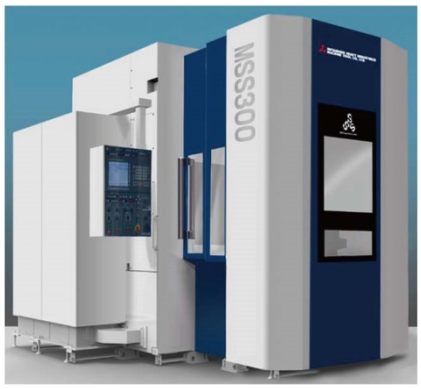
Development of MSS300 Super Skiving Machine – Realization of High-Precision, High-Efficiency Gear Cutting Method –



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In recent years, the automotive industry has been demanding high-efficiency processing of gears in terms of the trend in the increase in the number of transmissions shipped and the number of stages for multistage automatic transmissions. This trend is prevailing over not only the automotive industry, but also manufacturers in all fields including construction machinery and various reduction gears. With such a background, skiving cutting that mainly uses an internal gear has been attracting significant attention recently. Mitsubishi Heavy Industries Machine Tool Co., Ltd. also developed the MSS300 super skiving machine, which has both the optimum machine rigidity and control technology for skiving cutting. In addition, we developed a super skiving cutter, which is advantageous for tool life, which tends to be a problem in skiving cutting. This paper presents these gear cutting systems.

1. Introduction

Skiving cutting has a long history and is one of the gear cutting methods that was invented more than 100 years ago. However, it was difficult for skiving cutting to be steadily used at actual manufacturing sites because the requirements necessary for skiving cutting including machine rigidity, control technology and tool life are not sufficiently satisfactory.

In recent years, as NC technologies of machine tools and tool manufacturing technologies such as coating improve, skiving cutting has been attracting attention once again, and many machine tool manufacturers are working on the development of cutting machines and tools. We are also developing a super skiving system that consists of the following three pillars.

(1) Development of dedicated skiving machines that are superior in machine rigidity and synchronization accuracy.
(2) Development of super skiving cutter with an unparalleled tool life
(3) Development of cutting simulation software dedicated to skiving

This paper describes the developed MSS300 super skiving machine, with a focus on the machine specifications, structure, and case examples of actual cutting.

2. Skiving cutting

First, internal gear processing is explained as an example of skiving cutting. As shown in **Figure 1**, skiving cutting is one of the so-called rough cutting methods before heat treatment. Conventional main gear cutting methods consist of gear shaper cutting and broach cutting, but skiving cutting has been attracting attention in recent years.

Next, each cutting method is explained. **Figure 2** shows the cutting methods and tools used. Skiving cutting typically uses a pinion cutter. The developed super skiving machine can use not only a pinion cutter, but also our unique super skiving cutter described below. The user can freely use either of these cutters depending on the shape of the workpiece to be cut.

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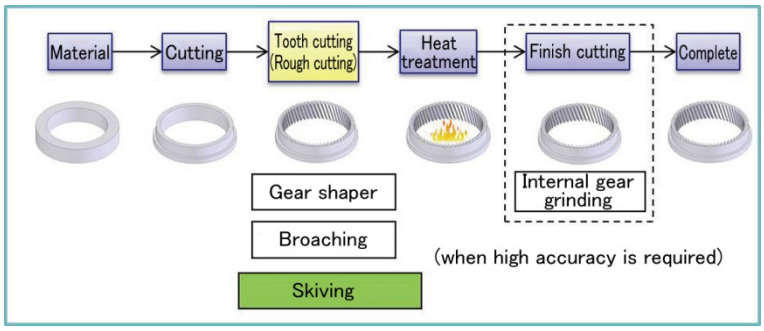

Figure 1 Manufacturing process of internal gear

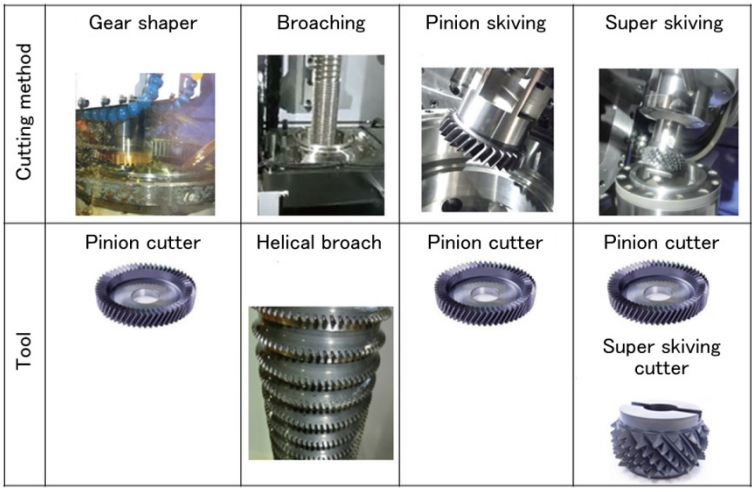

Figure 2 Gear cutting method of internal gear

Gear shaper cutting can cut a stepped gear with a minimum processing clearance and virtually without restriction in the shape of the workpiece. However, the cutting efficiency is not good and the productivity is low because chips are generated only in outward travel of the tool reciprocating motion.

Broach cutting is a mass production cutting method that is superior in productivity, but requires a high initial cost in terms of both the facilities and tools, and it is difficult to adjust its cutting accuracy.

Skiving cutting has a higher cutting accuracy than that of gear shaper cutting and broach cutting, and can attain a productivity three to five times higher than that of gear shaper cutting. In addition, skiving cutting can cut special tooth leads including crowning and tapering. The most important issue is that the tool life is short.

Figure 3 shows the principle of skiving cutting. Skiving cutting is a method to cut a gear using the slide generated on the contact point of the tool axis and the workpiece axis by rotating the two axes that are arranged so that the angle between them becomes a certain crossed axes angle.

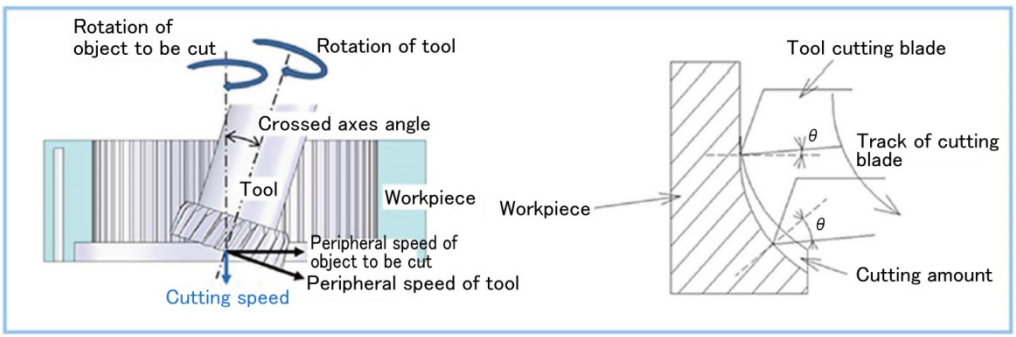

Figure 3 Principle of skiving cutting

This method can cut a workpiece to a machining accuracy of as high as ISO 4 to 5 because the tool axis and the workpiece axis use direct drive motors allowing high synchronization accuracy, and cutting with the tool meshed continuously with the workpiece makes the transfer of

the tooth profile accuracy of a tool to the tooth profile accuracy of the workpiece easy. As shown in Figure 3, however, skiving cutting has issues with large cutting resistance and significant heat generation at the tool blade tip resulting in short tool life, because the angle θ between the rake face of the tool and the cutting face of the workpiece becomes significantly negative during cutting.

3. Super skiving

Currently, the mainstream type of skiving cutting is pinion skiving, which uses a pinion cutter. However, there are still many cases where the tool life becomes a problem.

Therefore, we developed a super skiving cutter ahead of the rest of the world[(1)].

We focused attention on the barrel-shaped grinding wheel developed for our ZI20A internal gear grinding machine. The ZI20A is designed so that a large crossed axes angle is formed in order to increase the slide-cutting speed and improve cutting efficiency. The external shape of the grinding wheel used is barrel-shaped to prevent interference with the internal gear, which is the object to be cut (**Figure 4**(a))[(2)]. We developed the super skiving cutter by adding a gash and a relief angle to the barrel-shaped grinding wheel to form a multiple-blade tool (Figure 4(b)). In addition, the super skiving cutter has a tapered external shape that allows all of the multiple blades to be involved in cutting and the tool wear to be distributed (Figure 4(c)). In this manner, the tool life, which was considered to be an issue of skiving cutting, can be expected to be extended.

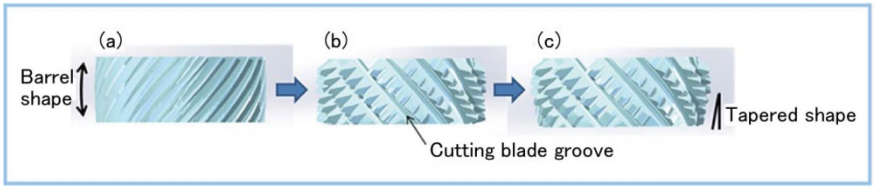

Figure 4 Barrel-shaped grinding wheel and super skiving cutter

4. Development of machine

This machine was developed based on the main concept that a high rigidity enough to deal with heavy cutting is achieved and a high positioning accuracy is ensured in order to derive the performance of the super skiving cutter. **Table 1** shows the main specifications of the developed MSS300 super skiving machine.

Table 1 Machine specifications

No.	Item	Specification	No.	Item	Specification
1	Maximum workpiece diameter (mm)	300	4	Maximum table rotating speed (min^{-1})	3000
2	Maximum cutting module	4.0	5	Maximum crossed axes angle (deg)	±30
3	Maximum spindle rotating speed (min^{-1})	6000	6	Spindle motor (kW)	33

4.1 Bed

A sliding guide surface that is superior in terms of vibration damping and rigidity is adopted for the X axis (the feeding axis in the direction of cutting during processing). Although this is a sliding guide, good positioning accuracy is secured and highly accurate cutting – also for special tooth leads including crowning as described below – is attained.

For skiving cutting that requires high productivity, the chip discharge method is also an important factor. The developed machine adopts a center trough structure, which is a method that discharges chips from the just under the cutting point directly onto the chip conveyor. As a result, it suppresses the thermal deformation of the bed to the utmost limit, resulting in stable cutting with little dimensional fluctuation (**Figure 5**).

4.2 Column and saddle

The column and the saddle have nearly symmetrical shapes and form a well-balanced structure that takes into consideration the heat flow and the force flow. In particular, the Z axis (for feeding in the workpiece tooth lead direction during cutting) eliminates the hydraulic cylinder from the conventional combination of a ball screw and a hydraulic cylinder, and adopts a twin ball screw

structure instead.

The hydraulic cylinder was used for holding the weight balance of moving objects of the Z axis (including the saddle and the spindle), but always caused energy loss during machine operation. The elimination of the hydraulic cylinder also contributes to energy saving. Naturally, the balance and the rigidity of the feeding system are significantly improved in comparison to existing technology (**Figure 6**).

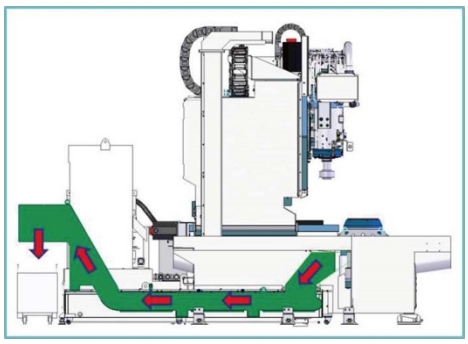

Figure 5 Center trough structure

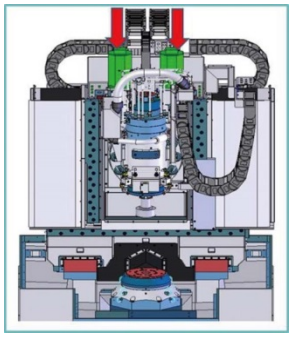

Figure 6 Tandem control of feed axis in tooth lead direction

4.3 Spindle and table axis

This machine adopted a built-in high-torque synchronous motor for the tool axis and the table axis in order to realize heavy cutting. Accurate synchronous control of the tool axis and the table axis is essential to achieve high-efficiency, high-accuracy skiving cutting. For this reason, the developed machine uses a high-accuracy encoder that has good results with our gear grinding machines to attain highly accurate synchronous control. In addition, we applied the same technology used in our high-speed machining centers for cooling of the spindle center in order to cool the spindle body and the front and back bearings, which enabled stable high-speed rotation (**Figure 7**).

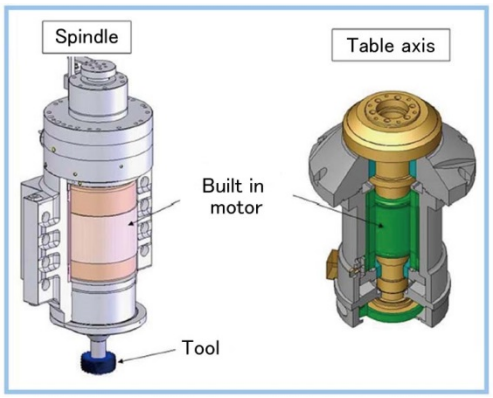

Figure 7 Structure of spindle and table axis

5. Cutting example

Figure 8 shows an example of cutting with the use of the developed cutting machine. The workpiece in this example (a ring gear (internal gear) of module 1, number of teeth: 100, helix angle of 15 degrees and face width of 25 mm) was cut to a machining accuracy of ISO 3 for the tooth profile accuracy and ISO 4 for the tooth lead accuracy in a cycle time of 60 seconds using a super skiving cutter (**Figure 9**).

In addition, a workpiece of module 1.5 (number of teeth: 70, helix angle of 20 degrees and face width of 35 mm) was cut by skiving cutting using a pinion cutter. In this case, crowning cutting (Figure 10) and tapering cutting (Figure 11), which are cutting of special tooth leads, resulted in the tooth leads as planned.

In this manner, high-efficiency, high-accuracy skiving cutting was realized.

When a super skiving cutter was used, 700 workpieces of module 1.5, which was same as the above-described one, could be cut per one time of edging. This means that the tool life is approximately four times longer in comparison to that of a pinion cutter.

Even after cutting of 700 workpieces, the maximum tool wear was still within the target

range. Therefore the test is being conducted continuously toward the final cutting target of 1,000 workpieces.

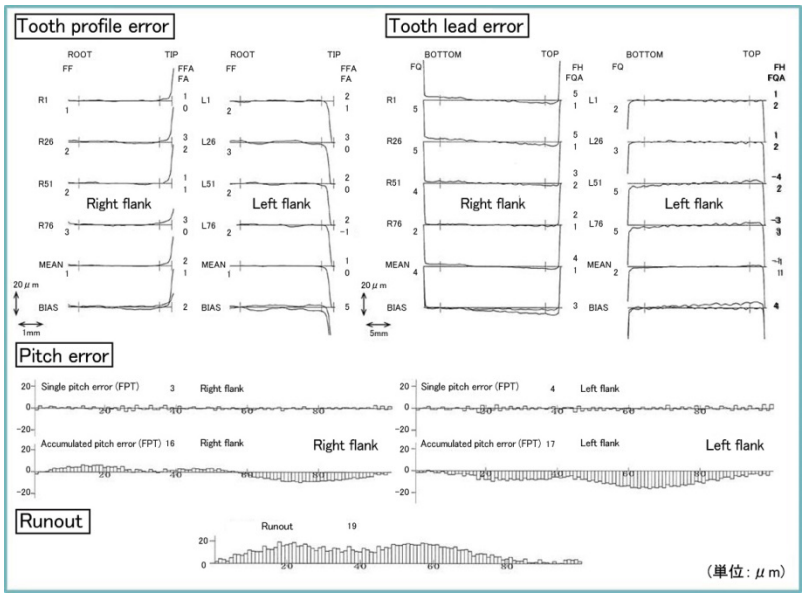

Figure 8 Cutting example

Figure 9 Super skiving cutter

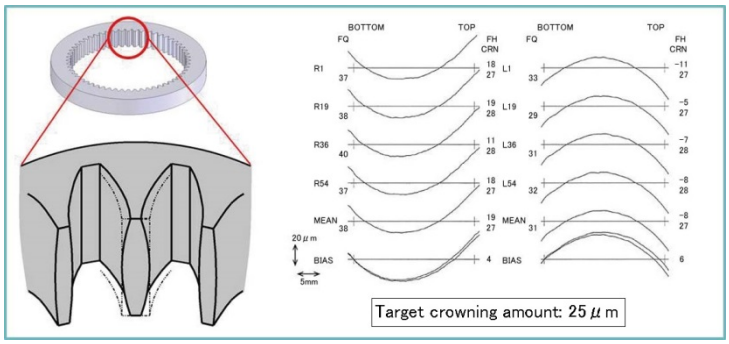

Figure 10 Tooth lead accuracy in crowning cutting

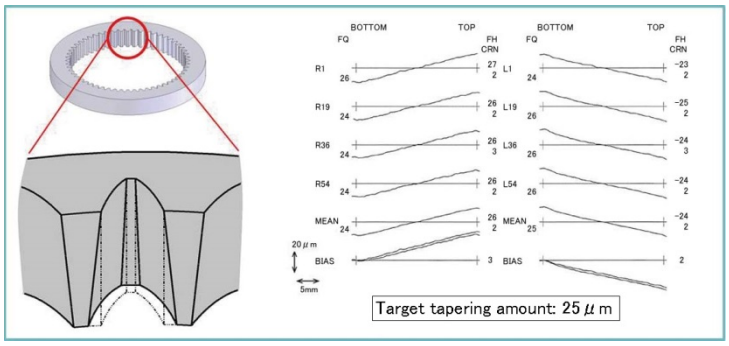

Figure 11 Tooth lead accuracy in tapering cutting

6. Conclusion

We developed the MSS300 super skiving machine, which is superior in machine rigidity and synchronization accuracy, with targeting high-accuracy and high-efficiency gear cutting, and confirmed through actual machining that the targeted cutting accuracy was successfully attained and special tooth lead cuttings such as crowning and tapering could be performed. In addition to the machine itself, we also developed a super skiving cutter that is a unique tool optimum for skiving cutting. In the future, we will continuously work on the development of new technologies such as further extending the service life of skiving tools and making the simulation software multifunctional, in order to offer the best solutions for machinery and tools to customers.

References

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