QUESTION #2

Differential Gears

Bevel gears used in differentials seem to be forged in most automotive applications. Old developments are Gleason Coniflex-cut developments, but it seems modern developments are computer-generated. I have never seen (literature) about who does this and wonder if it is true and why it is not (discussed).

Automotive differential gears are generally Gleason Revacycle designs. Revacycle gears are cut by a large circular broach, which is extremely productive (Fig. 1). Typical features of differential gears are the high pressure angle of 22.5° and coarse-pitch teeth with near-miter ratios. The wide root fillets of the Revacycle gears have a fully rounded radius for maximum root bending strength. The Revacycle process form-cuts the tooth profiles; the broach cutter moves from toe to heel during the roughing portion of the cycle and then back to the toe in a climb-cutting mode in order to finish the flank surfaces and generate a straight root line. However, the flank profile of the Revacycle blades has a radius that approximates the involute in order to create some profile crowning at the same time. Differential gears require the highest power density of all bevel gear types.

The variety of differential gears compared to hypoid gears in automotive axle drives is rather limited. This opened the door for forging companies to offer forged differential gears, which can be manufactured both in high volumes and very economically. The first electrodes for the spark erosion process of the forging dies were Revacycle-cut copper gears. The promoter of forged differential gears pointed out the possible advantages regarding strength attributable to the grain flow in material structure. Plus, forging presents the possibility to form webs on both toe and heel (Fig. 2) in order to reduce root bending stress and, consequently, further increase power density. However, the webs prevent the free bending that can initiate cracks in the web transition to the teeth; this also promotes early pitting due to the elimination of a "contact breathing" under varying loads. Figure 3 shows a typical forged differential gear with pittings on the left flank. Although there are geometry freedoms like the webs that can be applied in forging—but not in cutting, due to the constraints of a rotating cutter—the forged differential gears with highest strength are those that simply duplicate the Revacycle geometry.

Although forged differentials have near-net quality—thus requiring a calibration process step—the flank surface variations in production parts are significantly larger when compared to parts manufactured by the cutting process. This also influences tooth thickness and backlash; the backlash of differential gears should be zero. During the tool life of a die, the tooth thickness changes and may lead to unwanted backlash and jerking in the drivetrain of a vehi-

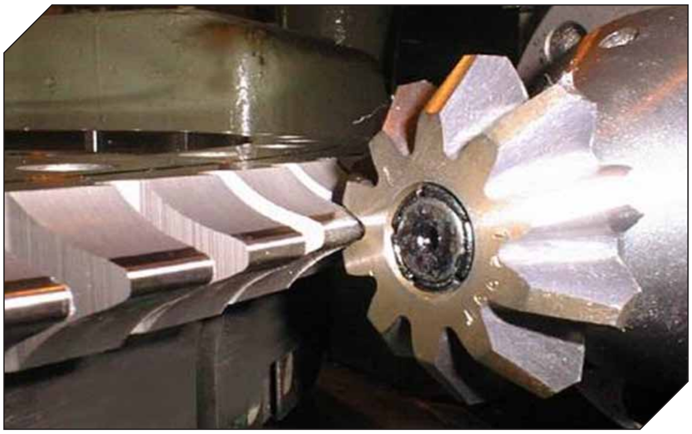

Figure 1 Broaching of a differential gear with Revacycle.

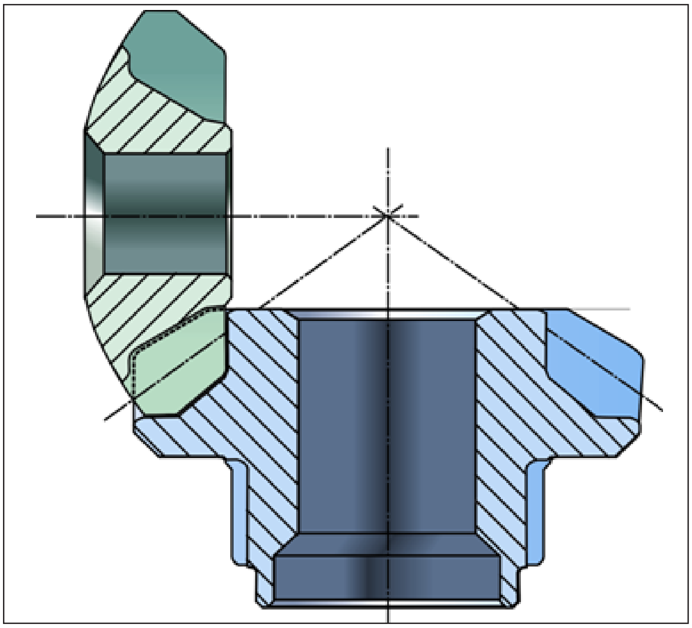

Figure 2 Cross-sectional drawing of forged differential gear pair with web-closed heel.

Figure 3 Forged differential gear with pitting.

cle. Also, noise unique to forged differentials is greater than that of cut parts. To address this problem, a practice was adopted combining two *forged* and two *cut* differential gears—an approach that provided excellent lubrication properties and low noise.

Today, however, some manufacturers of premium vehicles use either four Revacycle or a combination of two Revacycle and two forged differential gears. Most manufacturers of mass-produced differentials, however, use only forged differential gears.

Many truck applications, depending on the quantity, and all differentials for special applications, are still manufactured with Revacycle gearing or the alternative method—Coniflex—a Gleason process developed for cutting industrial straight bevel gears. Coniflex enables a close match of the Revacycle geometry. In the past, mechanical cradle-style machines with many setup axes were used to cut Coniflex gears—a rather slow process (Fig. 4).

The latest development is the ConiflexPlus technology. A single carbide stick blade cutter is used in a high-speed dry cutting process on freeform Phoenix machines (Fig. 5), which are also used for spiral bevel and hypoid cutting.

The gear design is made with *Windows* software that features analysis of tooth contact calculation, undercut check, calculation of backlash, clearance and more. Nominal tooth surface grids for a CMM are also a standard of the new software. If the measured flank form deviates from the theoretical target, then corrections can be calculated with *G-AGE* software, residing on the CMM computer. Thus the latest closed correction loop methods can be applied for Coniflex straight bevel gears.

Mathematically precise tooth surface definition and contact analysis (Fig. 6) helped to develop a modern version of the Coniflex design with increased strength and improved rolling behavior. US-Gear, a division of AxleTech International, is one of the manufacturers that offers this technology in the axle units for high-power density truck differentials.

Best regards,

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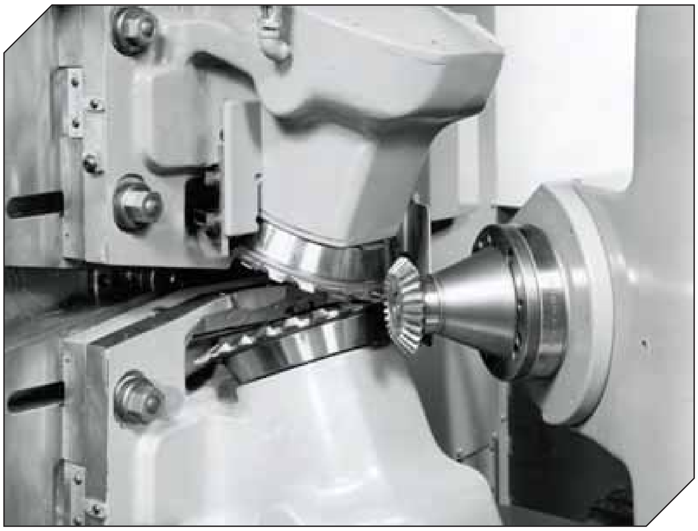

Figure 4 **Coniflex cutting with interlocking HSS cutter disks.**

Figure 5 **ConiflexPlus high speed dry cutting on a Phoenix 275HC machine.**

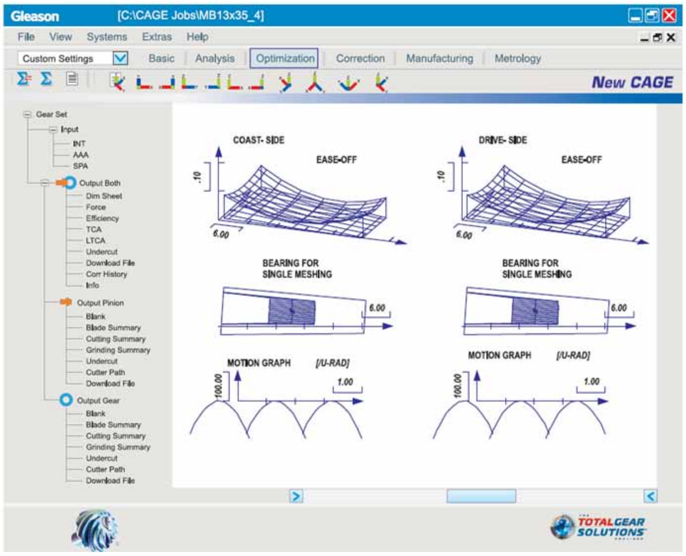

Figure 6 **Coniflex design and analysis software.**

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