

GRINDING INTERNAL PLANETARY GEARS

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MHI experts describe an internal gear grinding machine that has been developed for precise and efficient grinding of ring gears in automobile planetary gear systems.

Recently, various articles regarding planetary gear systems have been written and published in magazines such as *Gear Solutions*. In the main these articles cover design methods, simulation and numerical analysis to reduce the noise, vibration, and transmission errors, rather than describing the gear cutting methods to produce these systems.

Needless to say, to reduce the noise and vibration of planetary gear systems, high accuracy gear cutting is very important. Currently post heat treatment hard gear finishing of the external gear teeth, for components in the planetary system, has been established. Typically pinions and sun gears are hard finished by honing and/or grinding. However, for the internal ring gear, finish cutting after heat treatment has yet to be established.

We at Mitsubishi Heavy Industries, Ltd., would now like to introduce a newly developed grinding machine, model ZI20A, designed to grind internal gears in mass production after heat treatment with high productivity and high accuracy.

In recent years, the demand for precision machining of planetary gears has increased due to a need for reduced noise and vibration in automotive transmissions. For ring gears—one of the components of a planetary gear system—conventional finishing methods has been gear shaping or helical broaching, followed by heat

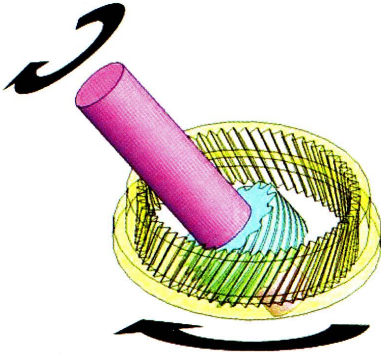


Fig. 1: Grinding method.

treatment. To meet the increasing requirement of the aforementioned demand, mass-produced planetary gear systems must be hard finished after heat treatment with high accuracy and efficiency. This article presents a new gear-grinding machine, developed specifically for the economical hard finishing of automotive internal ring gears in mass production.

INTRODUCTION

A planetary gear system is compact, provides a large reduction, and is used in many applications such as automatic automobile transmissions and hybrid drive systems. In order to reduce gear noise and vibration in these systems, the demand for higher quality internal gears as well as external gears has increased. To meet these goals, gear manufacturers require efficient post heat treatment gear finishing methods.

Generally, there are two different methods of grinding gears; generating, and form. The generating method is normally applied to mass production due to its high precision and efficiency. Though accurate, form grinding with an electroplated tool is not generally used in high produc-

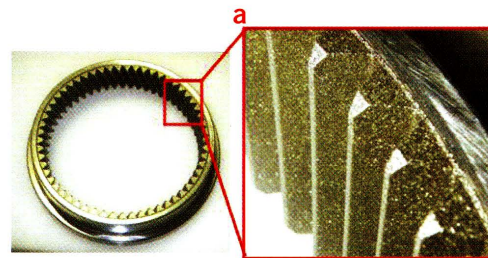


Fig. 2: The dressing gear (a) and the barrel-shaped grinding wheel (b).

tion due to low efficiency and the high cost of tools.

This article presents Mitsubishi's new gear grinding machine as a solution for efficient hard gear finishing of internal ring gears in mass production. The process is generating grinding utilizing a multi threaded vitrified grinding wheel. This machine with its targeted design has the following features:

- High speed generating grinding with precision synchronous control of the spindle units for the grinding wheel and the workpiece table.
- The crossed axis angle between the wheel and the workpiece axes is set over 10 degrees to obtain high sliding velocity at the grinding point. The grinding wheel is barrel-shaped.
- The grinding wheel is vitrified bonded and then easily formed and dressed on the grinding machine. The dressing unit is mounted to the machine bed with the dressing motion controlled by CNC.

This paper describes the grinding method of ring gears, machine structure, and the grinding application.

GRINDING METHOD

Machining principle: The internal gear grinding machine with the multi-threaded grinding wheel is shown in fig. 1. The grinding wheel and workpiece are meshed with a generating motion. In order to improve grinding performance and grinding ratio, the grinding wheel spindle and workpiece table are rotated synchronously with high speed. One feature of this machine is the crossed axis angle between the wheel and the workpiece axes from 20 to 35 degrees. This provides an elevated sliding velocity at the grinding contact point. By high speed grinding, gear accuracy—including pitch, profile and lead deviation—is improved, with tool life also extended.

Grinding wheel shape: The grinding wheel for this machine is barrel-shaped to avoid interference between the grinding worm and ring gear undercut surface. The profile of the barrel shaped grinding worm

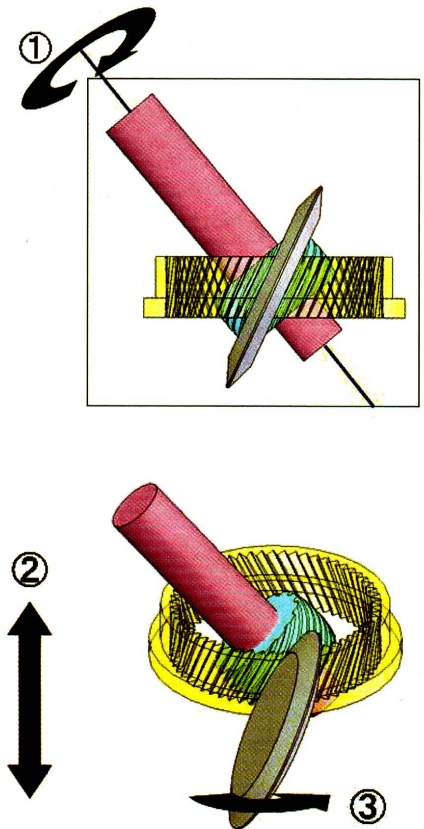


Fig. 3: The dressing motion.

and the dressing method are analyzed theoretically to develop the process.

Dressing method: The grinding wheel also requires dressing to maintain the grinding worm profile like other grinding wheels. Possible dressing methods are as follows.

Dressing gear (master gear): The master dressing gear, which has identical geometry to the finished workpiece, is electroplated with diamond on its toothed surface. The dressing gear is automatically loaded and clamped to the workpiece fixture during the dressing cycle, similar to workpiece grinding. The dressing gear and the barrel-shaped grinding wheel are shown in fig. 2.

Disk-type dresser: The profile of the disk-type dresser is similar to that of the tooth profile of the ring gear (the contact line between the grinding wheel and the ring gear). The grinding wheel is dressed one thread at a time. The dressing motion is shown in fig. 3. This method offers flexibility compared to that of the master dressing gear because of the ability to modify the tooth profile.

Tool life: Unlike the case for grinding external gears, the grinding wheel for internal gears is to be dressed with higher frequency since its diameter is small and less than that of the workpiece. This is not ideal in terms of cycle time and tool life. To solve this problem dressable vitrified CBN grinding wheels—with longer life than conventional vitrified wheels—are used in the machine. Furthermore, with the high speed spindles, in conjunction with the large crossed axis angles, it is possible to achieve more than 20 m/s grinding speed. This leads to extended tool life, reduced cycle time, and reduced tool cost.

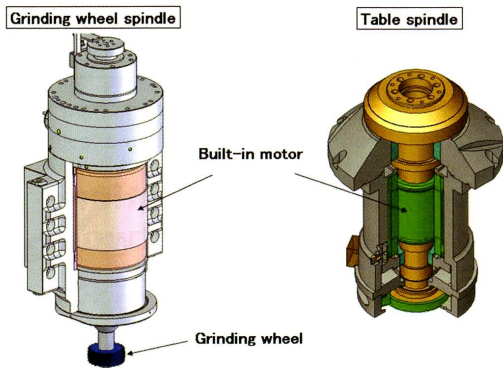


Fig. 4: Structures of the grinding and table spindles.

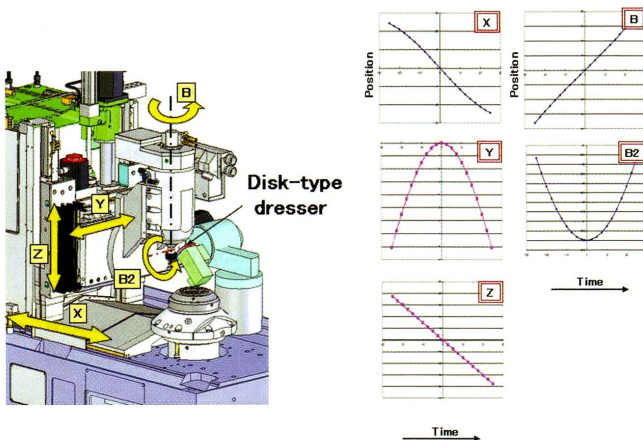


Fig. 5: The dressing unit and dressing motion axes.

MACHINE DEVELOPMENT

The new machine's development is based on Mitsubishi's successful external gear grinding machine, model ZE15A. The main specifications are shown in table 1.

Grinding/Table spindle design: In order to realize a maximum efficiency gear grinder using multiple threaded grinding worms, synchronous control of the grinding and table spindles with high precision is required. To achieve this integrated direct drive designs are adopted for the two spindles. The grinding and table spindles have a maximum speed of 15,000 and 6,000 rpm, respectively. The structures of the spindles are shown in fig. 4.

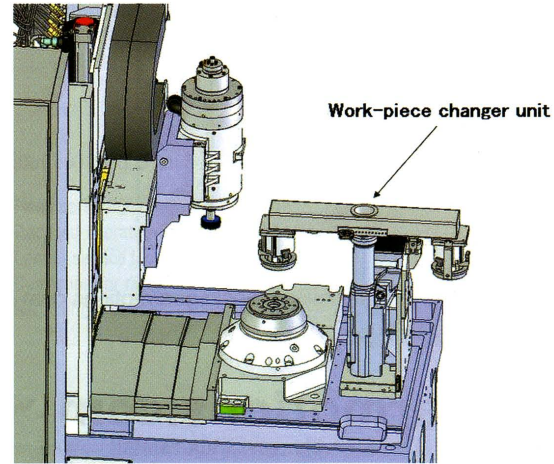


Fig. 6: The workpiece changer unit.

Dressing unit: Since the dressing gear is clamped in the workpiece fixture, a separate powered dressing unit is not required. The dressing gear is automatically loader into place from its storage location opposite the operator position.

As an alternative to the master dressing gear a CNC dressing unit can be purchased. This CNC dressing unit is positioned and clamped with a high precision coupling and placed in front of the grinding wheel during dressing. Since the barrel-shaped grinding wheel is different from the normal worm (gear), the dressing motion is complicated. The dressing unit has a swivel mechanism, an integrated direct drive, and a precision scale unit. Furthermore, the dressing program of the five axes synchronous

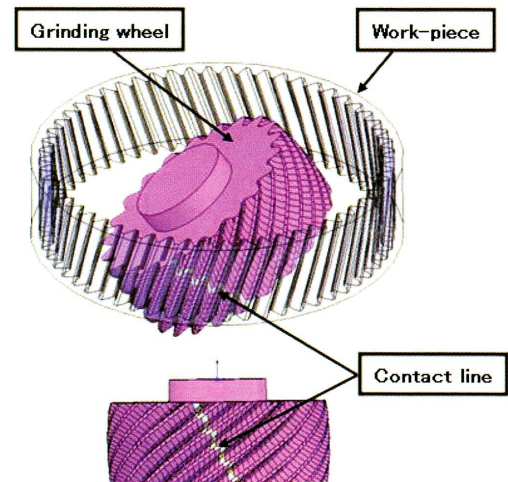


Fig. 7: A 3D-CAD example of the contact line between the grinding wheel and the workpiece.

No	Item	Specification
1	Outside diameter of work-piece (mm)	max 200
2	Module	max. 3
3	Max speed of grinding wheel (min ⁻¹)	15,000
4	Max Speed of work-piece (min ⁻¹)	6,000
5	Crossed axis angle	max. 40
6	Grinding spindle drive (kw)	25
7	No System	5 axes controlled simultaneously

Table 1: Main specifications.

control had to be developed for the new machine. The dressing unit and dressing motion axes are shown in fig. 5.

Automation: To grind ring gears efficiently in mass production, the machine is equipped with automation, as follows.

Workpiece changer: In order to reduce loading/unloading time, a high speed cam unit is used for workpiece changing, similar to a conventional ATC (automatic tool changer). Fig. 6 shows the workpiece changer unit.

Tooth meshing system: For gear grinding, it is necessary to detect the pre-cut tooth space of the workpiece, so that it can be automatically meshed with the grinding wheel. A non-contact sensor is used to detect the position of all the workpiece teeth and thus to set the meshing position. Since it is not easy to check meshing for internal gear grinding compared to external gear grinding, an automatic meshing system with AE (acoustic emission) sensor is equipped standard with the machine. This system leads to ease of machine use in setup and changeover.

SUPPORTING SOFTWARE

In the gear grinding process, analysis of machining errors and modification of the tooth surface errors are important to make high quality gears. Programming of the grinding wheel profile by numerical analysis, and using the simulation tool to check contact and interference between the grinding worm and workpiece by 3D-CAD, have been developed. These tools are necessary to design the specification of the grinding wheel and to modify the grinding or dressing motion in the case of tooth surface errors. Also, these tools are effective for prediction and troubleshooting. The example of the contact line between the grinding worm and the workpiece by 3D-CAD is shown in fig. 7.

MACHINING EXAMPLE

A machining example is shown in figs. 8 and 9. The machining accuracy of the ring gear (Module 2, P.C.D. 120 mm, face width 30 mm) is JIS class 4. The target production cycle time is 70 seconds. Since the workpieces are thin-walled, the pre-machining accuracy is JIS class 10 to 11 due to thermal distortion. Following grinding, the gear accuracy is improved to JIS class 4.

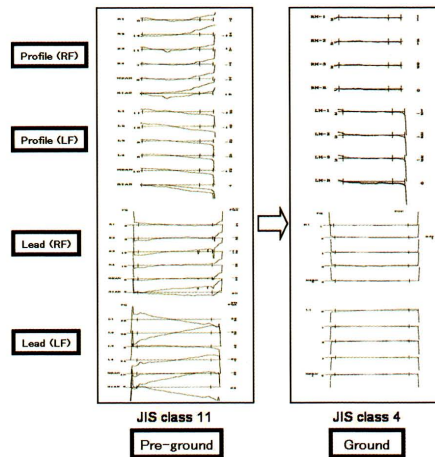


Fig. 8: The machining accuracy (profile and lead).

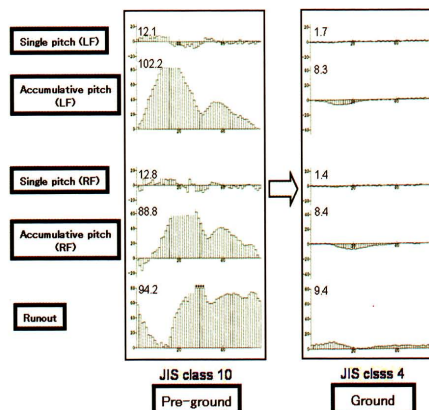


Fig. 9: The machining accuracy (pitch).

CONCLUSION

The Z120A internal gear grinding machine has been developed for high precision and high efficiency grinding of ring gears in automobile planetary gear systems. The machining result shows that the accuracy of the ring gear after heat treatment is JIS class 4, and that all gear geometries are improved by gear grinding. The issues of tool life and tool cost are resolved by the use of high speed grinding spindles and vitrified CBN wheels. The result is that the new machine is capable for mass production in the automobile industry.

We at Mitsubishi will continue to respond to the needs of the industry by offering gear grinding machines that feature higher precision, higher efficiency, and ease of operation and setup with automatic calculation for the grinding conditions. Planetary gear systems will continue to be widely used even in future transmissions for hybrid vehicles. As a consequence further demands for less noise and vibration are expected to increase.

With the development of the Z120A internal grinding machine, it is now possible to finish grind the ring gear of planetary gear systems after heat treatment with high productivity, high accuracy at affordable cost. This new development means that now all gears in a planetary gear system can be machined with high accuracy after heat treatment, and will thus be able to meet the needs for further reductions in noise and vibration.

Finally, one cannot overlook the advantage this internal gear grinding process brings to mass production in terms of its predictability and stability. Reliability for quality control also cannot be underestimated, an advantageous point which should not be underestimated for many manufacturers. 🚫