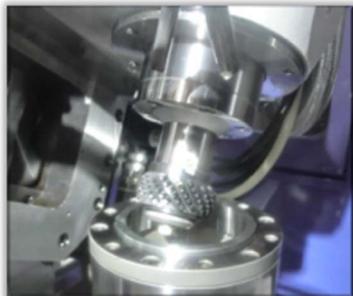


# MHI Super-Skiving System for Longer Tool Life and Enhanced Efficiency in Internal Gear Cutting



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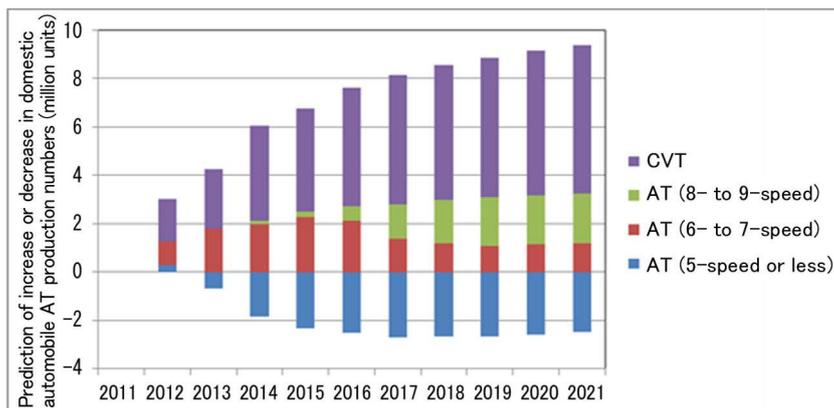
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In recent years, the automotive industry has been demanding high-precision and high-efficiency processing of internal gears (ring gears) used for planetary gear devices in terms of improvement of fuel efficiency and reduction of noise. To achieve these, manufacturers are developing a skiving cutting system expected to realize high precision and high efficiency. However, the conventional skiving cutting system using a gear shaper cutter (skiving cutting) has not come into practical use because, in principle, its cutting load is large and, therefore, tool life is shortened and production costs are increased. Against such a background, Mitsubishi Heavy Industries, Ltd. (MHI) has established a process technology with similar accuracy to the skiving cutting while exceeding it in efficiency and tool life. This paper presents the process technology.

## 1. Introduction

An internal gear is used mainly for planetary gear devices for automobile automatic transmissions (AT) and reducers of construction machines. **Figure 1** shows the increase/decrease prediction in domestic automobile AT production numbers by type. Production volume of internal gears is expected to expand along with the increase of the number of AT gear stages (increase of planetary gear devices) and of CVT and hybrid vehicles for the purpose of fuel efficiency improvement.



**Figure 1 Prediction of increase or decrease in domestic automobile AT production numbers** (This graph indicates the increase or decrease in production numbers taking 2011 as the base year.)

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**Figure 2** shows a typical manufacturing process for an internal gear. Manufacturing of an internal gear often has no finishing gear grinding process after heat treatment. Thus, it is necessary to suppress the effects of distortion caused by heat treatment as much as possible in the previous process and provide high-precision gear cutting before heat treatment. To meet these requirements,

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processing of internal gears requires high-efficiency and high-precision processing technology.

However, current gear cutting of internal gears is limited mainly to gear shaper cutting and broach cutting. These cutting methods have both advantages and disadvantages in terms of productivity, processing accuracy, production cost, etc., so the establishment of a cutting method that can attain high efficiency, high precision, and low cost was an issue. The skiving cutting previously researched is a highly efficient and highly precise method, but the tool life is too short for mass production machining. In recent years, manufacturers have been developing and researching skiving cutting methods using advanced tool materials and coating technologies. However, significant improvement of tool life has not been attained and the skiving cutting has not come into practical use.

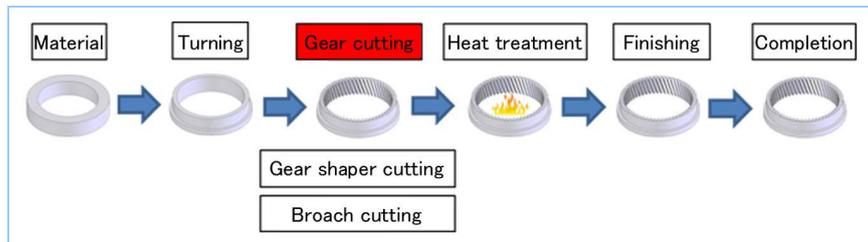


Figure 2 Manufacturing process of internal gear

## 2. Extending tool life and improving efficiency in internal gear cutting

### 2.1 Current status and issues of internal gear cutting

Figure 3 shows internal gear tooth cutting methods. Today, a gear shaper process with a gear shaper cutter and a broach process with a helical broach are mainly used. In recent years, however, skiving cutting using a gear shaper cutter has been attracting attention.

	Gear shaper cutting	Broach cutting	Skiving cutting
Cutting			
Tool			

Figure 3 Gear cutting methods of internal gears

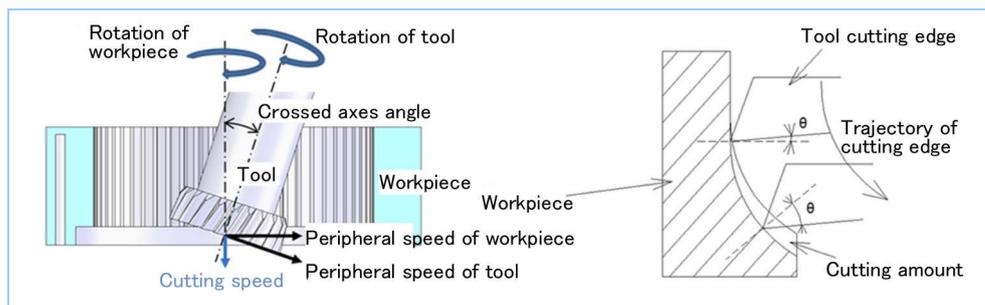
Table 1 shows the features of these process methods including the advantages and disadvantages. The gear shaper cutting is barely restricted by the shape of the workpiece, but requires a long cutting time because this process method uses the reciprocating movement of the tool for cutting, and therefore, the productivity is low. The broach cutting has better productivity, but the initial cost for the facilities is high and adjustment of machining precision is difficult. In addition, the broach cutting cannot cut large internal gears used for construction machines and stepped internal gears. To solve these issues, practical application of the high-efficiency and high-precision skiving process is being promoted.

Figure 4 shows the processing principle of the skiving cutting. As shown in this figure, the tool and workpiece (internal gear) are placed so that their rotating axes form a crossed axes angle, and are rotated synchronously to generate a sliding motion at the contact point, and thereby cutting is performed. Contrary to the gear shaper cutting that cuts the workpiece with a reciprocating motion, the skiving cutting uses a rotating motion to cut the workpiece, and then achieves high

efficiency. In addition, a processing accuracy as high as ISO class 4 to 5 is realized by transferring the tooth profile of a tool to the workpiece through continuous processing with the tool meshed with the workpiece. Also, the accuracy of tooth trace can be adjusted for such processes as crowning and taper cutting. However, the skiving process has issues with large cutting resistance and short tool life because the angle  $\theta$  between the rake face of the tool and the cutting face of the object to be cut becomes significantly negative as shown in Figure 4.

**Table 1 Features of internal gear cutting methods**

		Gear shaper cutting	Broach cutting	Skiving cutting
Cutting time		Bad	Excellent	Good
Machining precision		Moderate	Moderate	Excellent
Tool cost		Moderate	Good	Bad
Machine cost		Good	Bad	Moderate
Cutting restriction		Excellent	Bad	Good
Features	Advantage	- No cutting restriction. All shapes of workpiece can be cut.	- High productivity due to cutting motion in which the workpiece only moves up and down.	- High productivity and high machining precision.
	Disadvantage	- Low productivity because of long cutting time.	- Machine cost is very high. - Adjustment of machining precision is difficult. - Large internal gears and stepped internal gears cannot be cut.	- Tool life is short.

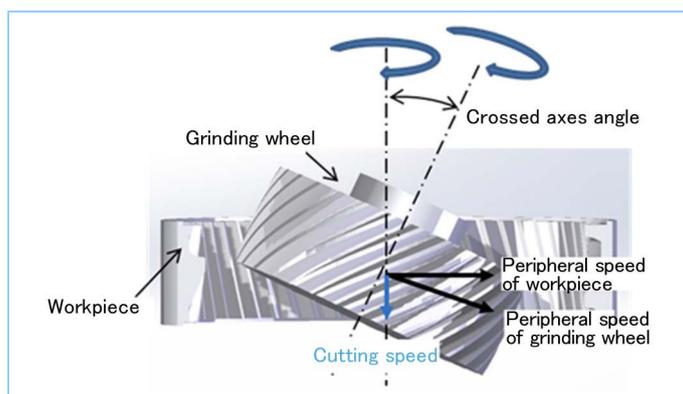


**Figure 4 Cutting principle of pinion skiving cutting**

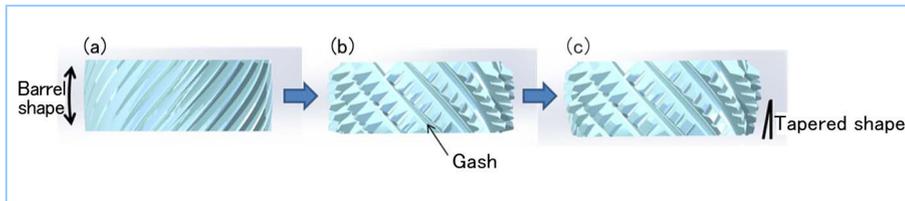
## 2.2 MHI super skiving system

### 2.2.1 Super skiving cutter

To solve the issue of short tool life with regard to the skiving process, MHI focused attention on the technology developed for the ZI20A internal gear grinding machine. As shown in **Figure 5**, the ZI20A is designed so that a crossed axes angle is formed as large as possible in order to increase the slide-cutting speed and improve processing efficiency. The threaded grinding wheel used is barrel-shaped for preventing interference with the internal gear. MHI has developed the super skiving cutter using this grinding wheel shape (**Figure 6**).



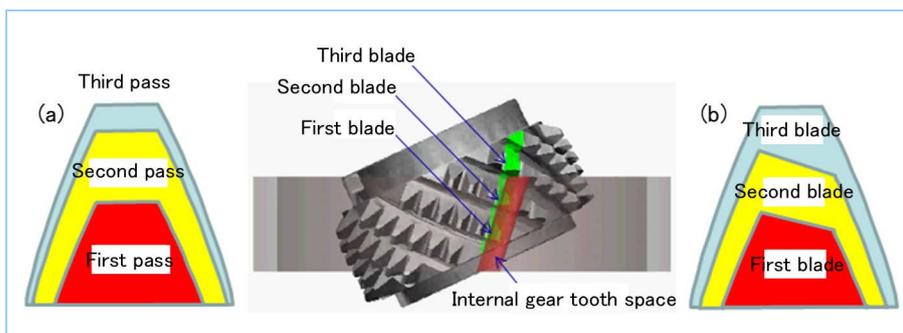
**Figure 5 Grinding method of ZI20A internal gear grinding machine**



**Figure 6 Barrel-shaped grinding wheel and super skiving cutter shape**

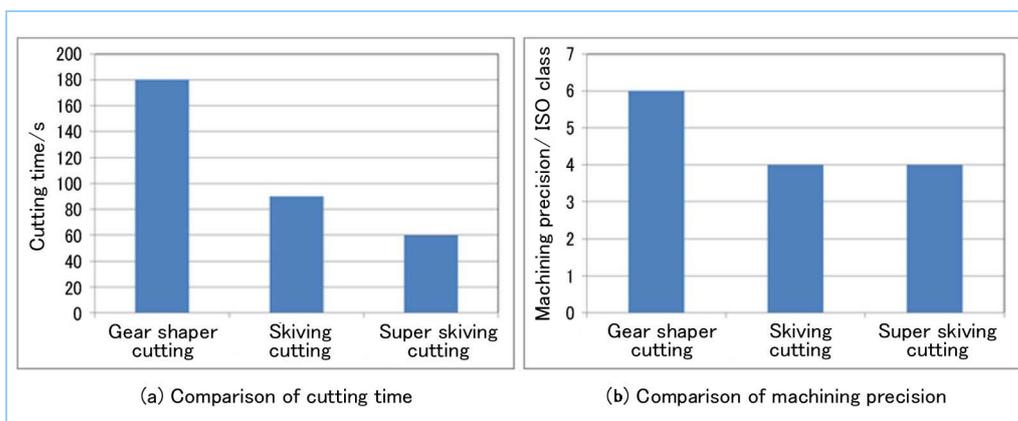
- (a) Barrel-shaped grinding wheel used for ZI20A internal gear grinding machine  
 (b) Addition of gash and relief angle  
 (c) Periphery of rough cutting area is tapered so that all teeth are involved in cutting

The processing principle of the super skiving cutter is similar to the skiving process. However, the super skiving cutter has a tool with multiple blades for cutting the tooth space of an internal gear in contrast to the gear shaper cutter that has a tool with only one cutting blade. This is attained by adoption of the tapered rough processing area of the tool that allows all of multiple blades to be involved in cutting. As shown in **Figure 7**, in the case where the skiving cutting requires three-pass cutting for processing the tooth space, the super skiving allows three blades to be involved in cutting, and therefore, the number of times one of the blades is involved in cutting is one-third of that of the pinion cutter. The reduction of the number of cutting passes also shortens the cycle time. As such, the super skiving cutter, with multiple blades and a tapered shape, can be expected to realize longer tool life and higher efficiency with the same machining precision as the skiving cutting. **Figure 8** compares the machining precision and cutting time of each cutting method.



**Figure 7 Cutting method of super skiving cutter**

- (a) Skiving cutting needs three passes with different cutting  
 (b) Super skiving cutter allows three blades to be involved in cutting in one pass



**Figure 8 Comparison of cutting performance**

### 2.2.2 Cutting simulation

With development of the super skiving cutter, cutting simulation has been developed at the same time. This simulation estimates the cutting reaction force and tool life, based on the specs of the workpiece, the characteristics of the tool and the cutting conditions, thereby resulting in the optimum tool specifications and cutting conditions.

## 2.3 Process test

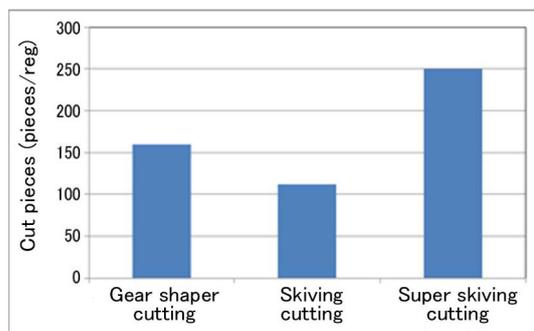
As shown in **Table 2**, the process test was conducted with the cycle time approximately half of the gear shaper cutting. According to the tool wear results in **Figure 9**, approximately 250 pieces can be cut until the wear limit of 0.3 mm is reached. **Figure 10** compares the number of cut pieces of each process method calculated from the characteristics of workpiece. The super skiving cutter is expected to approximately double the tool life compared to the skiving process. The actual wear of the tool after cutting conformed well to the cutting simulation result shown in **Figure 11**, and the validity of the simulation was verified. This tool life estimation was performed with a non-tapered cutter.

**Table 2 Characteristics of workpiece and cutting conditions**

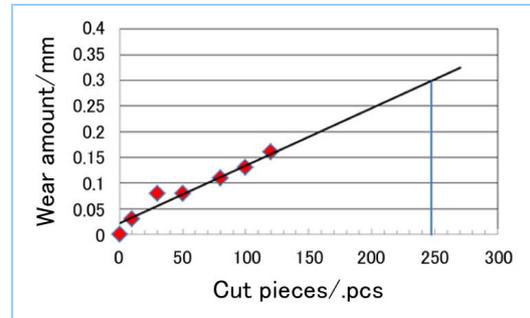
Characteristics of workpiece				
Module	Number of teeth	Pressure angle	Helix angle	Material
2	57	20°	18°RH	SCM415

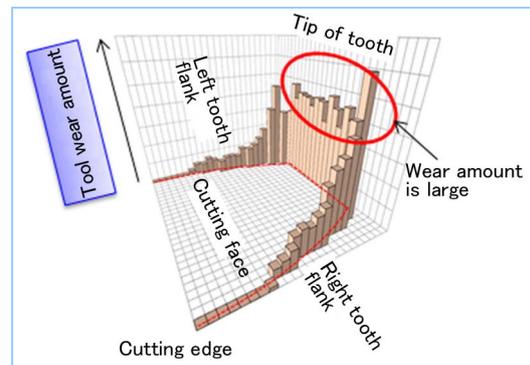
Cutting conditions		
	Cutting speed	Cycle time
Super skiving cutting	130 m/min	90s
Gear shaper cutting	50-90 m/min	180s



**Figure 10 Comparison of cut pieces**



**Figure 9 Tool wear amount**



**Figure 11 Cutting simulation result**

## 3. Future tasks

- (1) Task for super skiving cutter  
For further optimization of tool specifications, cutting results of the super skiving cutter will be fed back to the design stage.
- (2) Development of skiving grinding machine  
A skiving grinding machine will be developed in order to utilize the performance of the super skiving cutter to the maximum extent and attain efficient volume production of internal gears.

## 4. Conclusion

MHI has developed super skiving tools for internal gear processing in order to improve efficiency and extend tool life. This time, the tool life and the cutting simulation were evaluated, and validity of the simulation and extension of tool life in comparison to the skiving cutting were verified. In the future, MHI will continue development for longer tool life and higher efficiency through creating additional taper shapes and optimizing the tool design. MHI will integrate the developed tool, simulation, and machine into an internal gear processing proposal suitable to each customer.

## Reference

1. Yanase et al., The World's First Machine for Grinding Internal Gears in Planetary Gear Systems, Mitsubishi Heavy Industries Technical Review Vol. 46 No. 3 (2009)