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Introduction

As far back as the 1950s, car manufacturers realized that ground gears in vehicle transmissions caused annoying noises at higher rotational speeds. Studies show that this phenomenon could not be eliminated, no matter how precisely the gears were ground. Rather, it was found that the grinding grooves on the tooth flanks were almost parallel to the axis of rotation of the gear for all the grinding methods used at the time, which made noise development during the rolling process much higher than desirable.

To counter this phenomenon, the US-American company National Broach & Machine Co. launched its first honing machine to the market in 1956. With this machine, the workpiece to be machined engaged with an externally toothed honing stone under an axis cross angle. This resulted in machining grooves that were no longer parallel, but rather at an angle to the axis of rotation across the tooth flank. The noise behavior of gears honed in this way was significantly better.

In 1979, the Swiss company Fässler AG developed a gear honing machine with an internally toothed honing wheel. This machine was also designed for the finishing of pre-ground gears. The combination of gear grinding and gear honing (also termed continuous generating honing at the time) quickly spread on the market in the 1980s.

Continuous generating honing

The gear honing machine constructed by Fässler was already similar to the gear honing machines used today. The tool and the workpiece engaged under an axis cross angle. With this method, the artificial resin-bound internally toothed honing ring drove the workpiece. The workpiece did not have its own drive. The process was completely force-controlled. The stock removal that needed to be removed was controlled by means of the process time and process force. The removed material per flank was quite small at 0.01 mm to 0.02 mm. The method, which also became known as Fässler honing, was not a shaping method, it simply improved the properties of the flank surface. This made an upstream grinding process imperative.

On account of the high costs involved, Fässler honing was only used for demanding and high-priced applications, i.e., transmissions for luxury vehicles. In contrast, gears that were shaved when soft and not machined in the tooth flank in its hardened state were used for standard applications. This method required comprehensive noise tests to be carried out, however, in order to identify loudly rolling gears and remove these.

During the further development of vehicle transmissions, greater and greater demands were made on power transmission, the reduction of design space and noise, particularly for passenger car transmissions. These demands could only be met with gears whose tooth flanks were hard-machined and finished in a hardened state.

In 1993, all renowned gearing machine manufacturers presented newly developed gear honing machines at EMO, the leading show for metalworking technology. This was the break-through for the advanced technology of gear

Gear honing (power honing)

Fig. 1: Gear honing machine with direct drives and path-controlled process management (SynchroFine)

honing, which made prior gear milling unproductive and became known from this point onwards as power honing. Präwema was the only manufacturer to rely on a purely path-controlled process rather than the traditional force-controlled process.

In 1997, the honing machine shown in Figure 1 with a direct drive rotary axis and a high-speed control, managed to achieve gearing qualities which corresponded to those of ground gears in connection with vitrified-bonded honing rings. The advanced process allowed removal rates per flank of up to 0.1 mm. Since then, gear honing has gradually been capturing market segments for machining components both for manual shift transmissions as well as for automatic transmissions. Today, 35% to 40% of all hard-machined and finished gears in automatic transmissions are gear-honed.

Hard-machining and finishing of gears

Gears and shafts in vehicle transmissions are exposed to extremely high loads. To increase resilience and wear-resistance, these geared components are hardened following soft machining – generally after toothing. Quenching distortion is an undesirable side effect of the thermal impact and has a negative effect on the quality of the gear.
In order to improve gear quality after heat treatment and achieve maximum smooth running and power transmission, the gears and shafts are hard-machined and finished following the hardening process.

If gears engage under load, the result will be elastic deformation of the teeth. This can result in a so-called meshing impact. In this case, the tooth meshing with the mating gear touches the tooth flank of the driven wheel too early. This results in inefficient power transmission and, in the worst case gear damage.

Defined modifications of the tooth profile

Defined modifications to the gear profile which are created during hard-machining and finished of the geared components can ensure more even meshing and thus avoid meshing impact. These modifications – e.g., tooth tip relief – are usually defined deviations from the theoretical, i.e., involute tooth flank geometry. Modifications can also be made to the tooth width orientation, however, in order to achieve an optimum contact pattern on the tooth flank. The crowning and modification of the flank line angle avoids an irregular load on the tooth flank, leading to wear at the edges.

Method

Hard-machining and finishing methods can basically be classified in those with a geometrically defined cutting edge and those with a geometrically undefined cutting edge. The methods with a geometrically designed cutting edge include hard-skiving and progressive gear milling. The disadvantage of these methods is the feed marks on the workpiece tooth flanks. The advantage is that the same machines can be used as for the prior soft machining.

Established methods

Methods using a geometrically undefined cutting edge have become established for hard-machining and finishing. Continuous generating grinding, single flank generating grinding and profile grinding are some of the most important methods alongside gear honing.

Generating grinding is a continuous rolling method. A worm gear serves as a generating gear, a dressable grinding worm is used as a tool. The high-performance hard-machining and finishing method of generating grinding is extremely fast for large and narrow workpieces. Disadvantages include the risk of overheating during grinding, undesirable offset with width-corrected helical gearing due to the contact line running at an angle over the tooth flank and the lack of noise-optimized surface structure. Workpieces with constraining contours cannot be machined.

Profile grinding is a discontinuous non-rolling method. One tooth space after the other is machined in cycles by a grinding disk. The grinding disks used can be dressable or non-dressable. Profile grinding is suitable for very large workpieces, e.g., in the wind farm segment and for internal gear. Its flexibility makes it popular for small series. However, profile grinding is relatively slow compared with single flank generating grinding or gear honing.

Generating grinding is a discontinuous rolling method for which two disc wheels or a double-tapered grinding disc are used as tools. It is used, among other things, for machining diamond dressing wheels, which are used as dressing tools for gear honing. Generating grinding is an extremely precise but slow hard-machining and finishing method.