

The Latest Gear Manufacturing Technology for High Accuracy and Efficiency



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In recent years, the automotive industry has been demanding enhanced fuel efficiency and reduced noise, and in the trend of the increase in the number of stages for transmissions, the mass production processing of high-precision gears remains an issue. Conventionally, the manufacturing of gears was completed in the heat treatment process after gear green finishing. Lately, gear grinding is conducted after heat treatment to ensure high precision, and thus the reduction of production costs is also an issue. Using a high-speed spindle and our proprietary technology, we established a gear processing method with higher-precision and higher-efficiency compared with the conventional method, which will be described in this report.

1. Introduction

In recent years, in the automobile industry, an increase in the number of stages for automatic transmissions (AT), a reduction of weight and an increase in efficiency are being promoted to comply with fuel-economy regulations. In addition, efforts to reduce vibration and noise for the improvement of ride comfort are being made.

On the other hand, the shift from vehicles using conventional gasoline engines to hybrid electric vehicles (HEV) and electric vehicles (EV) is being promoted and the noise reduction of vehicles is progressing. Therefore, the further noise reduction of transmission gears is in demand. In the recent trend, planetary gear systems which take up less space but can transmit large torque are often used as transmissions for HEV and EV.

Under these circumstances, we have promoted the development of processing machines and tools for vehicle transmission gears. For the ring gears of planetary gear systems in particular, significant progress has been made in terms of high-precision and high-efficiency processing for internal gears and high-speed gear cutting and high-precision gear grinding for external gears.

This report mainly introduces efforts for the machining technology for vehicle transmission gears using the latest processing machines and tools. We proposed dry-cut hobbing using a specially-coated, high-speed steel hob and have continued to improve it. Furthermore, we realized high-speed hobbing using a carbide hob cutter. For the internal gears of a planetary gear system, we also developed a method of performing gear cutting using our proprietary super skiving cutter and grinding tooth flanks using a barrel-shaped threaded grinding wheel after heat treatment and established a total processing system for internal gears. We also increased the transmission efficiency of external gears by establishing a method of improving the surface roughness using a grinding wheel for finishing after normal grinding, which will be introduced hereafter.

2. Super high-speed hobbing

2.1 Direct-drive hobbing machine

In 1998, we proposed a dry-cut hob, and since that time, tools and processing machines have advanced. Conventionally, in machining using a dry-cut hob which is a specially-coated, high-speed steel hob, a cutter peripheral speed of 300m/min or lower and a high-axial cutting feed

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were mainly used. Recently, tools, such as carbide hobs and cermet hobs, which can be applied to higher-speed machining, have become available.

To respond to the needs for high-speed machining, we developed the GE10A high-speed hobbing machine (**Figure 1**) with a direct drive spindle, which realized a twofold increase in spindle speed without using the conventional spindle gear train. This allows machining at a speed of more than double the peripheral speed of a general dry-cut cutter, reducing the machining time.⁽¹⁾

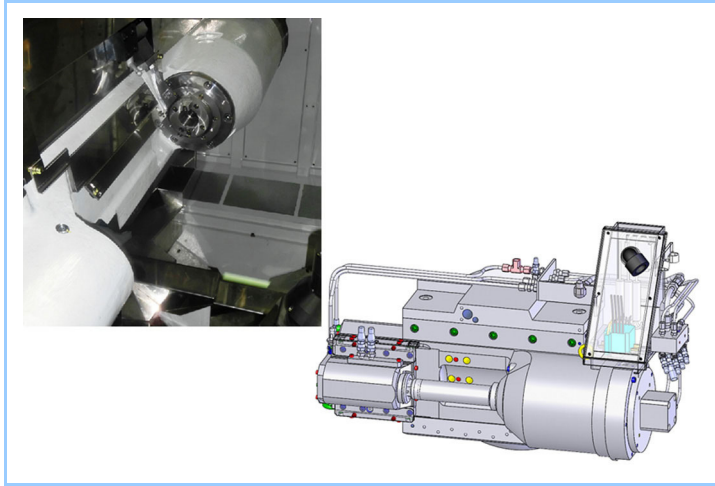


Figure 1 GE10A (built-in direct drive spindle)

2.2 Machining precision

The results of high-speed hobbing at a cutter peripheral speed of 1500m/min using a carbide hob cutter are shown in **Figure 2**. The machining time of high-speed hobbing in Figure 2 can be reduced by half compared with machining using a high-speed steel hob while maintaining the conventional hobbing accuracy.

Through the adjustment of the axial feed speed, smooth tooth lead accuracy equivalent to that of shaving in the gear finishing process can be obtained by hobbing as shown in the high-precision machining in Figure 2. Thus, it is expected that the production costs can be reduced by eliminating the shaving process.

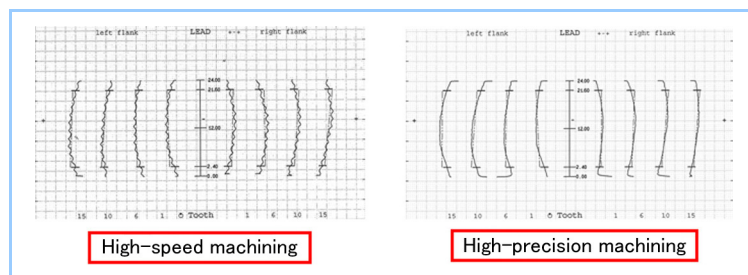


Figure 2 Machining precision with carbide cutter at 1500m/min

3. Skiving of internal gears

In the manufacturing of internal gears (ring gears) of planetary gear systems, gear shaping and broach cutting are mainly used, but their productivity and flexibility are issues. Along with the recent progress in NC technology, skiving processing is attracting attention, but it has an issue in that the tool life is short and has yet to be used in actual mass production. To solve the problem of the short tool life, we developed the MSS300 Super Skiving Machine, which can make the most of the newly-developed super skiving cutter and its cutter capability.

3.1 Skiving processing

As shown in **Figure 3**, in skiving processing, the tool and the workpiece (internal gear) are placed so that their rotating axes form a crossed-axis angle and are rotated synchronously to generate a sliding motion in the lead direction, enabling the cutting of gears. Compared with gear shaping, which uses reciprocating movement, skiving using rotational movement allows a substantial reduction of the machining time. However, as presented in **Figure 4**, the rake angle of

the tool changes significantly during machining, which places a significant burden on the tool, resulting in the shortening of the tool life.⁽²⁾

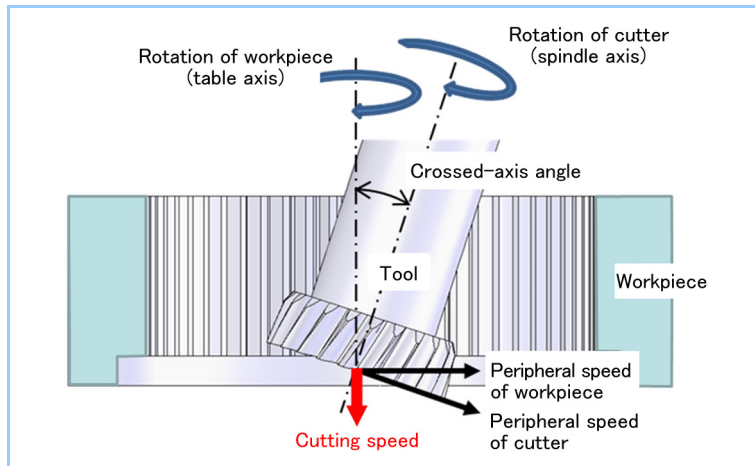


Figure 3 Skiving processing

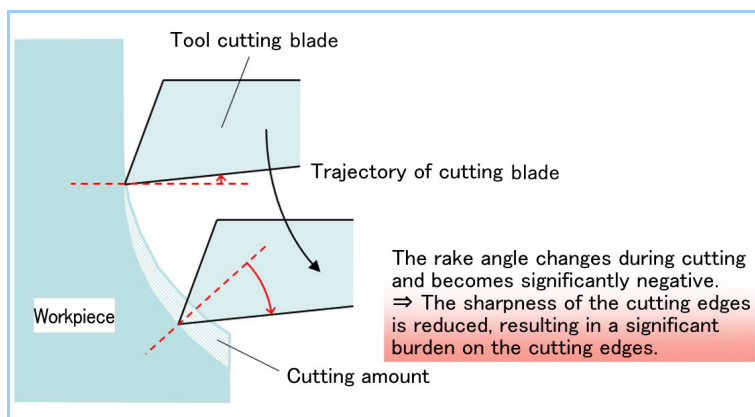


Figure 4 Change of rake angle

3.2 Super skiving cutter

In skiving using a pinion cutter, the cutting depth is changed several times during the machining of the material into a gear, and therefore the same cutting edges are used for rough processing and finishing. On the other hand, the super skiving cutter we developed has cutting edges aligned in the lead direction, as illustrated in **Figure 5**, by which the rough teeth and the finishing teeth play different roles, resulting in the reduction of the burden on the cutting edges and the reduction of the number of machining passes and the machining time.

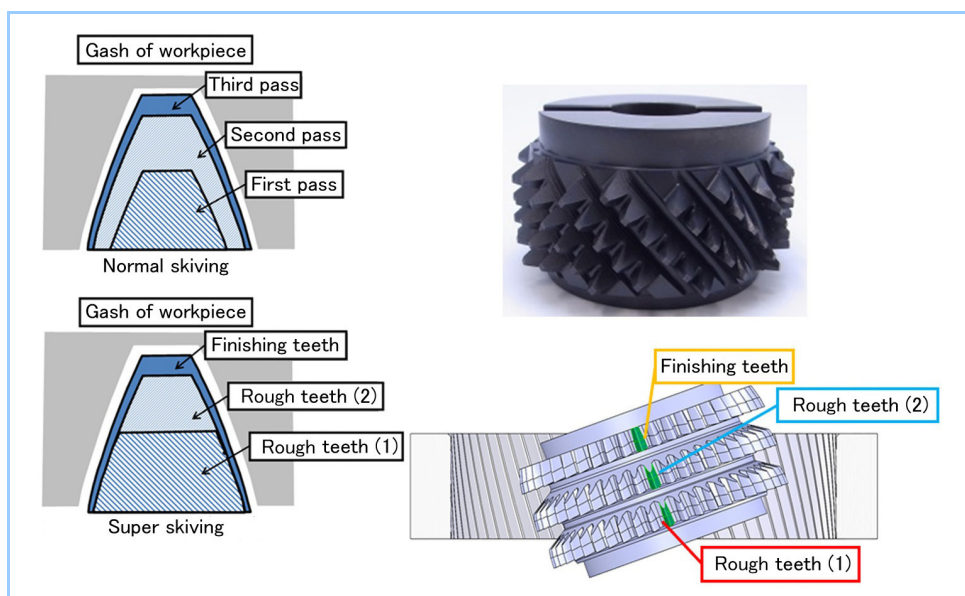


Figure 5 Super skiving cutter

3.3 MSS300 Super Skiving Machine

In super skiving, the increased number of cutting edges of the tool are used, and therefore (1) a high-load spindle/workpiece axis, (2) a mechanical rigidity that could bear a high load and (3) stable synchronous control, compared with pinion skiving were required for the cutting machine. As a processing machine that meets the required specifications, we developed the MSS300 Super Skiving Machine (photo under the title). In the MSS300, a high-load built-in motor, a wide sliding face and a symmetrically structured bed and column were adopted, and an optimal mechanical structure for super skiving cutting was realized as a result of thorough rigidity analysis.

3.4 Machining precision/tool life

The precision of workpieces machined by super skiving and the tool life are depicted in **Figure 6**⁽³⁾. General carbonizing material and carbon steel were used for the materials of the workpieces and internal gears equivalent to ring gears for vehicles were machined. The specifications of the workpieces are listed in **Table 1**. Through pinion skiving, the tool life lasts for the machining of 100 to 200 workpieces of carbonizing material. Using super skiving, 1200 workpieces can be machined during the tool life. For workpieces of carbon steel, the tool life lasts for the machining of 100 workpieces through pinion skiving, while 500 workpieces can be machined using super skiving. For both types of workpieces, the tool life in super skiving is 5 times longer than that in pinion skiving.

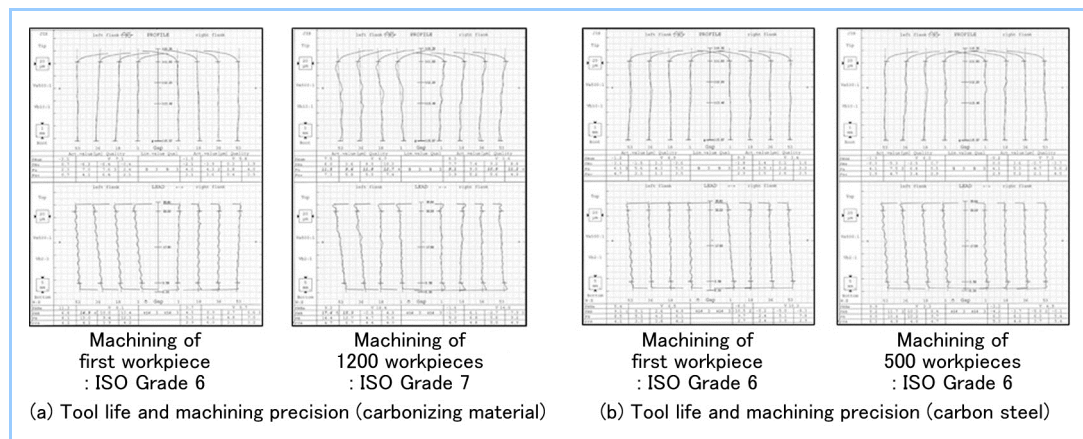


Figure 6 Tool life and machining precision

Table 1 Specifications of workpiece

Module	1.5
PCD	111.74
Number of teeth	70
Pressure angle	20°
Helix angle	20°

4. Gear grinding

The wear resistance and strength of gears are increased by hardening the surface. Therefore, after gear cutting, the tooth flank is subjected to heat treatment. On the other hand, however, the tooth flank is distorted by heat treatment and the gear accuracy is lowered. Therefore, generally, after heat treatment, gear grinding is performed to increase gear accuracy.

4.1 Internal gear grinding

For external gears, high-precision and high-efficiency gear grinding using a threaded grinding wheel has been adopted. For internal gears used in planetary gear systems, there were no appropriate gear grinding methods for mass production. Thus, we developed the ZI20A internal gear grinding machine for mass production using our proprietary barrel-shaped threaded grinding wheel^(4,5). With this machine, the crossed-axis angle between the grinding wheel axis and the workpiece axis is 20 to 35 degrees, and the grinding speed (sliding speed) is increased by high-speed synchronous control, allowing machining in about 1.5 minutes (**Figure 7**). The increase of the grinding speed improved the grindability, improving the accuracy of the gear tooth profile,

lead and pitch and increasing the grinding wheel life.

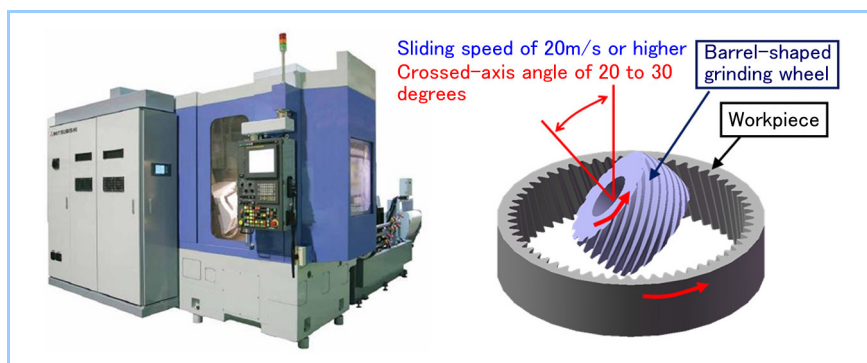


Figure 7 Internal gear grinding

4.2 External gear grinding

External gear grinding using a threaded grinding wheel is in widespread use. On the other hand, for a further increase in the fuel efficiency of automobiles and the reduction of noise and vibration, the implementation of surface finishing after normal gear grinding is being studied. The most commonly used surface finishing method is a method of machining with a grinding wheel for normal grinding and a grinding wheel for finishing being installed on the grinding wheel spindle in the same phase (**Figure 8**). Using a grinding wheel for normal grinding, the tooth flank is fully machined with abrasive grains providing sharp cutting to improve the gear profile precision. Next, using a grinding wheel for finishing, surface asperities are removed using the elastic grinding wheel of resin bonded with a small grain size to improve the surface roughness. The surface roughness using normal gear grinding is just about $Ra0.4 \mu\text{m}$, but by grinding with the grinding wheel for finishing, the surface roughness becomes $Ra0.1 \mu\text{m}$ or less, which shows a substantial improvement in the surface roughness (**Figure 9**). Thus, effects such as an increase in the transmission efficiency of gears, noise reduction and an increase in gear durability resulting from the prevention of pitching can be obtained.

Under the circumstances where demand for gear grinding has been increasing, we developed the ZE16C and ZE26C high-precision and high-efficiency gear grinding machines (**Figure 10**). These machines facilitate an increase of the gear grinding precision and productivity and feature an environmentally-friendly design that responds to user needs for space saving and the use of water soluble coolant.

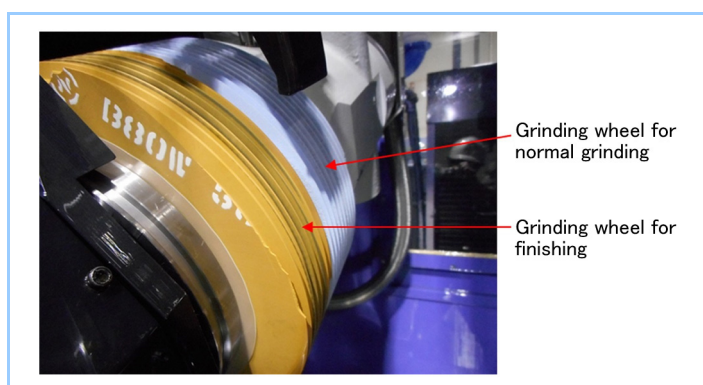


Figure 8 Grinding wheels for normal grinding and finishing

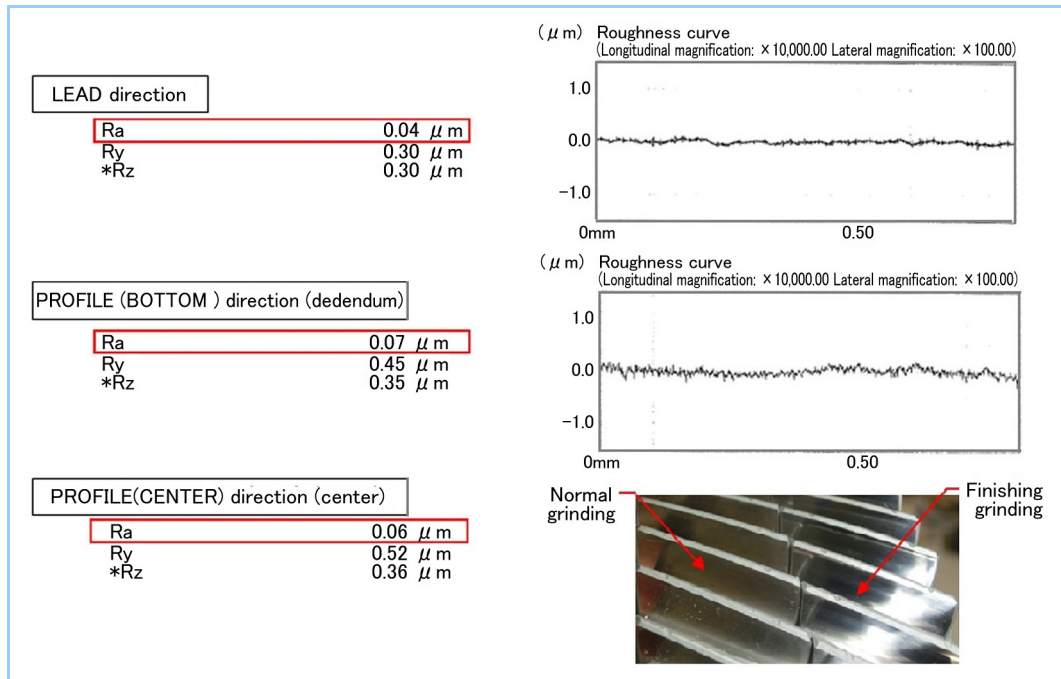


Figure 9 Results of normal grinding and finishing grinding



Figure 10 Appearance of the gear grinding machine ZE16C

5. Conclusion

To deal with the recent changes in the automobile market, such as the enhancement of fuel-economy regulations and the shift to EV, we have made efforts to improve the precision and efficiency of gears used in transmissions. For gear cutting, we developed a new machining method based on our development technologies for tools and machines, such as high-speed hobbing and skiving, and verified its effectiveness through a machining test. For gear grinding after heat treatment, a higher level of machining precision was achieved based on conventional technologies and user needs.

It is expected that progress and changes including the promotion of electrically-operated automobile power trains will continue in the future, and therefore the development of machining technologies and machine tools will be also accelerated. We will make further efforts to promote development in various fields by increasing precision and efficiency, as well as the use of skill-less techniques with machining support and the improvement of maintenance by status monitoring.

References

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