ZE16C/26C Gear Grinder - Supporting Gear Manufacturing with High Precision and Efficiency

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In recent years, the need for high-precision and low-cost gear manufacturing has been growing against the backdrop of increasing demand for the electrification of automobiles, low fuel consumption and low noise, as well as the miniaturization of reduction gears for robots. In the manufacture of high-precision gears, gear grinding is commonly performed to improve the deterioration of shape accuracy after heat treatment. Accordingly, there is an increasing demand for gear grinders that make the stable mass production of high-precision gears possible.

Mitsubishi Heavy Industries Machine Tool Co., Ltd. has developed the ZE16C that adopt - stracture and the ZE26C, a series of gear grinders on the basis of gear processing technology cultivated until now, to meet the needs for high-precision, highly-efficient gear manufacturing. This paper presents these products with our efforts for high-precision manufacturing and our unique water-soluble coolant that meets the needs for environmental load reduction and energy conservation.

1. Features of ZE16C/26C gear grinders

1.1 High-precision gear grinding

Mainstream gear grinders for mass production are continuous generation types that grind tooth flanks using a threaded grinding wheel. In case of this method, the threaded grinding wheel and the gear to be ground rotate synchronously at high speed in accordance with the ratio of the number of teeth, making high-efficiency grinding possible. However, to realize high-precision grinding, it is necessary to suppress the vibration and error components during grinding. The grinding accuracy of a gear is usually evaluated based on the error of the tooth profile and tooth helix and pitch error. However, since even a very small amount of undulation of a tooth flank at a micron level influences the vibration and noise at the meshing of the gears, minute undulation is also evaluated for high-precision gears. Accordingly, this machine adopts a revised-structure spindle to achieve the enhancement of the static rigidity by 50% and the dynamic rigidity by 35% compared with our conventional machine, and thereby realizes the improvement of the grinding accuracy and tooth flank undulation.

1.2 Improvement of productivity

Gear grinding requires non-grinding time for clamping, unclamping and replacing of the gear to be ground, as well as tooth meshing between the grinding wheel and the gear to be ground, dressing of the grinding wheel, etc., so shortening this non-grinding time is important for productivity improvement. Accordingly, the ZE16C/26C has a non-contact sensor for tooth meshing on the counter column side close to the gear to be ground, as well as an increased table rotation speed at the detection time to shorten the tooth meshing time (**Figure 1**).

In addition, the ZE16C adopted our proprietary gantry-type counter column structure to attain high-speed workpiece changing operation and tooth meshing operation (**Figure 2**). As a result, in the case of a ring type workpiece, for example, the time for changing the workpiece and tooth meshing is reduced from the conventional 17 seconds to 6 seconds, or less than half. By adopting the gantry-type counter column structure, the adoption of a high-speed workpiece changer is made possible and the grinding wheel dressing device can have a structure for moving up and down on the counter column side face. This structure enabled a 20% reduction of the machine bed length compared with the conventional machine and realized space saving.

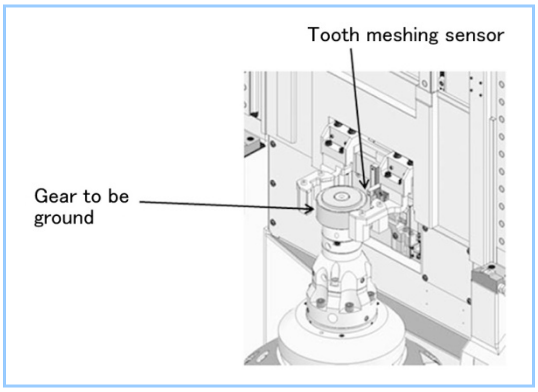

Figure 1　Tooth meshing sensor and gear to be ground

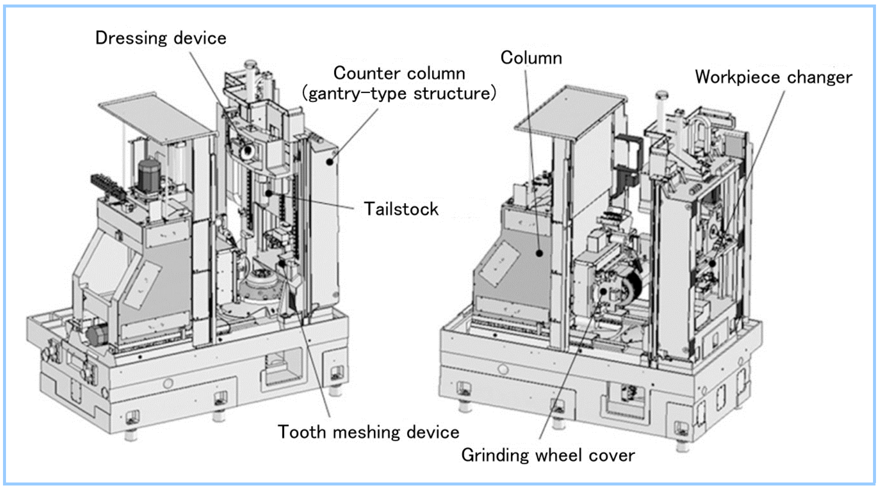

Figure 2　Machine structure (ZE16C)

By combining the reduction of non-machining time described above, the increase in the rotation speed of the grinding wheel axis and the extension of the grinding wheel life by enlarging its width, productivity can be improved by 20% or more in comparison with the conventional machine. In addition, the maintainability and reliability of the machine are improved by analyzing the sections that cause machine failure based on past results and reviewing the structure thereof. **Table 1** lists the machine specifications of the developed ZE16C and ZE26C gear grinders. The ZE16C can grind gears up to ϕ 160 mm, and the ZE26C can grind a wide range of gears up to ϕ 260 mm with high precision and efficiency.

Table 1　Machine specifications of ZE16C/26C gear grinders

Specifications	Unit	ZE16C	ZE26C
Workpiece diameter	mm	ϕ 20- ϕ 160	ϕ 20- ϕ 260
Module		1-4	1-6
Workpiece length	mm	200	350
Workpiece rotation speed	min^{-1}	Up to 3,000	Up to 2,000
Grinding wheel diameter	mm	ϕ 208- ϕ 300	
Grinding wheel width	mm	125/160	
Grinding wheel rotation speed	min^{-1}	Up to 8,000	

1.3　Grinding example

Figure 3 shows a gear ground by the ZE16C gear grinder. A gear with a module of 3, 31 teeth, a helix angle of 20°, an outer diameter of 105 mm and a tooth width of 40 mm was ground in a cycle time of 49.5 seconds, and the grinding accuracy of JIS N1 class (JIS B 1702: 1998) was attained. This indicates that this machine is capable of the mass production of high-precision gears.

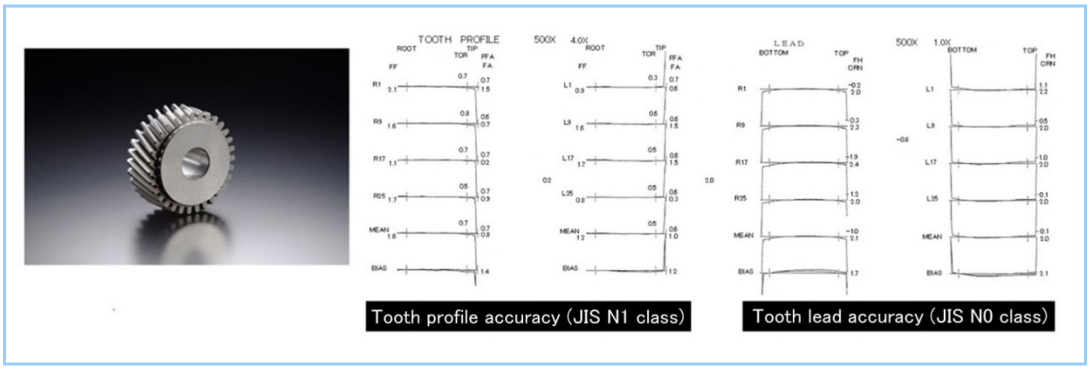

Figure 3 Grinding example (ground gear)

2. Efforts for high-precision grinding

2.1 Wide grinding wheel width for polish grinding

Surface finishing (polish grinding) after normal gear grinding for the manufacture of high-precision gears is being studied. The most common method is to attach a grinding wheel for normal grinding and a grinding wheel for polish grinding in the same phase to the grinding wheel axis (**Figure 4**). Polish grinding uses a resin-bonded elastic grinding wheel with a small particle size to remove the bumps from the tooth flank to improve the surface roughness. This machine supports simultaneous attachment of a grinding wheel for normal grinding and a grinding wheel for polish grinding to enable polish grinding. The surface roughness Ra of a normally-ground tooth flank is about 0.4 µm, but this machine achieves a surface roughness Ra of 0.1 µm or less by polish grinding (**Figure 5**). As a result, it is expected that the transmission efficiency and quietness of gears will be improved and that pitching will be prevented, which facilitates improved durability. In addition, it was confirmed that installing polish-ground gears on an automobile transmission enables a reduction in the vibration noise, or so-called gear noise, that occurs when the gears mesh with each other.

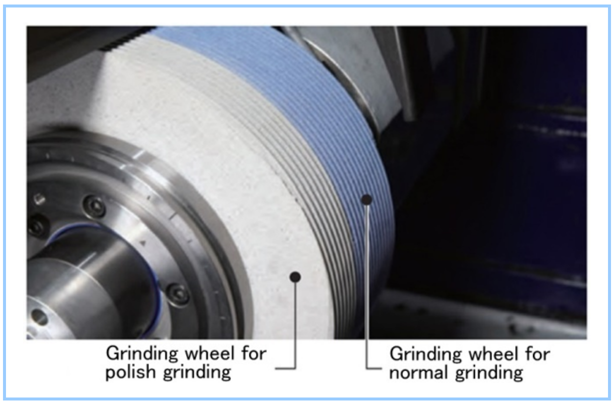

Figure 4 Grinding wheels for normal grinding and polish grinding

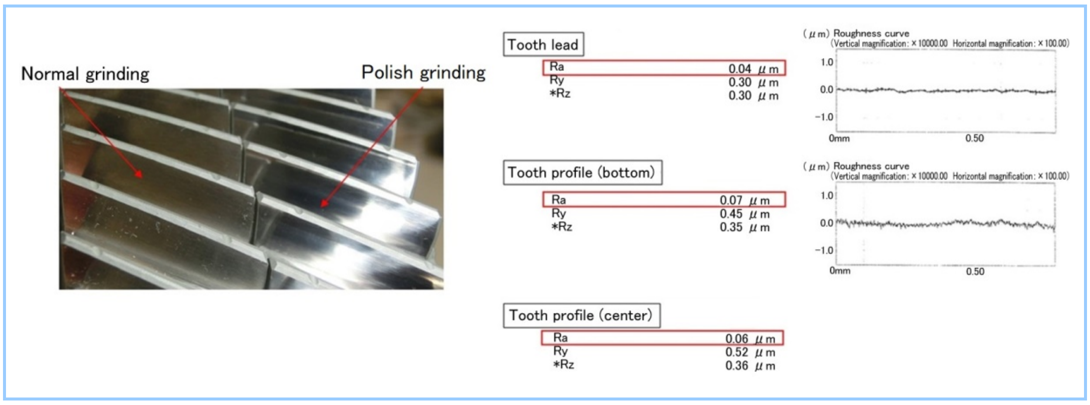

Figure 5 Grinding results of normal grinding and polish grinding

2.2 Simultaneous bias modification of both tooth flanks

In the field of gear systems such as automobile transmissions and reduction gears for robots, efforts to design, manufacture and verify complex tooth flank shapes are being made for the purpose of the downsizing and improvement of quietness. Among these efforts, bias modification that controls the twist of a tooth flank (so-called bias tooth flank) that occurs when crowning is applied to a helical gear in the tooth lead has become an essential technology in the electrification of automobiles in recent years (**Figure 6**). Generally, bias modification uses a grinding wheel formed by a dressing operation different from normal operation. Our conventional machines perform bias modification in which the tooth flanks of a gear are ground one by one. However, this machine uses a newly-developed rotary dresser swivel mechanism to enable simultaneous bias modification of both tooth flanks. As a result, gears with complicated tooth flank shapes, which cannot be made using normal processes, can be manufactured in a short time.

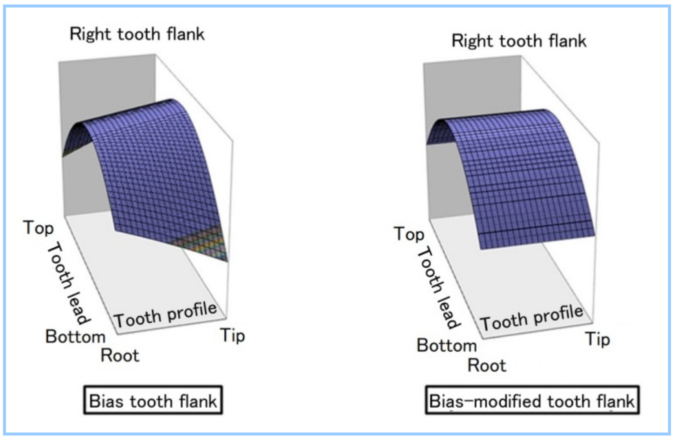

Figure 6 Crowned tooth flank shape (bias tooth flank) and bias-modified tooth flank shape

3. Mass production of gears using water-soluble coolant

Generally, the mass production of gears using generation type gear grinding often uses oil-based coolant. We have succeeded in the mass production of gears using generation type gear grinding with water-soluble coolant for the first time in the world, to be able to meet the increasing need for environmental load reduction and energy conservation. For the realization of the stable mass production of gears with water-soluble coolants, an optimal grinding wheel, coolant and coolant device are indispensable, so we worked with manufacturers of such items to conduct development including the verification of actual equipment (**Figure 7**). Using water-soluble coolant with high cooling performance enables the reduction of the amount of coolant used compared to oil-based coolant, resulting in a reduction in coolant cost of roughly 80%. In addition, the risk of fire can be eliminated, so there is no need to provide fire extinguishing systems, and the extension of the life of the dresser can be expected due to the use of a dedicated grinding wheel. Furthermore, by reviewing all the component parts used in the equipment and replacing them with parts compatible with water-soluble coolant to prevent failures caused by the use of water-soluble coolant, a mean time between failures (MTBF) equivalent to that when oil-based coolant is used is achieved. By these efforts, the grinder of the environmental consideration type suitable for future age was realized.

Figure 7 Paperless and environmentally-friendly coolant device dedicated for use with water-soluble coolant

4. Future prospects

It is considered that demand for electrification, low fuel consumption and low noise of automobiles will continue to increase in the future, as will the trend toward higher precision and higher efficiency in gear manufacturing. While further accelerating efforts for high-precision grinding and the reduction of environmental load presented in this paper, and working to improve efficiency including the reduction of non-processing time, we will continue to develop products that meet customer needs such as the enhancement of process support applications, machine status monitoring using IoT technology, preventive maintenance, etc.