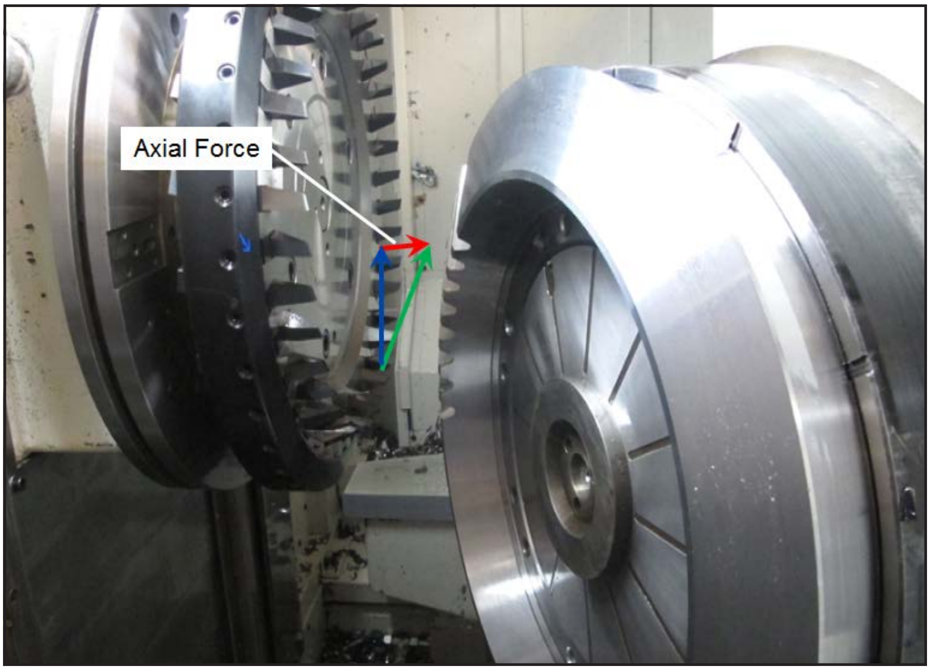

Figure 1 Right-hand gear cut with right-hand cutter.

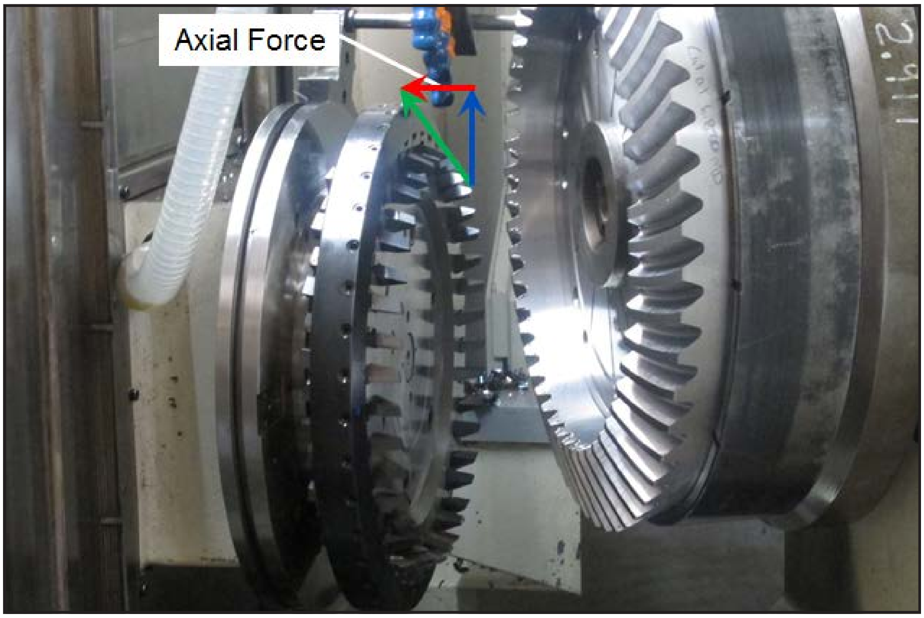

Figure 2 Left-hand gear cut with right-hand cutter.

Ring gears (Figs. 1 and 2) are centered radially by the expander dish spring and axially by the arbor face. The distance between the axial force application point of the expander spring and the outside of the ring gear is generally too great to assure a firm axial seating. In other words, the contact force on the outside of large ring gears diminishes to zero. In order to achieve good axial clamp forces on the outside, all gear arbor face plates are manufactured with a dish angle of, for example, 7 minutes; the dish angle will assure that the first contact is on the outside of the ring gear. While the draw rod pulls the expander disk and the gear back, the contact area on the back seating surface of the ring gear spreads from the outside in.

The arbor dish angle provides a more uniform axial seating, but it should not be underestimated that the distances from the clamping bore surface to the outside of the ring gear can be more than a third of the gear's radius. In particular, the inside flange with holes for the connection of the ring gear to the transmission shaft presents a severe drop of stiffness when compared to the outside ring. This drop of stiffness reduces the contact forces on the outside diameter of the ring gear in some cases to zero — even if the arbor plate has the correct dish angle.

The problem described above is eliminated if the cutter hand and the hand of the ring gear spiral angle match. The red cutting force component in Figure 1 has a significant component that presses the ring gear back, against the arbor plate. This not only creates axial contacting forces, it also generates sufficient friction that will prevent the gear ring from vibrating during the slot cutting; the opposite scenario is shown in Figure 2. The already-critical condition of axial seating contact — particularly in the case of ring gears with an ID connecting flange — now becomes more problematic because the axial cutting force component (red vector in Fig. 2) even pulls the ring away from the arbor plate. The result is a chatter sound during the plunge, which causes shadows and waves along the face width of the teeth.

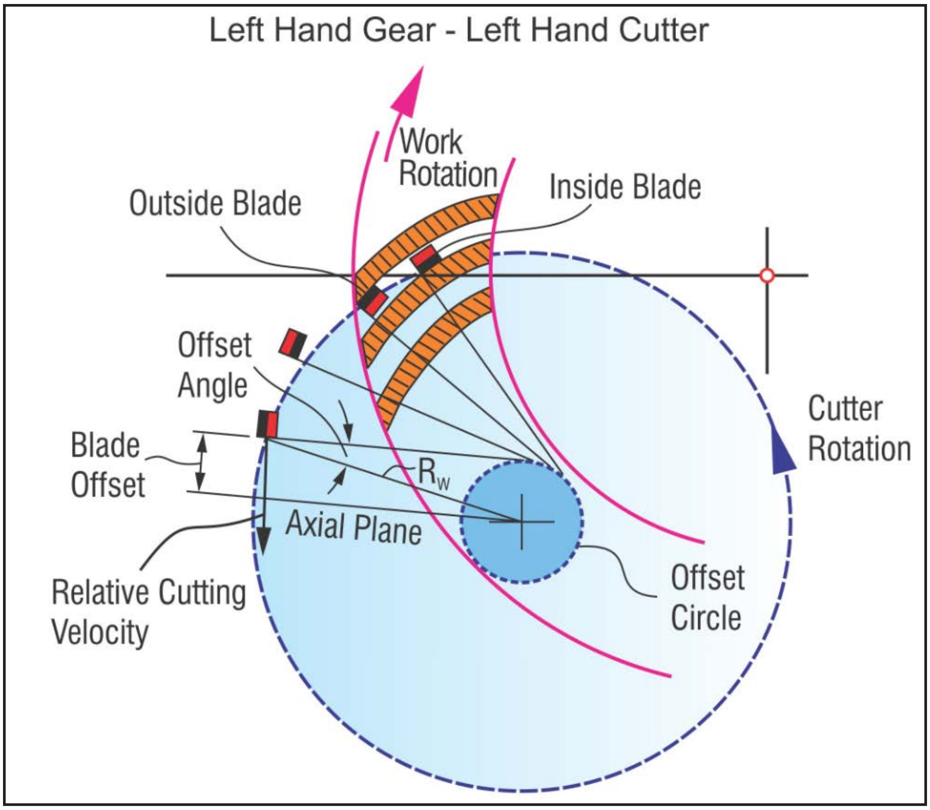

Figure 3 Face hobbing, left-hand gear with left-hand cutter head.

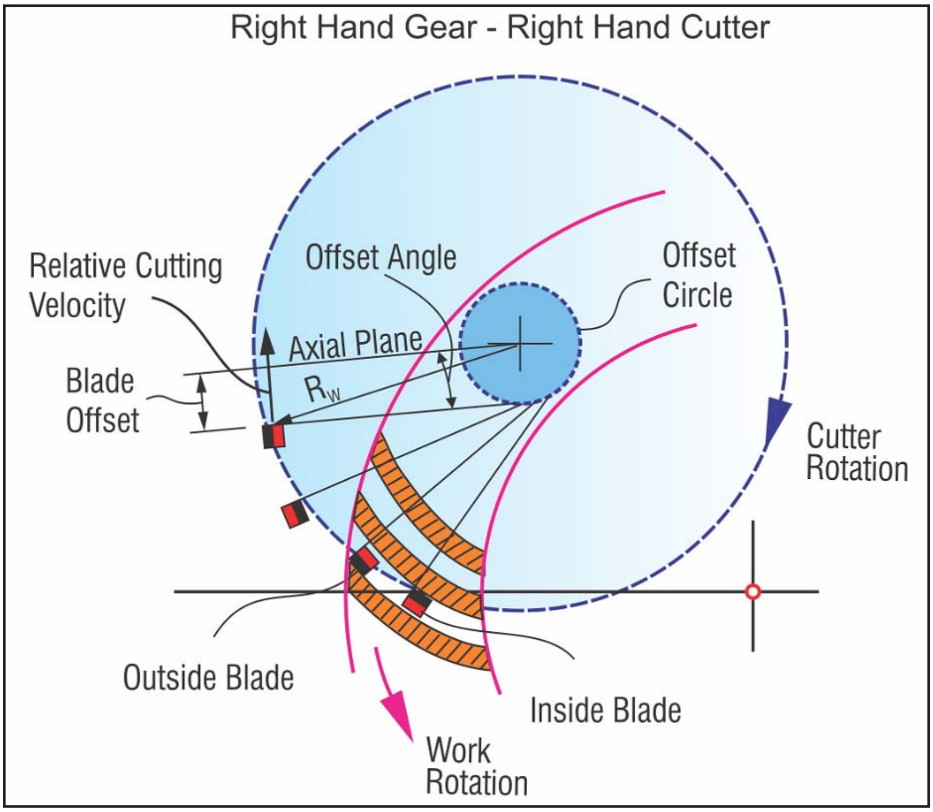

Figure 4 Face hobbing, right-hand gear with right-hand cutter head.

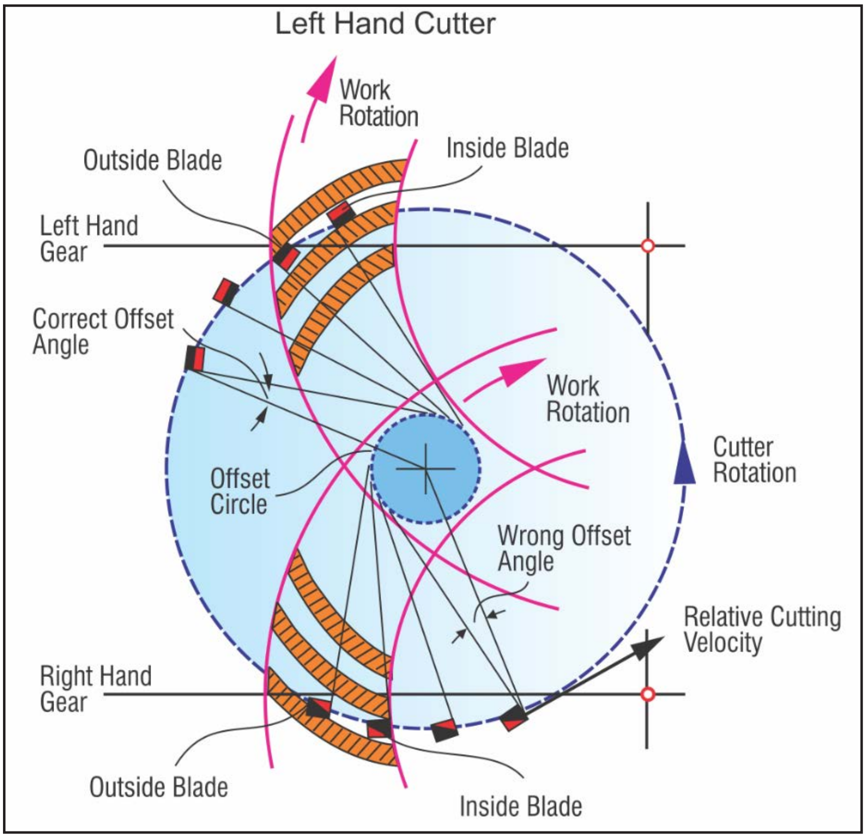

Figure 5 Left-hand cutter with left-hand gear (top) and right-hand gear (bottom).

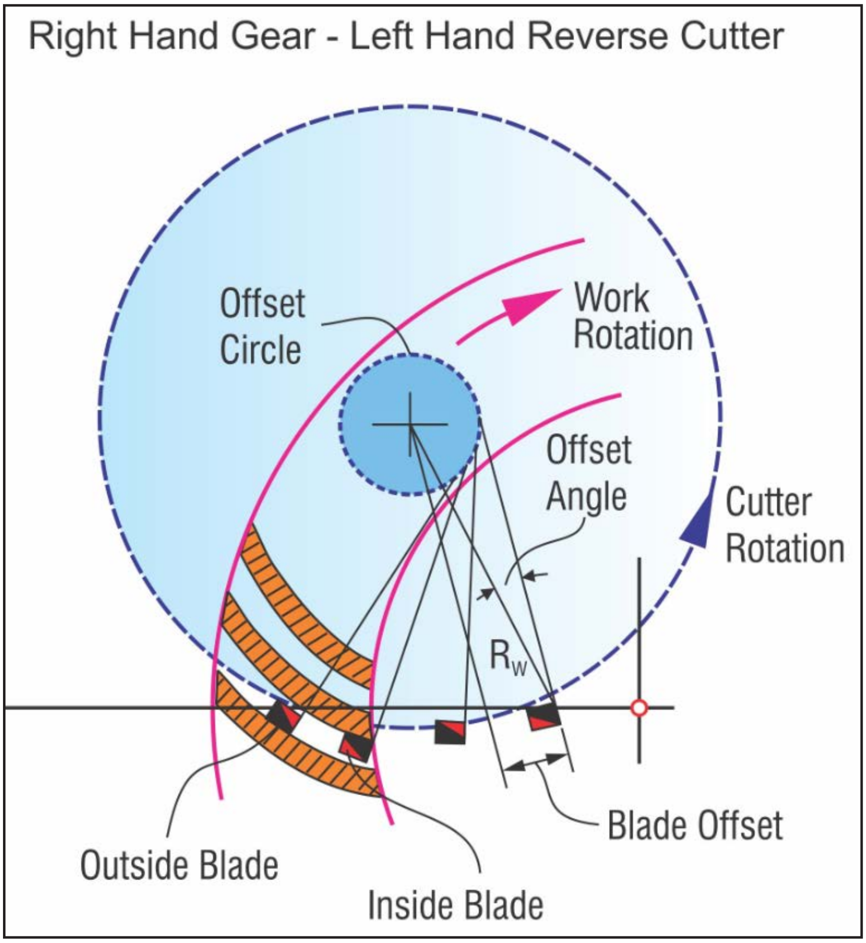

Figure 6 Face hobbing, right-hand gear with left-hand reverse cutter head.

Is a Left-Hand Cutter Required for a Left-Hand Face Hob Part?

In face hobbing, the face width function of the flanks is the result of the cutter radius and the simultaneous rotation of cutter and work. One blade group moves through one slot, while the preceding blade group moves through the following slot. Figure 3 shows the outside blade cuts the slot first, followed by the inside blade. The rotation between outside and inside blade (when passing the same face width position), rotates the work exactly by one half pitch (equally spaced blades). This work rotation, which is connected to the cutter rotation, created the correct slot width.

The case of cutting a right-hand pinion would also require a right-hand cutter. The right-hand cutter shown (Fig. 4) is a mirror image of the cutter in Figure 3. Because the directions of work and cutter rotation change versus Figure 3, also the right-hand pinion is cut from toe to heel with the outside blade cutting the slot first and the inside blade following by 360°/(2*Number of Blade Groups). As can be seen (Figs. 3 and 4), the front of the cutting blades is oriented in the direction of the tangent line to the offset circle; the radius of the offset circle is equal to the blade offset.

The blade offset defines the linear displacement of the cutter head slot front, perpendicular to an axial plane (Fig. 4). If the offset angle δ_w is known, then the blade offset can be calculated with the following relationship:

$$\text{Blade Offset} = \tan(\delta_w) * R_w \tag{1}$$

The offset angle of a cutter head is defined during the cutter head design in order to orient the tangent line (Figs. 3 and 4) perpendicular to the relative cutting velocity direction in face hobbing. The formula for the offset angle in order for a particular job to fulfil this requirement is:

$$\delta_w = arcsin[(z_w * m_n)/(2 * R_w)] \tag{2}$$

Where:

δ_w Off-set angle
z_w Number of blade groups
m_n Normal module
R_w Nominal cutter radius

Relatedly, it should be mentioned here that the offset angle is calculated for a certain average bevel gear design. Because every cutter head has to cover an entire range of job designs, the offset or offset angle of the cutter head will in most cases deviate from the ideal value of a particular job. For 2-face ground blades, a deviation of 3° is permissible and will not influence the cutting condition too significantly. In the case of 3-face ground blades, the offset angle discrepancy is completely eliminated by the direction of the ground front face (Ref. 1).

It is possible in the face milling process to break the rule cited above and to use a cutter that has the opposite hand than the part; this is often done if a cutter of the sam*ed* hand as the part is not available. Another process-related reason is in the case of a generated part where the cutting starts at the heel roll position and then rolls to the toe. If this described process uses a cutter head hand that matches the hand of the part, then the process is conventional cutting. If the opposite-hand cutter is used, then the cutter spindle rotation has to be reversed, resulting in a climb cutting process. Some bevel gear manufacturers prefer the climb cutting process for pinions because of an improvement in surface finish. However, it has to be noted that the chip removal from heel to toe (reverse cutter hand) will pull the part away from the workholding, which could lead to flank geometry errors or, in severe cases, to a crash. A crash can happen when the part is pulled out of the workholding by one millimeter or more — which leads to blade breakages.

Another collateral effect of an opposite cutter hand and work spiral direction is the burr, which in this case is not on the heel, but on the toe. If a manufacturer either likes to apply a climb cutting process or prefers the burr to be created on the toe side of the teeth, then the opposite cutter hand can be considered in connection with reduced roll rates.

Is a Different Cutter Hand Possible in Face Hobbing?

In the continuous indexing face hobbing process, in addition to the facts explained in the last section, the blades are arranged in blade groups that adjust the outside blade radius and the following inside blade radius to the indexing rotation of the bevel gear and to the resulting epicyclical flank lead function. Some tricks could be applied to utilize, for example, a left-hand cutter to cut a right-hand bevel gear. Figure 5 shows the change from a left-hand cutter, cutting a left-hand gear (upper half of the graphic) to the same left-hand cutter cutting a right-hand gear (lower half of the graphic). The cutter spindle has to rotate in the opposite direction from that shown in Figure 4, and subsequently the work indexing rotation has to be reversed, versus Figure 4. That's because now that the cutting motion is directed from heel to toe, the inside blade has to cut the slot first, followed by the outside blade; this is solved automatically. The inside blade from one blade group and the outside blade from the following blade group now form one new blade group of the heel-to-toe cutting process (Fig. 5, bottom).

The major problem with this arrangement is the wrong blade offset or offset angle. In order to cut a right-hand gear with an epicyclical flank lead function, the blade offset needs to be in the opposite direction of the cutting motion. As Figure 5 shows, the left-hand cutter cutting a left-hand gear on top (from toe to heel) has a blade offset in the opposite direction from the cutter rotation. The left-hand cutter cutting a right-hand gear at the bottom (from heel to toe) would require a blade offset in cutting direction in order to align the blade with the slot. The inside and outside blade in the slot of the right-hand gear demonstrate very well a severe misalignment between the blade sides and the slot "walls." This misalignment is in the range of 15° to 40°, which only leads to a very exotic blade front face and relief surface appearance. In the case of 2-face ground blades, the inside blade has a side rake angle that could be up to 60°, and the outside blade has an up to 50° negative side rake angle, and therefore cannot remove chips. Although 3-face blade grinding can correct for the side rake angle, the exotic blade appearance with very small cross-sections in the cutting area of the blade makes this a poor-performing cutting tool.

The Reverse Cutter Head

If the offset angles of the blades in the lower section of Figure 5 are reversed, then the cutter from Figure 5 becomes a left-hand reverse cutter that can cut from heel to toe with good performance characteristics. In this case the blades will look like the blades in a regular left-hand cutter and the changed slot offsets make up for the changed cutting conditions. The example of a left-hand reverse cutter head in Figure 6 shows the differences from the standard left-hand cutter in Figure 5.

Left-hand or right-hand reverse cutter heads do not exist for completing stick blade cutters. The older Cyclo-Palloid system from Klingelnberg used left-hand cutter heads for cutting right-hand bevel gears, and vice versa (Ref. 2). When a manufacturer of Cyclo-Palliod gears was asked why Cyclo-Palloid is the only bevel cutting system in the world cutting from heel to toe, he answered: "You wouldn't sharpen a pencil with a knife from the tip to the stem of the pen," Regarding the pencil, this is a good point which might, however, not be applicable to bevel gear cutting. The Cyclo-Palloid system uses a two-part interlocking cutter head that achieves only low chip removal volume per time unit. The fact that the cutting forces try to pull the work away from the workholding might not be too significant for the low cutting forces of the Cyclo-Palloid cutting process. Today, Klingelnberg has also adopted, with their modern processes (like Oerlikon in 1945 with their SKM2 machine), the Gleason method of cutting from toe to heel.

Summary

In short, a left-hand cutter (Fig. 5) can be theoretically used to cut a right-hand pinion or gear if 3-face ground blades are used. In order to realize such a scenario, and generate a correct blade grinding summary with existing software, a number of steps have to be followed. First, the blade offsets in the *SPA* file or in the cutter section of the *UNICAL* file have to be increased so that the offset angle is tripled, versus the original cutter head offset angle (twice the value of offset angle has to be added to the standard left-hand cutter offset angle). While this is done, attention has to be paid to $R_W = [(\text{normal cutter radius})^2 + \text{offset}^2]^{½} = \text{constant}$, because a sole offset value change, would increase R_W. The comparison between the upper and lower part of Figure 5 provides some explanation to the statements in the last sentences.

After the preparation of the basic data files and cutter table data, a 3-face blade summary is calculated and the blades are ground and built in the left-hand cutter. In many cases this will not be possible, because the blade distance is either close to zero or larger than the blade width. Even if the blade profile still fits on the blade shank, the blades will look very exotic, with strange angles and less-than-optimal cross-sections in any cases using the opposite cutter hand.

On the cutting machine, in order to use existing *MMC* software the basic settings are entered from the standard right-hand part summary, but the hand of the part is entered as "LH" and the signs of all roll positions have to be reversed. In the case of a Formate ring gear, not the roll positions but the "vertical-setting" that has to be entered with a negative sign. The cutting will now take place from heel to toe, with a left-hand cutter cutting a right-hand part with the correct flank geometry.

The photo in Figure 7 shows a left-hand face hobbing cutter head with one blade group with standard blades for cutting a left-hand gear in slots 35 and 36 (outside blade in slot 35). The green arrow points in the velocity direction of the two blades relative to the work gear. Two blades for the opposite-hand work gear cutting have been inserted in slots 32 and 33. In this blade group, the inside blade in slot 32 cuts first, followed by the outside blade in slot 33. The red arrow points in velocity direction of the two blades relative to the work gear.

The velocity directions of the two blade groups differ by about 40°. In order to make this experiment work, the nominal cutter radii had to be reduced in order to fit the blade profiles within the cross-section of the stick blade. This experiment is only of an academic nature because standard software does not support the blade alterations, and the change in cutter radii would not produce the originally intended flank geometry.

The solution for a left-hand face hobbing cutter to the manufacture of a right-hand gear (or vice versa) would require, as mentioned in connection with Figure 6, a specially designed cutter head with the reverse hand.

For more information. Questions or comments regarding this paper? Contact Dr. Stadtfeld at *hstadtfeld@gleason.com.*

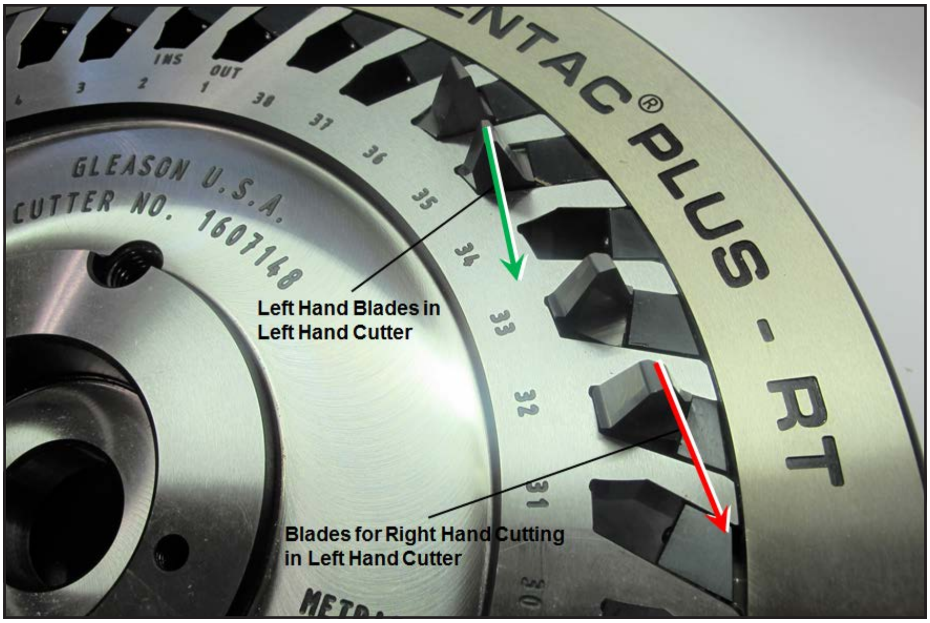

Figure 7 Standard blades for LH cutter and special blades for RH gear.

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Dr. Hermann J. Stadtfeld is the Vice President of Bevel Gear Technology and R&D at the Gleason Corporation and Professor of the Technical University of Ilmenau, Germany. As one of the world's most respected experts in bevel gear technology, he has published more than 300 technical papers and 10 books in this field. Likewise, he has filed international patent applications for more than 60 inventions based upon new gearing systems and gear manufacturing methods, as well as cutting tools and gear manufacturing machines. Under his leadership the world of bevel gear cutting has converted to environmentally friendly, dry machining of gears with significantly increased power density due to non-linear machine motions and new processes. Those developments also lower noise emission level and reduce energy consumption.

For 35 years, Dr. Stadtfeld has had a remarkable career within the field of bevel gear technology. Having received his Ph.D. with summa cum laude in 1987 at the Technical University in Aachen, Germany, he became the Head of Development & Engineering at Oerlikon-Bührle in Switzerland. He held a professor position at the Rochester Institute of Technology in Rochester, New York From 1992 to 1994. In 2000 as Vice President R&D he received in the name of The Gleason Works two Automotive Pace Awards — one for his high-speed dry cutting development and one for the successful development and implementation of the Universal Motion Concept (UMC). The UMC brought the conventional bevel gear geometry and its physical properties to a new level. In 2015, the Rochester Intellectual property Law Association elected Dr. Stadtfeld the "Distinguished Inventor of the Year." Between 2015–2016 CNN featured him as "Tech Hero" on a Website dedicated to technical innovators for his accomplishments regarding environmentally friendly gear manufacturing and technical advancements in gear efficiency.

Stadtfeld continues, along with his senior management position at Gleason Corporation, to mentor and advise graduate level Gleason employees, and he supervises Gleason-sponsored Master Thesis programs as professor of the Technical University of Ilmenau — thus helping to shape and ensure the future of gear technology.