Figure 1 Continuous generating gear grinding

Modification of Surface Structure and Geometry on Gears

■ Walter Graf, Reishauer AG, Switzerland

Demands placed on today's automotive transmissions include, among others, low gear noise levels (NHV), weight reduction, fuel economy, increased longevity and high power density. Modifying the surface structures and flank geometry can lead to higher transmission performance in line with these demands. Continuous generating grinding can contribute to higher transmission performance in several ways. This paper touches on three relevant features that generating grinding contributes to ground gears, and by extension, to the entire transmission. Two of these features, Low Noise Shifting (LNS) and Polish Grinding positively alter the surface structure, and the third, Twist Control Grinding (TCG) adds control over the gear flank geometry and the surface bearing ratios.

- Low Noise Shifting (LNS)
- Polish Grinding
- Twist Control Grinding (TCG)

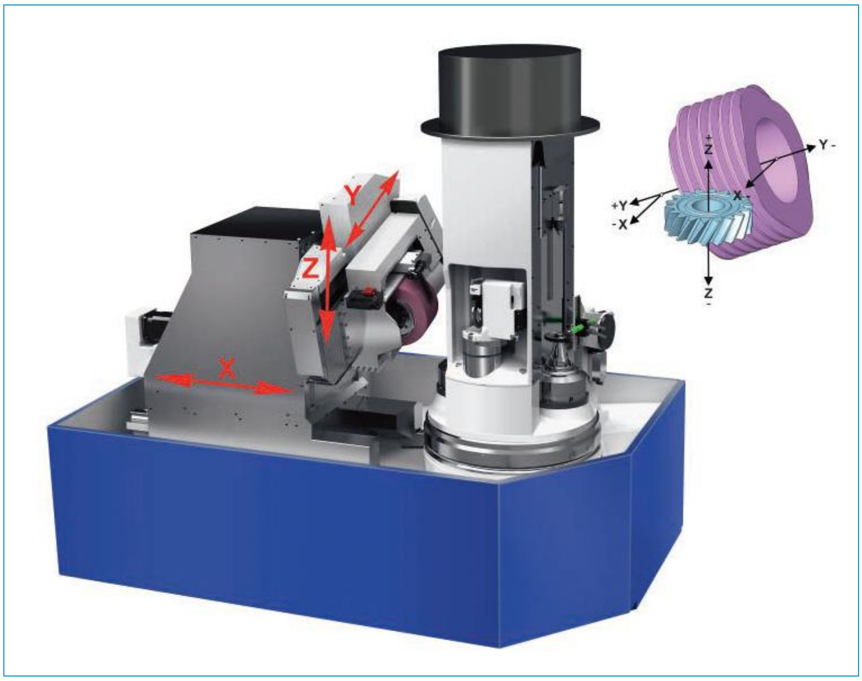

Figure 2 Continuous generating machine

Low Noise Shifting (LNS)

LNS is an additional machining movement within the grinding kinematics of continuous generating grinding. As LNS runs unobtrusively in the background of the grinding process, most users are unaware of the existence of this feature. The machine's software automatically defines and sets LNS parameters. In principle, the kinematics of continuous generating grinding can be understood as a worm drive with additional abrasive machining properties (see Fig. 2). This process consists of an infeed X to set the depth of cut, a vertical feed-rate Z, and the lateral shifting motion Y. This lateral motion ensures that the abrasive worm shifts continuously sideways by a small amount for each mm of vertical feed-rate. In this manner, the grinding always takes place with fresh, unused abrasive grits.

The operator defined shifting motion Y is used for the roughing stroke, whereas the LNS shifting motion is calculated and defined by the machine and applied in the finishing stroke. Continuous generating grinding creates grinding traces of a uniform axial waveform across the gear flank in the direction of the lead (see Fig. 3, chart top right). Since the orientation of these waveforms is at right angles to the plane of rotation, this may cause high-frequency excitation during gear meshing, which vehicle occupants may perceive as unpleasant. To put simply, the effect of LNS is to shorten and to reduce axial waveforms. LNS results in irregular surface structures (see Fig. 3, chart bottom right) that prevent the generation of tonal excitations and allows the pairing of sets of ground gears.

Polish Grinding

As emissions and fuel efficiency are becoming more stringent in all major markets, automotive companies are facing huge technological and economic challenges to comply. These requirements can only be met by improvements in all aspects of motor vehicles, and specifically to the powertrain, i.e., the engine and the transmission. Polish grinding reduces the friction of meshing gears and increases the bearing ratio of gear flanks. For these reasons, transmissions can be made more energy efficient. The established continuous generating method is the

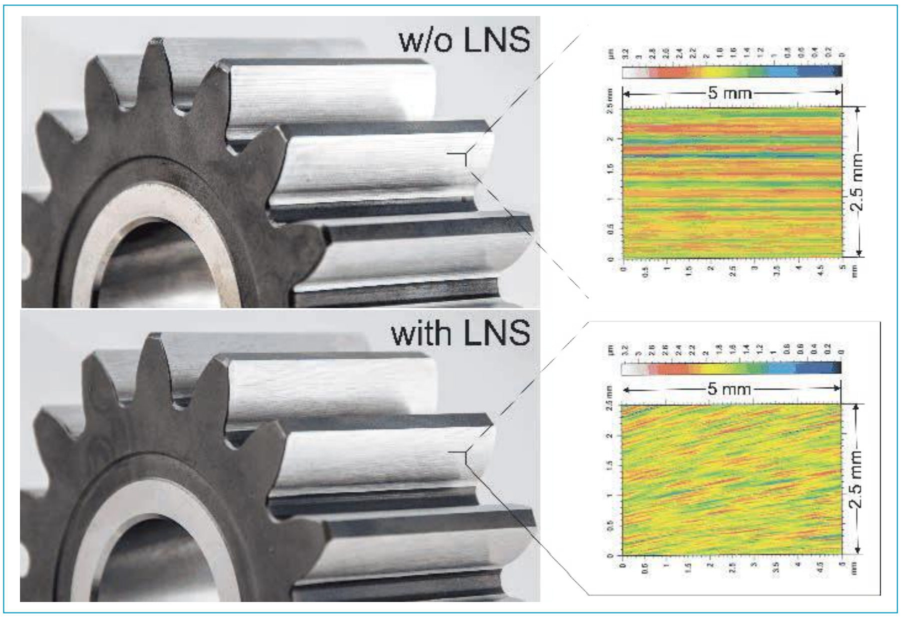

Figure 3 Surface structure w/o and with LNS

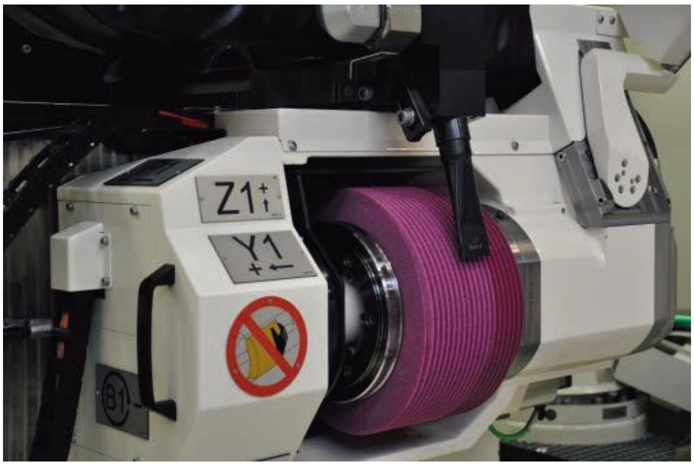

Figure 4 Two-zone grinding worm (Grinding & Polishing)

base technology for the polish grinding process. Without interrupting the gear grinding cycle, polish grinding is performed as a final machining sequence on the manufacturer's existing continuous generating gear grinding machines while the workpiece remains clamped on the part holder during both grinding and polish grinding. Polish grinding, as a general rule, consists of one polish grinding pass with the resin-bonded section integrated into the end section of the 2-zone grinding worm which performs the grinding operation (Fig. 4).

During polish grinding, only the roughness peaks are removed, reducing the roughness profile height and, therefore, this method increases the contact bearing area of the gear flanks while the geometrical accuracy of the gear flanks is not affected. The polish grinding process delivers surface qualities with mean roughness values of Ra 0.15 µm compared with the standard values of Ra 0.4 µm used in industry on continuous generating grinding machines. It is important to note that Ra surface values are only of limited utility and that the reduced peak height (Rpk) for example, is a more useful indicator of a surface's functionality. Often, there is a misunderstanding that polishing should produce mirror finishes. However, for engineering purposes, polish grinding should only remove the surface roughness peaks and must leave intact the valley surface roughness such that oil films can adhere to the polish ground surface. With the roughness profile height removed, the contact area of the gear flanks is increased. Consequently, the augmented surface contact area allows transmission designers to increase the power density of transmissions.

Twist Control Grinding

Weight reduction can contribute a major share of the total fuel consumption reduction. Hence, modifying the flank twist, also know as bias, by Twist Control Grinding (TCG) allows modification to the contact pattern of gear teeth, thus leading to higher power density and allowing a reduction in the overall weight of gears, and by extension, a weight reduction of the transmission itself. Furthermore, TCG ground

Figure 5 Ground and polished gear flanks

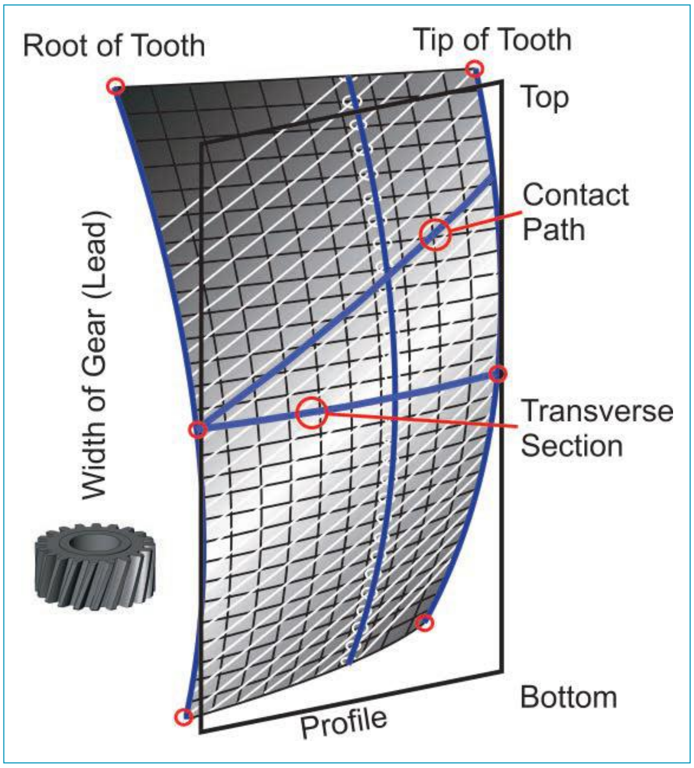

Figure 6 Twist on individual gear flank

gears have shown noise reductions in transmissions of 2 to 3 decibel (dB). Flank twist occurs as a matter of course when machining helical gears that feature lead modifications such as crowning.

This phenomenon is brought about by the geometries and kinematics inherent in the continuous generating grinding of helical gears. Simply put, the purpose of TCG is to either eliminate twist, to deliberately introduce a counter-twist, or to add a specific twist to counteract the deformation of gears under load. More often than not, twist has some negative connotations attached. However, with TCG grinding, the word twist should be seen in a positive light as it allows gear designers to use this phenomenon to fine-tune the gear geometry. By controlling twist, the contact bearing patterns of meshing gear sets can be fully controlled, and therefore, the forces acting on the bearing surfaces can be ideally distributed, which leads to higher power density, more efficient transmission of power and an increased longevity of gears. The TCG method gives gear design engineers a high degree of freedom to design gear flank geometries to match the demands made on automotive gears and to translate desired design features into an economical manufacturing process.

One-Button Twist-free Grinding

Up to very recently, when users wanted to grind twist-free, the machine maker had to calculate the process parameters and to design a gear specific dressing tool. This process was not only expensive but also inflexible with dependence on the machine tool builder. For this reason, a customer-friendly solution was required and recently brought to market. "One-Button Twist Control" means what it says. The user simply pushes the button "Twist-free," and the machine will do the rest; calculate and implement all necessary geometric and process calculations. Furthermore, the diamond dressing tools remain the same as for many existing conventional processes. Also, the Twist-free process requires no additional operator training if the operators already have experience with standard continuous generating grinding. Today, regarding grinding times, Twist-free grinding is on par with the standard continuous generating grinding which is well established in the industry. The benefits gained from controlling twist justify the small software investment and the influence of additional wheel dressing time. Following intensive research work and several years of industry application, Twist Control Grinding technology has proven itself in the marketplace and has, in many cases, eliminated gear honing, often thought to be the only method for large-scale twist-free, or defined twist hard finishing of gears. High volume TCG production of twist-free gears, or gears with a defined twist, is now standard production practice. The minimal additional process costs over conventional gear grinding are far outweighed by the benefits of the reduction in torque loss, the increase in bearing capacity of TCG-ground gears, and higher resulting power density in transmissions.

Ease-of-Operation for Deliberate Twist

The same ease-of-operation and economy of process as for twist-free grinding apply now also to the grinding of any specific twist. Again, with standard tooling, the customer will be empowered to simply define the desired twist with few data points on the gear flank via the machine's graphic interface, click one button, and the machine will generate a program to grind the gear's geometry accordingly. Trials have been successfully concluded, and rollout is imminent.

Conclusion

With the three features of continuous generating gear grinding outlined in this paper, the users have powerful und simple to use tools at their disposal to fully exploit required changes in geometry and surface structure to address the transmission issues of NHV, higher power density, and fuel savings.