Cylindrical gear production

Continuous generating gear grinding is a simple method of making modifications to geometry and surface structure in order to improve transmission NVH and increase its power density

In the manufacturing of gears, modifying the surface structures and flank geometry can improve transmission performance by reducing NVH, lowering the weight, providing increased longevity and high power density, and improving vehicle fuel economy.

Advances in cylindrical gear production, specifically continuous generating gear grinding, enable targeted modification of gear surface structures and gear geometry. There are three key features that the generating grinding process provides in ground gears, providing benefits to the complete 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.

Figure 1: Continuous generating gear grinding

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 Figure 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 millimeter 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 Figure 2, 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 it simply, the effect of LNS is to shorten and to reduce axial waveforms. LNS results in irregular surface structures (see Figure 3, bottom right) that prevent the generation of tonal excitations and enables the pairing of sets of ground gears.

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 continuous generating method is the 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 work piece remains clamped on the part holder during both grinding and polish grinding. As a general rule, the polish grinding process consists of one polish grinding pass with the resin-bonded section integrated into the end section of the two-zone grinding worm, which performs the grinding operation (Figure 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 0.15µm compared with the standard values of Ra 0.4µm used in industry on continuous generating grinding machines. 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 so 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 enables transmission designers to increase the power density of transmissions.

Weight reduction can contribute a major share of the total fuel consumption reduction. Hence, modifying the flank twist, also known as bias, by TCG enables modification to the contact pattern of gear teeth, resulting in a higher power density and enabling a reduction in the overall weight of gears, and therefore a weight reduction of the transmission itself. Furthermore, TCG ground gears have shown noise reductions in transmissions of 2-3dB. Flank twist occurs as a matter of course when machining helical gears that feature lead modifications such as crowning.

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 negative connotations. However, when it comes to TCG grinding, the word 'twist' should be seen in a more

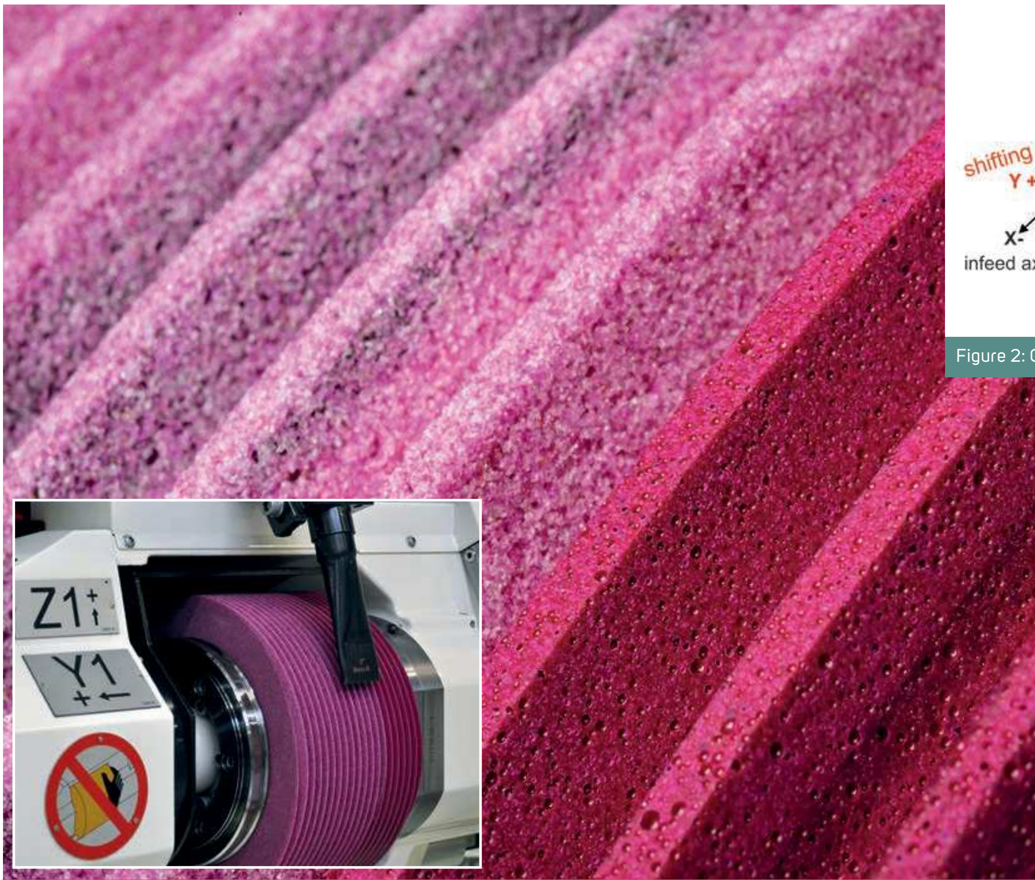

Figure 4: Two-zone grinding worm (grinding and polishing)

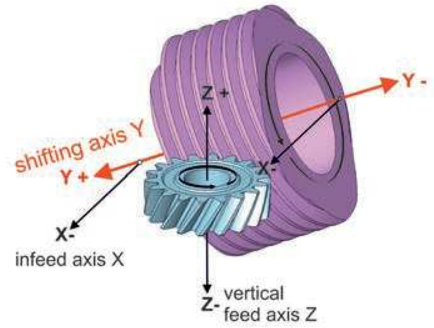

Figure 2: Continuous generating grinding axis motions

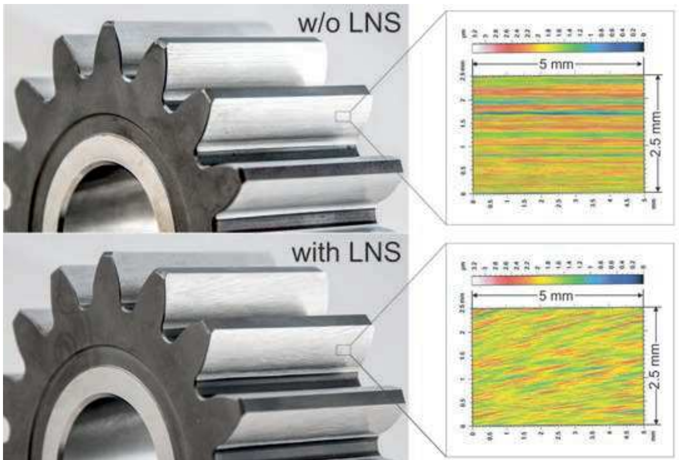

Figure 3: Surface structure without and with LNS

positive light, as it enables 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 results in a higher power density, more efficient transmission of power, and increased longevity of gears. The TCG method gives gear design engineers a high degree of freedom to design gear flank geometries to match demands made on automotive gears and to translate desired design features into an economical manufacturing process.

Until very recently, when users wanted to grind twist-free, the machine maker had to calculate the process parameters and design a gear-specific dressing tool. This process was not only expensive, but also inflexible in terms of its dependence on the machine tool builder. For this reason, a customer-friendly solution was required and has recently been brought to market.

One-button twist control means that 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 twist-free process requires no additional operator training if the operators already have experience with standard continuous generating grinding. Grinding times of the twist-free method are about the same as those for standard continuous generating grinding, which is an established method in the industry. The benefits gained from controlling twist justify the small software investment and the influence of additional wheel dressing time. 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 reduction in torque loss, increase in bearing capacity of TCG-ground gears, and higher resulting power density in transmissions.

The same ease-of-operation and economy-of-process of twist-free grinding now applies to the grinding of any specific twist. Again, with standard tooling, the customer will be empowered to simply define the desired twist with four 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 are complete and the method has proven itself commercially.