Technology for High-speed and High-performance Milling of LH250 High-precision Double Column Machining Center

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When viewed from the size of workpieces to be cut, there are only a few machine tools that are positioned between machining centers and large machines. Therefore medium-sized workpieces are often cut by large machines. However, as the tolerance requirements for such workpieces cut by large machines have become tighter and it is difficult to achieve such tolerance only with machine performance, an increasing number of markets depend on the skill of operators. MHI has combined long-time stabilization technologies applied on the µV1 micro milling machine with the manufacturing techniques of double column large machines to develop the LH250, which attains a machining accuracy equivalent to that of micro milling machines. This document describes the technical features, performance and machining accuracy of the LH250, which includes a high-speed spindle as standard equipment and enables long-term high-precision machining.

1. Introduction

Although many products have been made smaller and thinner, some cannot because they are used with users sitting, working or riding on them. In addition, there are some products such as motors that are even becoming larger to meet demand for higher power output. Double column large machines have been used to cut some of these relatively large products, because there are no conventional machining centers of an appropriate size. However, as higher machining accuracy is in demand along with products becoming more efficient and more sophisticated, such accuracy requirements cannot be achieved only by machine performance, and thus there are a growing number of products that depend on human skill.

MHI developed the µV1 micro milling machine designed for high-precision machining. Many of the fundamental technologies employed on the µV1 can be used to provide long-term high-precision machining regardless of the machine size to which they are applied. MHI has combined these technologies and double column large machine manufacturing techniques to develop the LH250 high-precision double column machining center, which includes a high-speed spindle as standard equipment and attains long-term high-precision machining equivalent to that of micro milling machines (**Table 1**). Its technical features, performance and machining accuracy are described below.

Table 1 LH250 specifications

Table working surface	(mm)	2,500 × 1,000
Maximum loading capacity	(kg)	3000
Axes travel (X × Y × Z)	(mm)	2,500×1,000×600
Spindle taper		HSK-A63
Spindle diameter	(mm)	ϕ 80
Spindle speed	(min^{-1})	Max 20,000
Spindle motor output	(kW)	22/18.5
ATC tool storage capacity	(tools)	40（Opt：60）
Machine foot print	(mm)	7,380×3,300
Machine height	(mm)	3,593
Machine mass	(kg)	21,000

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

The LH250 has been developed with the primary objective of the achievement of high value-added surface quality, unlike conventional large machining centers that focus on the weight of chips generated in the cutting process. In Japan in particular, there are an increasing number of cases where a process starts with material already rough-machined and only semi-finishing and high-precision finishing are required. For such a process, machining speed cannot be increased with the spindles equivalent to a BT#50 rotating at a speed of around 6,000min^{-1} that are commonly employed on machines of this size today. In addition, spindle thermal displacement correction techniques are only used when the need arises. Therefore it is difficult to assure the stable achievement of high surface quality, and only technicians who understand the characteristics of the machine can achieve machining accuracy. The LH250 includes as standard equipment a spindle equivalent to a BT#40 rotating at a speed of 20,000 min^{-1}, which is optional equipment for typical machines, and removes self-heating completely, focusing mainly on the achievement of stable machining accuracy and machined surface quality even without an understanding of the characteristics of the machine, which cannot be realized with conventional machines. In addition, the LH250 has also been designed for sufficient cutting performance with a spindle equivalent to a BT#40, because production efficiency cannot be increased due to the occurrence of necessary setup changes of the workpiece from a rough-machining and semi-finishing machine to a finishing machine if the machine only performs finishing. Furthermore, the transportation of large machining centers is limited by their size and weight under the road traffic law. For a reduction of setup time on site, the size of the LH250 has been determined so that it can be transported without disassembly while complying with the law.

3. Technologies employed on LH250 high-precision double column machining center

3.1 Thorough suppression of heat generation

Typically, one of the factors that cause larger machines to become less accurate is the attitudinal change of the machine along with temperature change. When machine size increases, the absolute amount of thermal displacement of the machine due to attitudinal change increases, and therefore it is difficult to maintain a level of accuracy equivalent to that of smaller machines unless sensitivity to temperature change is suppressed. Attitudinal change of the machine along with temperature change is classified into two types; that due to temperature change of the room where the machine is installed and that due to heat generation of the machine itself. In the development of the LH250, a reduction of attitudinal change along with lengthy operation of the machine has been achieved by eliminating the heat generation of the machine itself as much as possible. For a machining center, heat generation by the machine consists mainly of that from the spindle, the feed mechanism and electric equipment including the electric cabinet. This section describes the cooling of the spindle and the feed mechanism that was especially focused on during the development of the LH250.

The LH250 includes as standard a spindle rotating at a speed of 20,000min-1, which is optional for typical machining centers. Such a high-speed spindle was not standard in many cases because of lower rigidity and higher heat generation. However, through the employment of cooling both inside and outside of the spindle and special lubrication of the bearing, which has been employed on the μV1 micro milling machine, the LH250 achieves a higher initial preload and reduction of heat generation at the maximum speed and then minimizes the extension of the spindle along with its rotation (**Figure 1**). Cooling oil for the spindle controls cooling so that temperature at the outlet of the spindle is always kept identical to the temperature at the base of the machine. Together with the heat generation, cooling oil circulates to remove the heat quickly to maintain a constant temperature. Because the LH250 has larger bearings and generates higher heat than a micro milling machine, a special cooling circuit is added for cooling inside the front bearing of the spindle to improve cooling capacity for the achievement of higher cooling efficiency. This suppresses the thermal expansion of the spindle and the bearings even at speeds up to 20,000 min^{-1}, and therefore the spindle and bearings rotate while maintaining the initially assembled state. As a result, the gap between the bearings and the housing can be minimized, a higher preload can be set and as a result, a high-precision and high-rigidity spindle is provided. The transition of the thermal displacement of the spindle is shown in **Figure 2**.

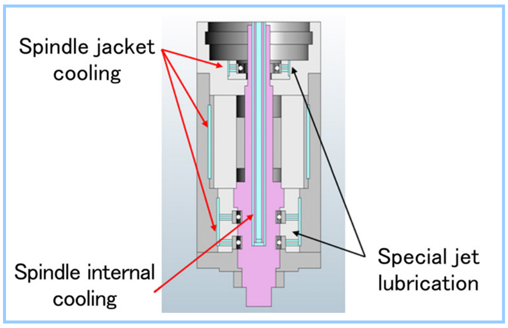


Figure 1 Cooling of spindle

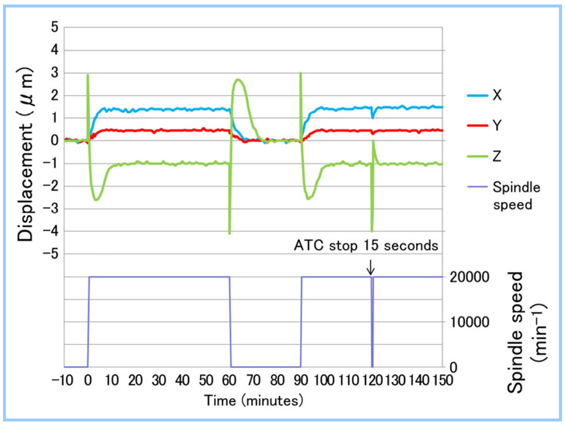


Figure 2 Thermal displacement of spindle

For conventional spindles that are lubricated with grease or oiled air, it takes a long time to achieve stabilization and warm-up is required as a standard prerequisite. The LH250 can achieve stabilization of thermal displacement, using no electrical correction, after 12 minutes running at maximum speed even from a cold start. In this case, the displacement is 2 μm or less and subsequently stabilizes within +/- 0.2 μm. These values mean that there are no problems when the LH250 runs without warm-up, which is required for conventional machines. In this way, the LH250 successfully eliminates the effect of thermal displacement caused by the fact that a high-speed spindle is included as standard.

In addition, the occurrence of secondary delayed thermal displacement, etc., due to heat transferring from the spindle to the machine main body is prevented. Consequently, by only paying attention to the initial extension during warm-up of the spindle, many hours of stability without the occurrence of displacement caused by other factors can be achieved.

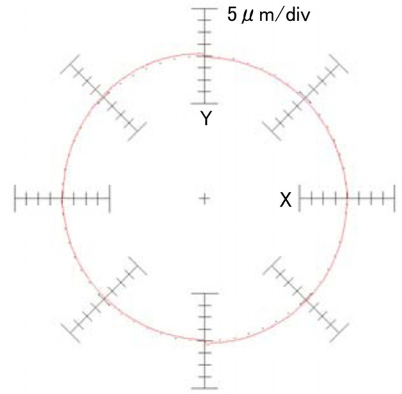
The feeding mechanism employs sliding guideways for the Z and Y axes, on which the spindle travels, to take advantage of the high-performance spindle. It also uses a low friction ball guideway for the longitudinal X axis, on which workpieces weighing up to 3000 kg can be mounted, to achieve constant feeding control regardless of the weight. The drive train also uses a high-rigidity fine pitch ball screw. In this feeding mechanism configuration, the heat sources are the drive motors, the support bearings and the ball screw. The LH250 achieves thorough cooling of each component on each axis. For the driving servo motor, the coupling flange is cooled to prevent generated heat from transferring to the machine body, while a fan is installed on the cover of the X axis motor to circulate air and prevent a temperature increase.

For the ball screw, cooling oil circulates inside the screw and the support bearings are lubricated in order to suppress heat generation. The ball screw nut, which only had its mounting bracket cooled in the past, is now cooled inside the nut in order to prevent the thermal effect from affecting the moving parts. In this way, by cooling the feeding mechanism thoroughly, there will be no attitudinal change of the machine even if the feeding axes are moved repeatedly. In addition, for sliding guideways, the reference plane of the Y axis is cooled by coolant passing beneath the sliding guideway to suppress heat transfer to the machine body because its contact pressure is increased by the weight of the moving object, and therefore heat generation occurs when high-speed feeding is continuously performed.

3.2 High-precision feeding mechanism

For the development of the LH250, each component was selected so that follow-up performance of feeding axes equivalent to that of micro milling machines could be achieved for higher accuracy and surface quality. The size of the servo motor was selected so that sufficient follow-up performance of the servo could be assured, and a ball screw that is rigid enough to take advantage of the servo motor was included. In addition, the unique tuning of the control system applied to micro milling machines was also implemented on the LH250. As a result, a roundness of

1.8 μm, which is equivalent to micro milling machines, was achieved for the circle cutting performed by synchronized two plane axes (**Figure 3**).



XY plane

Roundness	1.8μm
Diameter	20mm
Cutting feed rate	1000mm/min

Figure 3 Measurement of roundness

3.3 Manufacturing techniques

For the implementation of the high accuracy of the LH250, the most challenging issue was the achievement of X axis longitudinal accuracy. To maintain straightness of 10 μm or less for the entire travel distance, even with workpieces weighing up to 3,000 kg, the rigidity of the machine bed and the accuracy of the machine that cut the bed were specified. First, 3D-CAD was used to simulate the displacement of the maximum weight workpiece in order to consider the rigidity of the machine so that the final machine accuracy could be within the acceptable value (displacement of 0.001 mm or less for the overall length of the bed) as shown in **Figure 4**.

Next, the static accuracy of the machine tool for cutting the bed was measured, the machine was adjusted so that there was a portion with a straightness of 2 μm on a bed length of 6,000 mm, and the bed was set and cut at the position where the highest accuracy was assured (**Figure 5**). As a result, the straightness of the guideway mounting surface was maintained at 4 μm. Finally on the completed LH250, an X axis straightness of 5.3 μm/2,500 mm was attained while the target was 10 μm/2,500 mm.

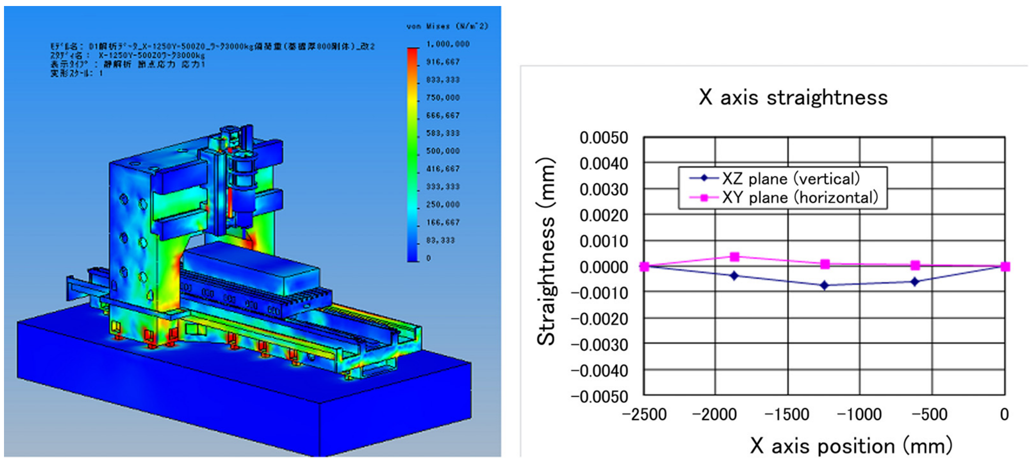


Figure 4 Analysis of X axis straightness

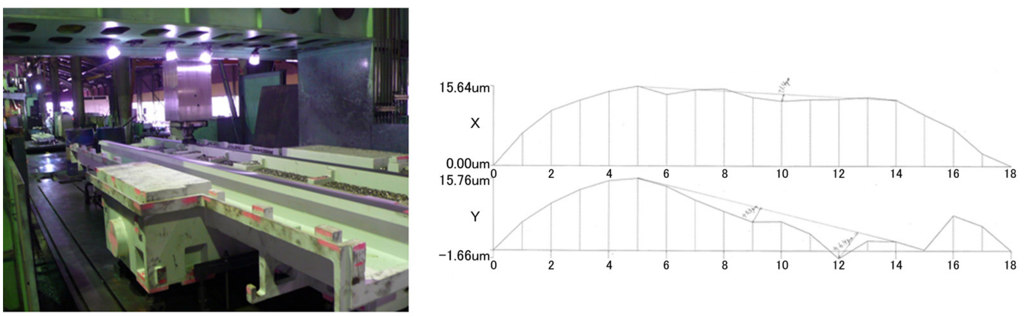


Figure 5 Accuracy adjustment of bed cutting machine and bed cutting

4. Cutting result of LH250 high-precision double column machining center

4.1 Die plate cutting

To verify the high machining accuracy of the LH250, a test workpiece (**Figure 6**) simulating a progressive die plate was cut. **Table 2** shows the cutting conditions.

As a result of measurement of the cut test workpiece, the pitch accuracy of six bored holes at a diameter of 38 mm was 2.3 µm for an X axis longitudinal length of 2000 mm, the pitch accuracy of 34 bored holes at a diameter of 22 mm was within +/- 2 µm and the roundness of a hole at a diameter of 100 mm cut by circular end milling was 1.9 µm. In this way, the LH250 achieved high machining accuracy equivalent to that of micro milling machines.

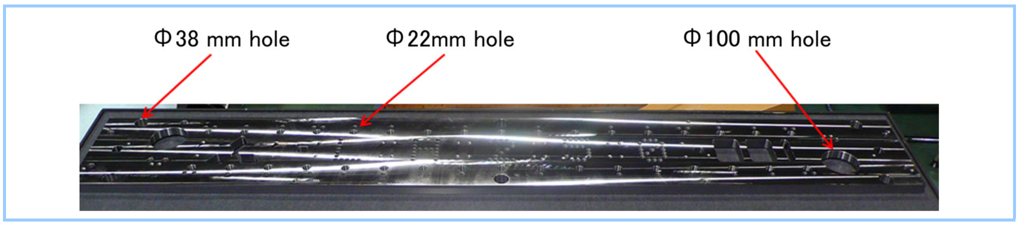


Figure 6 Test workpiece for die plate cutting

Table 2 Die plate cutting conditions

Workpiece	Material			S50C		
	Size (mm)			2,200×300×30		
Process	Tool			Cutting conditions		
	Type	Diameter (mm)	Number of blades	Spindle speed (min^{-1})	Feed rate (mm/min)	Cutting depth (mm)
Φ38 hole	Boring	ϕ 38	1	1500	450	0.02
Φ22 hole	Boring	ϕ 22	1	3300	825	0.02
Φ100 hole	Roughing end mill	ϕ 10	2	7000	700	0.03

4.2 Forming die cutting

To verify the high-quality and stable machining of the LH250, a forming die of a CFRP part used in an automotive seat (**Figure 7**) was cut. **Table 3** shows the cutting conditions.

The final finishing took approximately 20 hours. If attitudinal change of the machine due to a temperature change during the final finishing occurred, steps would appear on the cut surface. In this verification test, the LH250 suppressed its attitudinal change using thorough heat generation suppression techniques, and therefore no steps appeared on the surface of the cut die. In addition, due to the high-precision feeding mechanism of LH250, no disordered cutting such as biting occurred on any bending points (i.e., corners of the die) where the cutting direction changes. As a result, a very high-quality finished surface was achieved.

Table 3 Forming die cutting conditions

Workpiece	Material			FC250			
	Size (mm)			1,000×500×400			
Process	Tool			Cutting conditions			
	Type	Diameter (mm)	Number of blades	Spindle speed (min^{-1})	Feed rate (mm/min)	Cutting depth (mm)	Pick (mm)
Roughing 1	Radius end mill	ϕ 32	3	2200	2,640	1.0	22.0
Roughing 2	Ball end mill	R10	2	3500	2,640	0.9	1.0
Semi-finishing 1	Ball end mill	R10	2	4800	2,450	0.9	0.5
Semi-finishing 2	Ball end mill	R8	2	5000	3,000	0.6	0.4
Semi-finishing 3	Ball end mill	R8	2	5000	3,000	0.4	0.3
Finishing	Ball end mill	R8	2	5000	2,200	0.22	0.15

Figure 7 Test workpiece for forming die cutting

Figure 8 CFRP part

A CFRP part was actually formed using the machined die (**Figure 8**). Typically, a machined die surface is hand polished because the surface of a formed part on which the surface of the die is transcribed would be rough if the die was used in an as-cut state. In this test forming, however, the die was used without hand polishing. As a result, the formed part had a very neat surface that could be used as a commercial product. This test verified that the LH250 can achieve such a high-quality surface that enables polishless die making.

4.3 High-efficiency cutting

To verify that the LH250 can achieve not only high-precision cutting, but also high-efficiency cutting, heavy duty cutting of steel and aluminum was performed. **Table 4** shows the cutting conditions.

The LH250 could cut steel at 400 cc/min and aluminum at 2000 cc/min, which are sufficient for a spindle equivalent to a BT#40.

Table 4 Heavy duty cutting conditions

Workpiece material	Tool			Cutting conditions			
	Type	Diameter (mm)	Number of blades	Spindle speed (min^{-1})	Feed rate (mm/min)	Feed rate (mm)	
						Radial	Axial
S50C	Roughing end mill	ϕ 20	4	1600	2,500	8.0	20
A5052	Roughing end mill	ϕ 20	2	8000	12,000	8.4	20

5. Conclusion

This document described technologies for the achievement of the high-speed and high-efficiency processing employed on the LH250 high-precision double column machining center and the results of processing with such technologies. The LH250 and its machining workpieces were exhibited at the 26th Japan International Machine Tool Fair (JIMTOF2012) and highly appreciated by visitors. The LH250 can perform the high-precision processing of workpieces that can be handled by only a few machine tools due to their size, and therefore improve conventional poor production efficiency because of dependence on past technologies. In addition, the LH250 may have a positive effect on the design of final products, because workpieces that were separated to assure accuracy can be integrated into a single workpiece through the use of this machine.

In the future, MHI will continue to produce accessories and applications for machines in response to the needs of various industries, and is willing to make efforts to contribute to the development of the manufacturing industry in various aspects.