High-precision Machining Technology for Large Machining Centers Special Jet Lubrication and Advanced Thermal Displacement Suppression System

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As the precision required for machined parts of industrial machinery and large dies of automobiles increases, the need for high-precision machining of large parts is increasing. To enable high-precision machining, it is imperative to reduce the heat deflection of machine tools used in large machining centers due to internal and external temperature changes of the tools themselves. A new high-precision machining technology is required because the existing technology, which compensates for heat deflection due to heat generated by the spindle, can no longer meet the aforementioned need for high-precision machining. To overcome the problem, Mitsubishi Heavy Industries, Ltd. (MHI) has applied an internal cooling method for the spindle to large machining centers that was perfected through our experiences with small precision machine tools, in addition to a spindle heat deflection reduction technique using special jet lubrication. The company also developed an advanced thermal displacement suppression (ATDS) system for the entire machine body.

1. Introduction

As the precision required for machined parts of industrial machinery and large dies of automobiles increases, the need for high-precision machining of large parts is increasing. It is often necessary to achieve machining precision of ±10 μm. To enable such high-precision machining, measures to deal with heat deflection have usually been taken, such as to install the machine in a temperature-controlled factory or to carry out the finishing process separately. However, there is increasing need for high-precision machining to be carried out even if the machine is installed in a general-purpose factory environment without air conditioning. Thus far, heat deflection compensation measures have been employed to deal with heat deflection due to internal factors such as heat generated by the spindle, while measures using heat stabilizing wall plates and thermally symmetrical structures have been implemented to deal with external factors such as room temperature changes around the machine. However, it is no longer possible to sufficiently meet such needs for high-precision machining with these measures. To tackle the issue, MHI developed MVR, a double-column, five-face milling machine, equipped with the new ATDS system that allows high-precision machining in general-purpose factories. The following outlines the milling machine.

2. Problems of and challenges for existing technology

Since large parts machining by large machining centers involves large machining tools as well as large workpieces, the heat deflection caused per degree Celsius of machine temperature can be several times as high as processes carried out by smaller machining centers. This significantly affects the machining precision. Therefore, to enable high-precision machining, it is imperative to

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reduce the heat deflection of the machine tools used in the large machining center due to internal and external temperature changes of the tools themselves, and measures must be applied for both the spindle and the machine body. Existing heat deflection compensation technology compensates for heat deflection in accordance with the amount of heat generated by the spindle. The precision of heat deflection compensation using this method is only ±15 µm at the most. However, since the heat deflection compensation precision is lower than the required level of machining accuracy (±10 µm), it is essential to improve the precision of spindle heat deflection compensation by effectively removing the heat generated by a spindle bearing. In addition, to meet the need for high-precision machining in a general-purpose factory environment, it is necessary to achieve stable high-precision machining by providing a structure that is hardly deflected by heat, even in an environment where the daily temperature fluctuations are significant. For that purpose, MHI developed a technique to compensate for the heat deflection of not only the spindle, but also of the entire machine body.

3. Spindle heat deflection reduction technique

3.1 Purpose

Requirements regarding the heat deflection of the spindle include: a smaller amount of spindle heat deflection even during high-speed rotation; a shorter period of time required to stabilize heat deflection, thus resulting in a reduced time for warm-up; and a stable amount of heat deflection during lengthy machining processes. To meet such needs, MHI applied an internal cooling method for the spindle to large MVR machines that was perfected through our experiences with small precision machine tools, in addition to a special jet lubrication technology for ball bearings. The following outlines the structure and effects of the special jet lubrication spindle.

3.2 Internal structure of spindle

Figure 1 illustrates the structure of the tip end of a spindle. Ball bearings, which are the source of the heat, are supplied with lubrication oil cooled in accordance with the generated heat so that the bearings are effectively cooled. In addition to cooling the outer housing of the spindle, which is a method that is already employed, the cooling oil is circulated inside the rotating spindle, thereby preventing the spindle temperature from rising.

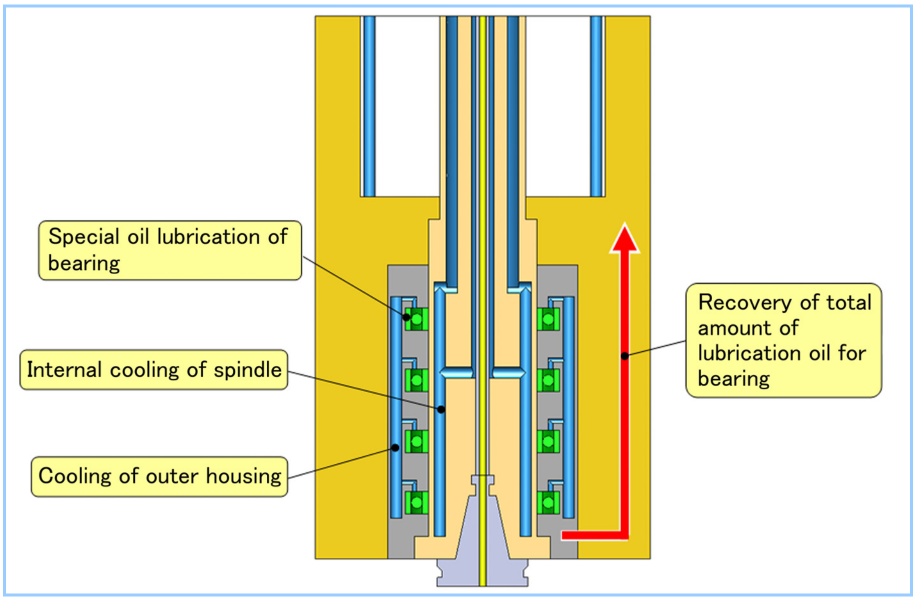

Figure 1 Internal structure of spindle

3.3 Effects of internal cooling of spindle and special jet lubrication of bearings

With these spindle heat deflection reduction techniques, the amount of heat deflection of the spindle is suppressed to ±5 µm or less, thus achieving a level of precision that meets the aforementioned need for high-precision machining (**Figure 2**). In addition, with the provision of a mechanism to recover the total amount of lubrication oil supplied to the bearings, oil dripping from the spindle can be prevented, making the spindle suitable for materials that are incompatible with oil, such as carbon and ceramics, as well as for resin processing.

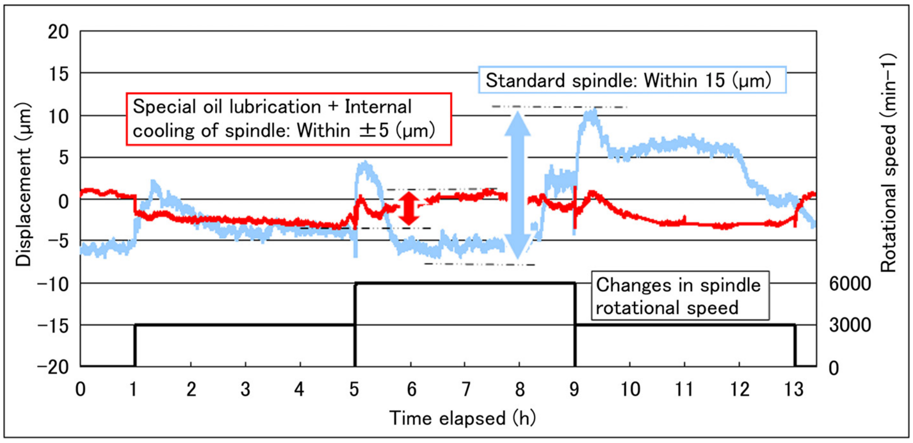

Figure 2 Actual measurements of spindle heat deflection

4. Advanced Thermal Displacement Suppression (ATDS) System for machines

4.1 Purpose

In general, capital investment and a decrease in production efficiency pose issues when taking measures for high-precision machining by large machining centers. To counter this issue, MHI developed a new ATDS system designed to improve user productivity and add further value to high-process machining, based on a concept of "a machine resistant to ambient temperature changes."

4.2 Designing of machine structure resistant to ambient temperature changes

Heat deflection of machining tools is caused by changes in structure temperature resulting from ambient temperature changes in a factory. Accordingly, it is important that the structure temperature should not be easily changed, even when the ambient temperature changes, and that the temperature of the entire machine should be changed uniformly so as to prevent inclination or torsion. MHI simulated an optimum machine structure that is less likely to cause heat deflection even when the ambient temperature changes, optimized the structural shapes of cross rails and columns and determined the arrangement of heat stabilizing wall plates (**Figure 3**).

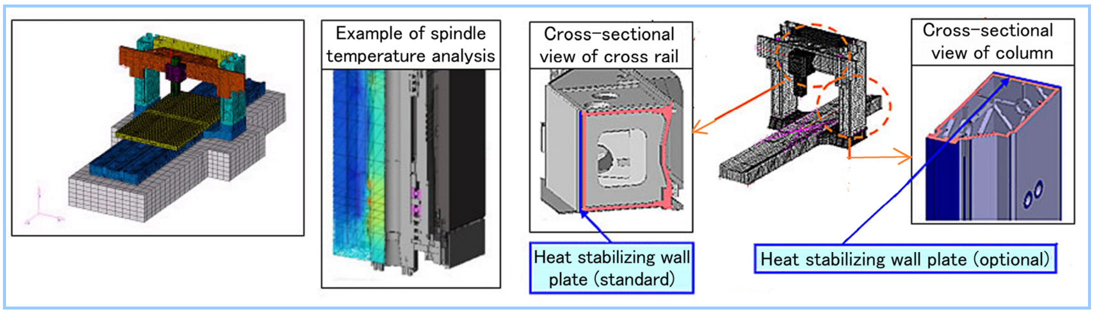

Figure 3 Example of heat deflection analysis

4.3 Advanced Thermal Displacement Suppression (ATDS) system

The ATDS system is a technique developed by applying MHI's proprietary thermal analysis technology, which was perfected through our experiences with power generation turbines and other equipment, to machining tools. The system combined, in a well-balanced manner, three thermal analysis technologies based on thermal analysis simulations: 1. machine structure; 2. cooling system; and 3. thermal displacement prediction/compensation technology. This significantly reduced the impact of heat deflection and enabled a machining process that requires no warm-up and ensures stable precision over lengthy periods.

Figure 4 illustrates an overview of the system. The system not only reduces heat deflection through the improvement of robustness to changes in ambient temperature, but it also adopted a method to compensate for generated heat deflection by monitoring the temperatures of various parts of the machine. MHI also developed a technique to correct the spindle position through the real-time measurement of column inclination due to heat deflection, as well as a technique to three-dimensionally compensate for the deflection of detachable attachments (additional spindles).

Thus, the system is characterized by its ability to compensate for the heat deflection of the entire machine.

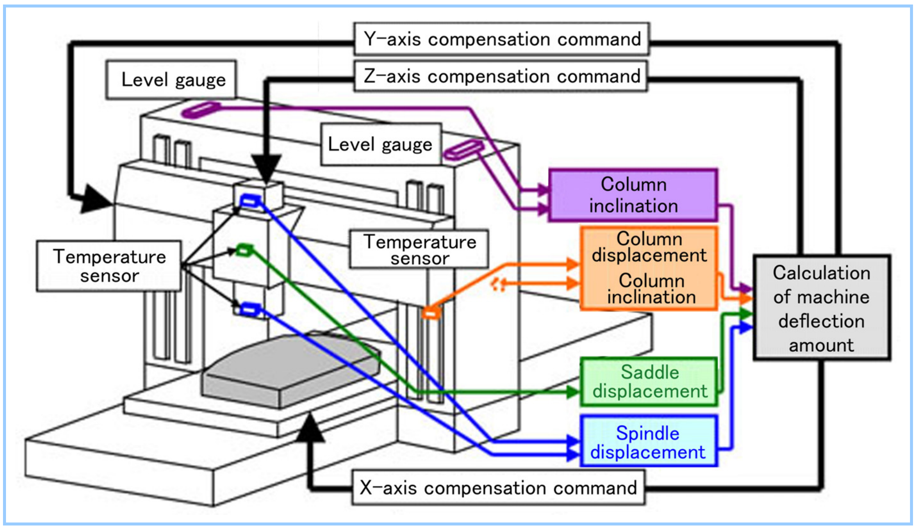

Figure 4 Schematic view of ATDS system

Figure 5 illustrates the measurements of heat deflection when using the ATDS system. The machine using the system, even when exposed to room temperature changes in a general factory environment (8.4 °C/40 hours), was able to ensure a stable precision of ±10 μm or less, which is comparable with that of machines installed in temperature-controlled facilities. This allows stable high-precision machining for lengthy periods without much concern for room temperature changes or changes in spindle rotational speed.

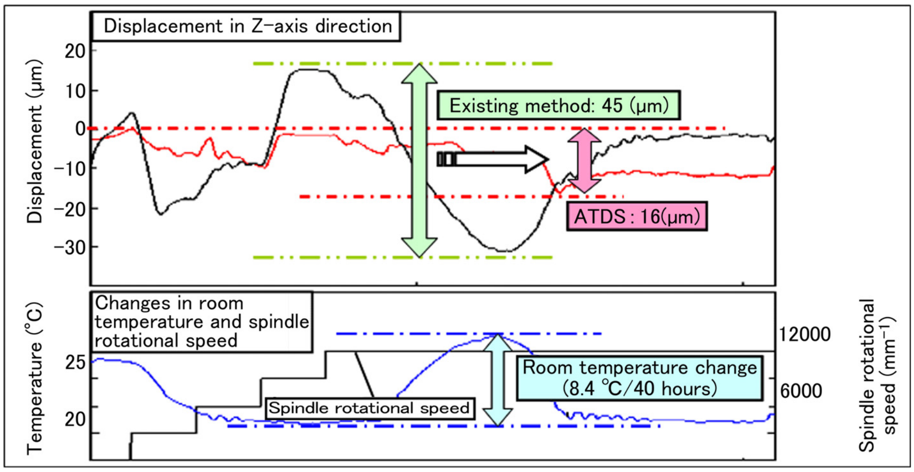

Figure 5 Measurements of heat deflection of machine equipped with ATDS system

5. Conclusions

MHI developed the special jet lubrication method, spindle heat deflection reduction technique and machine body heat deflection compensation technology, each of which is a one-of-a-kind technology in the field of large machining centers. With these technologies, a high machining precision can be attained even during machining that involves frequent changes in spindle rotational speed or lengthy machining of large workpieces. The technologies also made it possible to meet the need to improve the required machining precision on large workpieces and to enable stable high-precision machining even in a general-purpose factory environment where the factory room temperature around the machine tends to change drastically. We believe that our new system, which is designed from the perspective of users, is capable of meeting the demand for "higher productivity" and "higher environmental friendliness." As a pioneer in the development of double-column machining centers, we will continue making helpful and advanced suggestions on how to deal with heat deflection, which is a mutual problem shared with our customers' machining processes, so that we will be able to contribute to the improvement of user productivity.