Modern Technology Achieving High-Precision, High-Efficiency Processing for Machining Centers

YOSHIKATSU SATO*1

In recent years, demand for high-precision processing has also been increasing, in machining of relatively-long parts and dies used for automobiles, semiconductor manufacturing devices, electronic components, etc. The size range of these workpieces is positioned between machining centers and large machines. Looking at the entire industry, there are only a few machine tools that target such workpiece sizes, and therefore the demanded accuracy has not been fully met. Mitsubishi Heavy Industries, Ltd. (MHI) developed and markets the LH250, which is one of the largest machining centers realizing machining accuracy equal to that of micro milling machines. This time, MHI developed additional new optional functions that enable high-precision machining without significantly changing the factory environment.

1. Introduction

As many products around us, typified by automobiles, have been enhancing their functionality in recent years, demand for very high-precision processing is also increasing in machining of relatively-large parts. Even across all industries, however, there are only a few machine tools for workpieces with a size range positioned between machining centers and large machines, and therefore the demanded accuracy for these workpieces has not been fully met. There are a number of relatively-long parts that require high accuracy including not only automotive components, but also semiconductor manufacturing devices and parts needed for the production of electronic components. At the manufacturing sites of these parts, it is necessary to repeatedly execute trial and error, and therefore the poor yield has been a problem.

MHI developed the LH250 high-precision double column machining center, which is already on the market. **Table 1** shows the main specifications. In the development of this product, fundamental technologies for the μV1 micro milling machine designed for high-precision machining and double column large machine manufacturing techniques were combined. With a high-speed spindle as standard equipment, the LH250 attains long-term stable and high-precision machining equivalent to that of micro milling machines. Following the development of the machine itself, MHI advanced the development of new options in order to satisfy further market demand. This paper presents these technologies and their examples.

Table 1 LH250 specifications

Table size	(mm)	2,500 x 1,000
Maximum loading capacity	(kg)	3,000
Axes travel (X x Y x Z)	(mm)	2,500 x 1,000 x 600
Spindle taper		HSK-A63
Spindle diameter	(mm)	Φ80
Spindle speed	(min^{-1})	Max 20,000
Spindle motor output	(kW)	22/18.5
ATC tool storage capacity	(tools)	40 (Opt: 64)
Machine foot print	(mm)	7,200 x 3,300
Machine height	(mm)	3,593
Machine mass	(kg)	21,000

*1 Manager, Engineering Department, Machine Tool Division, Machinery, Equipment & Infrastructure

2. Features of LH250 high-precision double column machining center

2.1 High-performance spindle

Typical machining centers have a spindle a speed of around 10,000 min^{-1} as standard, and a high-speed spindle is available as an option. When a high-speed spindle is used, the initial preload of the bearing that supports the spindle has to be reduced because of greater heat generation, and therefore the rigidity of the spindle decreases to the level where rough processing at a low speed cannot be performed. For this reason, two specifications of the spindle are available so that customers who need rough processing and other customers who need high-speed operation only can select one that suits their respective purpose.

However, through the employment of cooling both inside and outside of the spindle and special lubrication of the bearing, which was developed for the μV1, the LH250 achieves a higher initial preload and reduction of heat generation at the maximum speed, and then realizes as standard a high-rigidity spindle rotating at a high speed of 20,000 min^{-1} that can also perform rough processing at a low speed. This machine handles rough processing and high-speed finishing with its single unit, and therefore improves machining efficiency.

Even when the spindle rotates at the maximum speed of 20,000 min^{-1} from a cold start, the LH250 limits the spindle thermal displacement to 2 μm or less in all of the X, Y, and Z axes directions[(1)] and the spindle vibration to 2 μm^{P-P} or less over the entire rotation speed range using no electrical correction. As a result, the LH250 contributes to the improvement of the machining accuracy and the machined surface quality.

2.2 High-precision feeding mechanism

Also for the feed axes, the LH250 employs narrow-pitch large-diameter ball screws and a strong supporting method similar to the μV1 to attain a high-rigidity and high-response feed axes system. In addition, the LH250 uses the HGP2 control, which features proprietary control tuning, and realizes machining operation without losing its shape even in high-speed shape machining. For example, a roundness of 1.8 μm, which is equivalent to micro milling machines, was achieved for the circle cutting (Φ218 mm) performed by synchronized two-plane axes[(1)].

Furthermore, coolant flows into the inside of the ball screws, nuts, support bearings, and driving motor mounting flanges in a similar manner to the spindle to drastically reduce heat generation, consequentially realizing a stable and accurate feeding mechanism.

3. W-2 thermo-stabilizer

The LH250 employs the cooling of the heat-generating parts of the machine such as the spindle and the feed axes to suppress thermal displacement caused by the heat generation of the machine itself. If a change in the ambient temperature around the machine occurs, however, the thermal displacement of the machine is an inevitable physical phenomenon. Although there is an electrical correction method using temperature sensors embedded in various points of the machine, thermal displacement is not always simple motion and the method may result in an adverse effect.

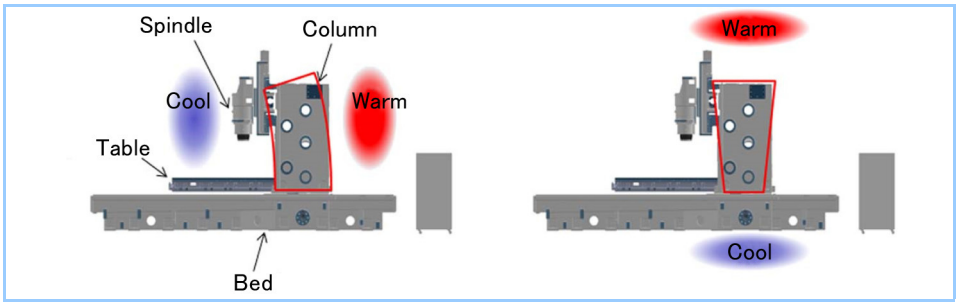

Figure 1 Column deformation caused by temperature difference around machine

When there is a temperature difference between the front and rear or upper and lower positions around the machine, for example, the column deforms and the spindle inclines (**Figure 1**). In this case, some electrical offsetting methods intended to correct the displacement in the X axis direction succeed in the correction, but other electrical offsetting methods, moving the Z axis for

example, result in a further increase of displacement (**Figure 2**). Squareness correction or spatial correction may be possible solutions, but in such cases, correction becomes difficult when using tools of different lengths or when warpage unlike simple inclination occurs, as well as under other circumstances (**Figure 3**).

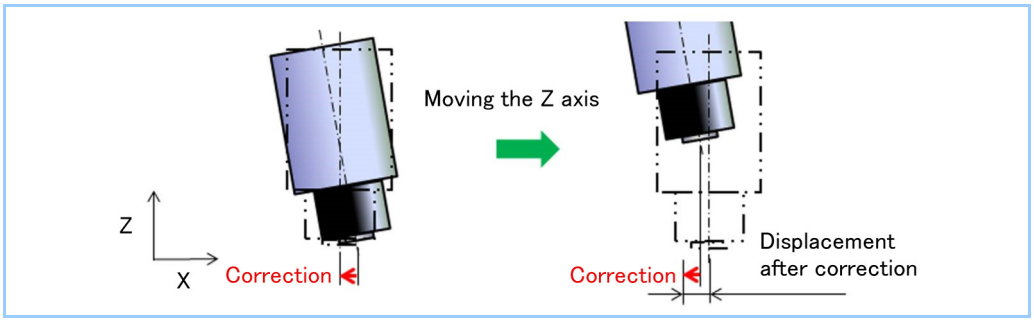

Figure 2 Adverse effect caused by moving the Z axis in correction of spindle inclination

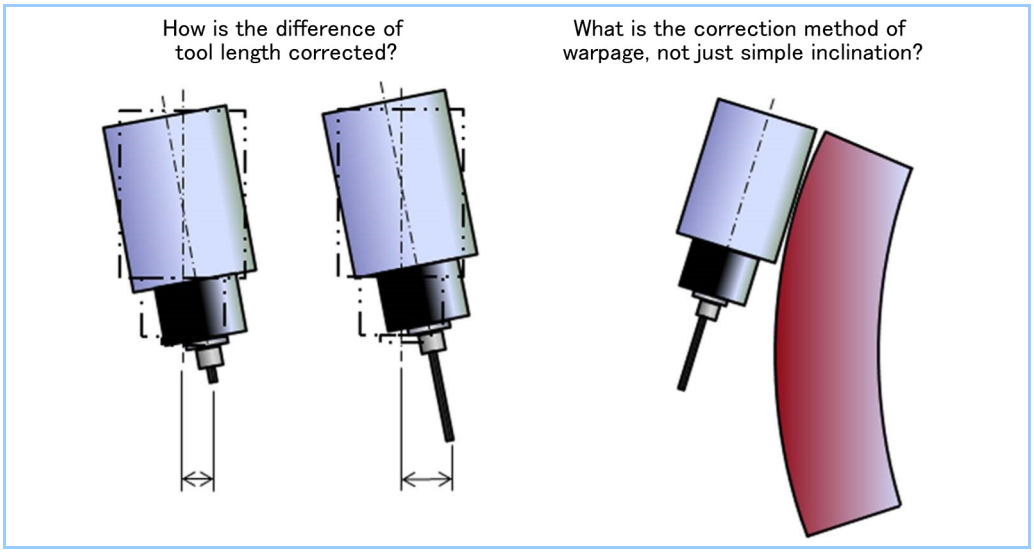

Figure 3 Example of conditions where the spindle inclination is difficult to correct

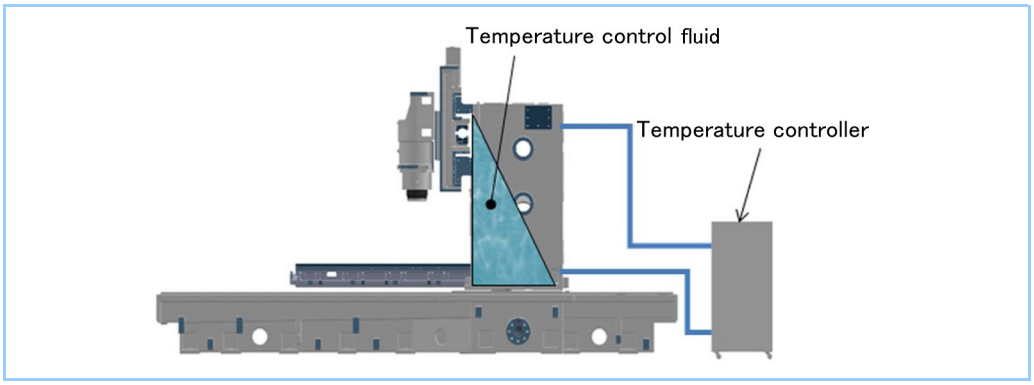

Figure 4 Configuration of W-2 thermo-stabilizer

Therefore the LH250 does not use electrical correction and employs the optional W-2 thermo-stabilizer, a method to make the column temperature uniform to suppress inclination and thermal displacement using a temperature control fluid that circulates and controls temperature in the column (**Figure 4**). The temperature of the temperature control fluid is controlled to same level as that of the bed by installing a temperature sensor thereon, because the bed is placed near the large-heat-capacity floor, and therefore is relatively stable and rarely results in a temperature difference. In addition, the temperature of the aforementioned coolant that flows into the spindle and the feed axes is controlled in reference to the bed temperature. Furthermore, when the optional cutting fluid temperature controller is added, temperatures of the spindle, the feed axes, the column, the bed, the table, and the workpiece all become identical and therefore attitudinal changes and the thermal displacement of the machine can be suppressed.

Figure 5 shows the actual measurement results of the thermal displacement of the machine against the environmental temperature change of the machine periphery. The results indicate that the thermal displacement of a machine equipped with the W-2 is approximately half of that of a machine without the W-2.

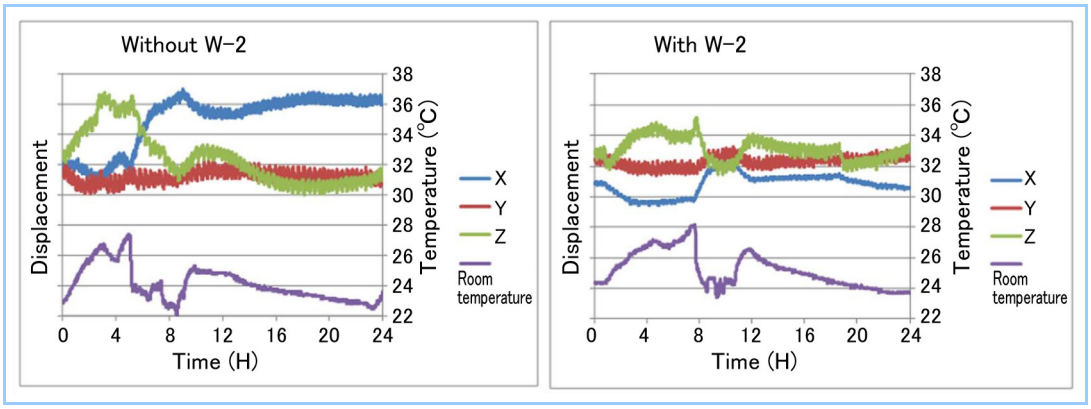

Figure 5 Comparison of machine thermal displacement between unit with and without W-2

4. Large-diameter tool handling capability of optical image type tool measurement system

The optical image type tool measurement system is an on-machine tool measurement application developed uniquely as optional equipment for the μV1. As its advantage, this system can confirm that thermal displacement has saturated and stabilized using a CCD camera to perform measurement of the tool that rotates at the same speed as machining, and therefore can suppress machining errors caused by thermal displacement and tool change.

The spindle used for the μV1 is the HSK-E32 (tool holder flange diameter of 32 mm), which uses a tool with a maximum diameter of around 10 mm, and the optical image type tool measurement system has specifications that suit the tools used. On the other hand, the spindle used for the LH250 is the HSK-A63 (tool holder flange diameter of 63 mm), which uses a tool with a maximum diameter of 125 mm. The optical image type tool measurement system can measure large-diameter tools in principle, but the lens focusing range in which accurate measurement can be made (depth of field) is very narrow, and therefore the probability that the tip of the rotating tool is settled within the depth of field decreases proportionally to the tool diameter (**Figure 6**). As a result, there were concerns about unstable measurement accuracy, long measurement time, etc., in the measurement of large-diameter tools.

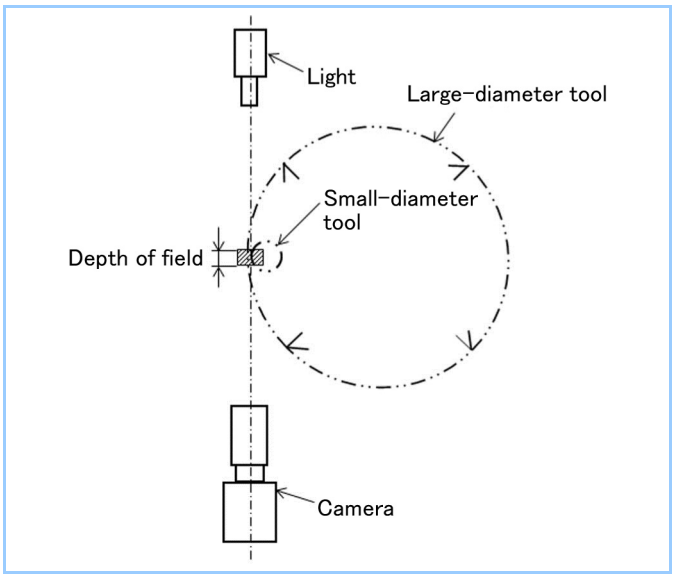

Figure 6 Conceptual diagram of large-diameter tool measurement with the use of optical image type tool measurement system

This time, the imaging method was changed from the conventional one in which multiple images were taken in a random manner, to the new one in which images are taken efficiently according to the spindle speed in order to accurately measure even large-diameter tools. **Figure 7** shows the actual measurement of a tool with a diameter of 125 mm with the use of the optical image type tool measurement system and an example image. **Table 2** compares repeated measurement results of the conventional random imaging method and the developed method for five types of tools. It was verified that the developed measurement method can improve the measurement accuracy and reduce the measurement time generally, depending on conditions such as the number of tool flutes and the spindle speed.

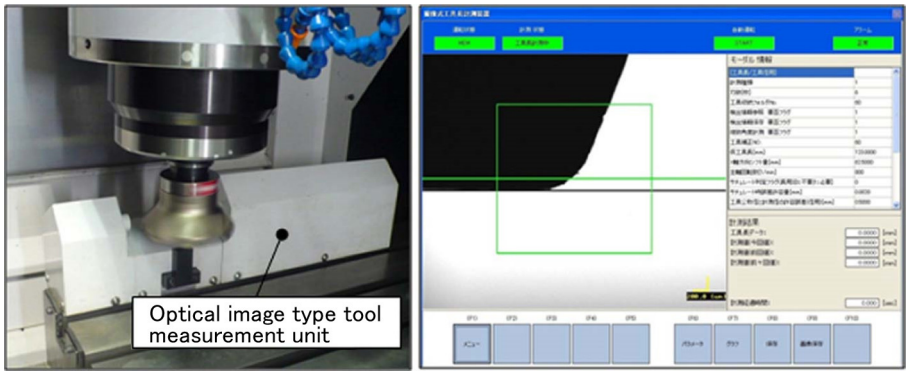

Figure 7 Example of large-diameter tool measurement with the use of optical image type tool measurement system

Table 2 Tool measurement results with the use of optical image type tool measurement system

No.	Tool type	Tool diameter Φ (mm)	Number of flutes	Spindle speed (min^{-1})	Time of three-time repeated measurement (Ratio to conventional method of No. 1)		Fluctuation of ten-time repeated measurement (Ratio to conventional method of No. 1)	
					Conventional method	New method	Conventional method	New method
1	End milling	10	2	10,000	1	0.69	1	0.67
2	End milling	20	4	4,000	1.05	0.93	1.78	1.33
3	Milling	50	6	2,000	1.08	1.07	3.44	1.56
4	Milling	125	6	800	1.12	1.28	6.78	1.22
5	Boring	36	1	500	1.25	0.77	2.0	1.56

In addition, this method can measure a tool flutes individually in association with the spindle rotation angle. Therefore the detection of unevenness of the tool tip height and chipping, which was difficult in the past, becomes possible, and the further improvement of the machining accuracy and the machined surface quality can be realized as a result.

5. Conclusion

This paper presented the features of the LH250 high-precision double column machining center and the newly developed optional functions. The LH250 contains technologies that achieve high precision and highly-efficient processing of mid-sized workpieces, which are hard to machine with a machining center or a large machine. The newly developed optional functions are considered to have advantages such as the capability to eliminate poor yield without significant improvements of the factory environment.

MHI will continue to further advance machine tool, optional functions, and machining technologies to satisfy market needs, and contribute to the development of the manufacturing industry.

Reference

1. Sato, Y. et al., Technology for High-speed and High-performance Milling of LH250 High-precision Double Column Machining Center, Mitsubishi Heavy Industries Technical Review Vol. 50 No. 1 (2013) pp. 43-48