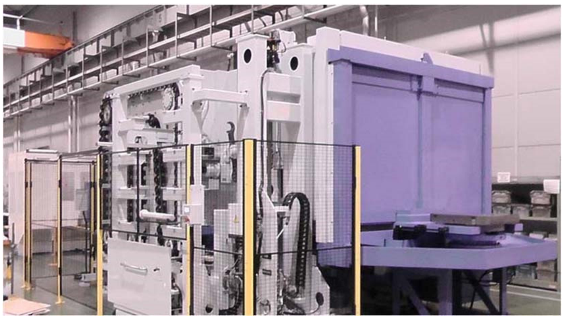
"M-CM5BG" Large Engine Part-Compatible Horizontal Machining Cell for Mass Production Processing Lines



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The present machine tool market has no machining centers capable of completely processing the parts of a 13,000 cc displacement–class engine (1,000 mm in total length), the largest size offered by domestic truck/bus manufacturers. It is, therefore, necessary to build a dedicated line equipped with special purpose machines, and existing processing lines were poor in terms of benefit-cost ratio and are inflexible. Crank-hole drilling on a cylinder block as a key engine part requires the long tool called a line borer. To meet this requirement, Mitsubishi Heavy Industries, Ltd. (MHI) developed the M-CM5BG horizontal machining cell with equipment that automatically replaces long tools of a maximum of 1,350 mm (and stores four tools at one time). Along with a high-rigidity bed for which the Z-axis stroke of 1,700 mm needed for long tool machining has been realized by supporting it at three points, the technologies mounted on this machine for maintainability, automation and labor saving are featured in this paper.

1. Introduction

For cylinder blocks (hereinafter CB) and cylinder heads (hereinafter CH), which are key components of the engines used in trucks/buses fabricated by domestic manufacturers, a machining center (hereinafter MC) capable of totally processing a 10,000 cc displacement- (800 mm total length) class model workpiece is being placed on the market in numbers. Nevertheless, there is no MC capable of totally processing a 13,000 cc displacement- (1,000 mm total length) class workpiece as the largest size, and despite its lower output than the 10,000 cc displacement class (800 mm total length), it requires, as processing equipment, a dedicated line using special purpose machines to be installed, raising the problems of a poor benefit-cost ratio as well as inflexibility in the production line. This is why the development of a high-productivity MC capable of totally processing 13,000 cc displacement- (1,000 mm total length-) class engine parts (CB/CH) is in strong demand on the market. Meanwhile, due to its high maintainability as well as possible automation/labor saving and in prospectively coping with the trend toward aluminum for lighter-weight parts to improve fuel efficiency, making high-load processing by an MC compatible with high-speed processing also further in demand.

In meeting such market needs, MHI developed the M-CM5BG horizontal machining cell[note], which shows high productivity in processing the parts of a medium- or large-sized engine to be mounted on trucks/buses. **Table 1** shows the principal specifications.

The mounted technology's characteristics and performance are described below.

Note: The machining cell is a machining center specialized for mass-production lines and is included as a component of the mass production line or cell production system, particularly because of its improved productivity, reliability and space efficiency.

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Table 1 Principal specifications of the M-CM5BG

Stroke	X axis	mm	1250
	Y axis	mm	1200
	Z axis (standard/option)	mm	1150/1700
Spindle	Taper shape		HSK-A100/KM10080
	Maximum rotational speed	min^{-1}	6000/15000
	Diameter (6000/15000 min^{-1})	mm	φ120/φ100
Feed speed	Fast feed speed (accelerated speed)	X axis mm/min (G)	60 (0.4)
		Y axis mm/min (G)	60 (0.6)
		Z axis mm/min (G)	50 (0.6)
APC	Pallet size	mm	□800
	Maximum loading mass (including pallets)	kg	2500
	Number of pallets	sheet	2
Long ATC	Number of tools to be stored	unit	4
	Maximum tool length	mm	1350
	Maximum tool diameter	mm	φ140
Standard ATC	Number of tools to be stored	unit	120
	Maximum tool length	mm	800
	Maximum tool diameter	mm	φ350

APC : Automatic Pallet Changer
ATC : Automatic Tools Changer

2. On-board M-CM5BG technology

2.1 Machining work specific to cylinder block

(1) Issue

Machining work specific to cylinder blocks is the crank hole drilling shown in **Figures 1 and 2**. At present, special purpose machines are adopted for this drilling, and so that MC can implement this process, it is necessary to enable automatic replacement of long tools and secure such a stroke as allows a long tool to be removed/inserted (1,350 mm in total length of the tool, 80 kg in tool mass and 1,700 mm in Z-axis stroke). To realize this, long and heavy tools must be stored stably without being dropped or affected by pot friction. In addition, the tool shape is not always the same since it is designed to match the workpiece shape. There is another issue of space saving to make the frontage as narrow as possible in further consideration of its possible application in a mass production line. **Table 2** summarizes issues as well as solutions.

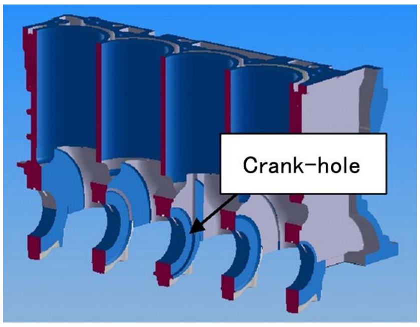

Figure 1 Cylinder block section

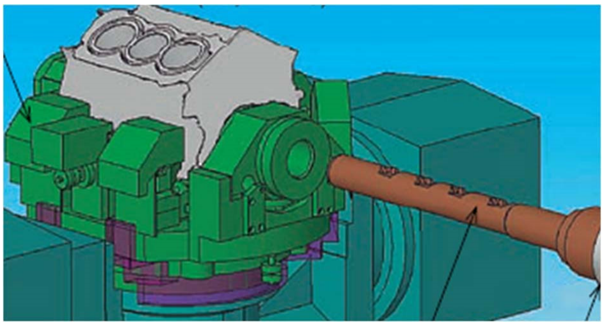

Figure 2 Crank-hole drilling

Table 2 Automatic long tool changer: issues and solutions

Issue	Solution
Dropping of a long tool during automatic replacement operation	A dedicated carrier with the tool supported at two points or at both ends was developed.
The pot to store tools is less durable. (Pot friction affects stable operation.)	A fixed rack is used instead of the storage pot.
Crank-hole drilling to be flexibly worked on for each different-size workpiece	With only the tool-end locating portion designed for exclusive use, tool diameter/length difference has now been flexibly handled.
Space needs to be saved	Using dead space, a dedicated storage rack was arranged (instead of a standard magazine).

(2) Solution

Although concept development and mechanical planning for each piece of equipment are normally the tasks of the design sector, a cross-function team (CFT) was organized for this development. The members were summoned from not only design, but also the assembly, procurement and production management sectors and the team grasped and analyzed the “functions” to be fulfilled by the equipment from the perspective of users using the VE (value engineering) method and figured out a variety of ideas about means to achieve these goals in the search of optimum solutions to the aforementioned issues.

As a result, the selected automatic long tool replacement structure shown in **Figure 3** safely composed the equipment without widening the installation, utilizing dead space as shown in **Figure 4**, thereby enabling the frontage to become 500 mm narrower than in the case where tools were stored in standard magazines. Moreover, by placing tools on fixed racks, the influence of pot wear could be excluded. Furthermore, in coping with different tool shapes to match each workpiece, a tool receptacle system as shown in **Figure 5** was adopted and only the tool-end locating portion was designed for exclusive use, developing a structure that can quickly respond to a change of workpiece.

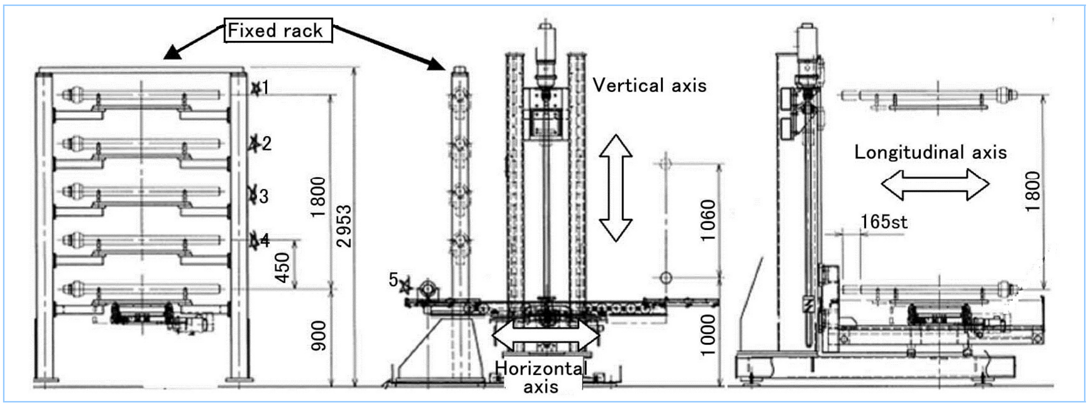

Figure 3 Automatic long tool changer

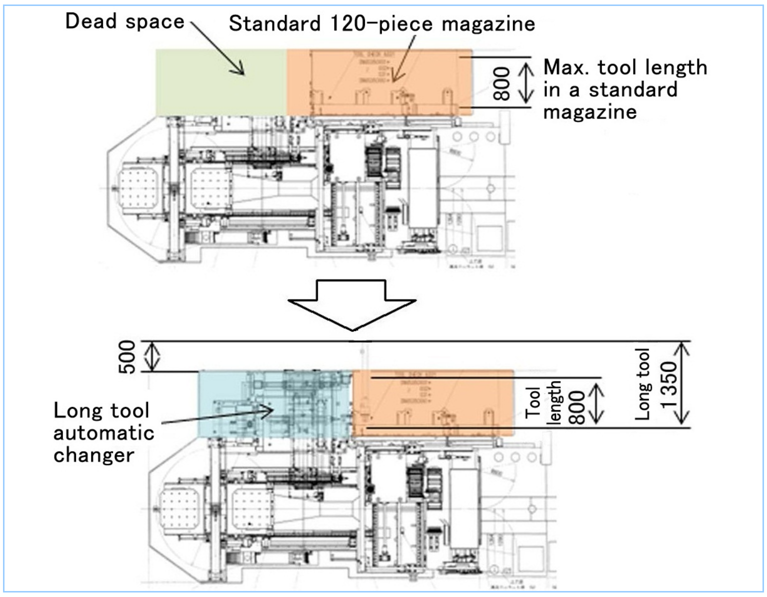

Figure 4 Tool storage using dead space

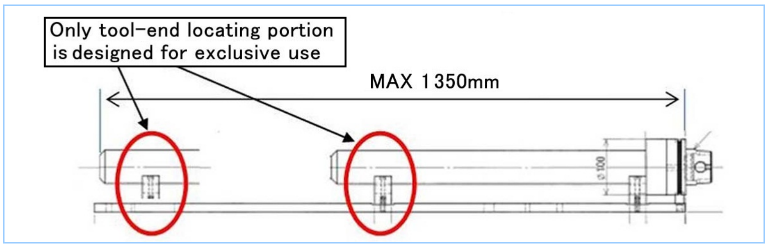

Figure 5 Tool receptacle

2.2 Easier maintenance and accuracy preservation

(1) Issue

Machine tools have the problem of the need to suppress the deterioration of machine accuracy due to changes in its foundation over time, as well as to facilitate accuracy adjustment when deteriorated. But machining with a long tool necessitates a stroke of 1,700 mm as mentioned in Section 2.1, and with this level of stroke, a multipoint-supported bed is normally used. A multipoint-supported bed has the problem of time-consuming jack adjustment accompanied by deterioration in maintainability.

(2) Solution

The 3D models of the entire machine and the three-point support bed shown in **Figures 6 and 7** were prepared, and using a numerical analysis approach (finite element method: FEM), the rib shape, thickness and arrangement within the casting structure were optimized, thereby successfully coming up with the three-point supported bed that maintained compatibility with a 1,700-mm stroke.

This robust bed has not only excluded the effects of changes in foundation level to suppress machine accuracy deterioration, but also limited changes in the straightness of the 1,700-mm stroke within 3.2 μm as shown in **Figures 8 and 9**, maintaining the high accuracy of the machine.

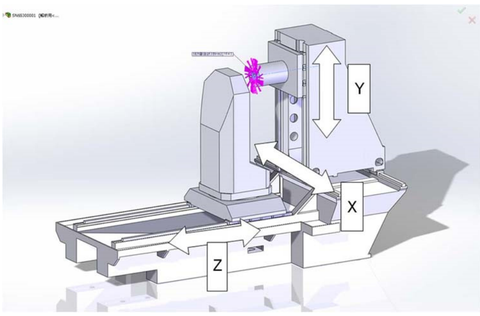

Figure 6 3D Model built in

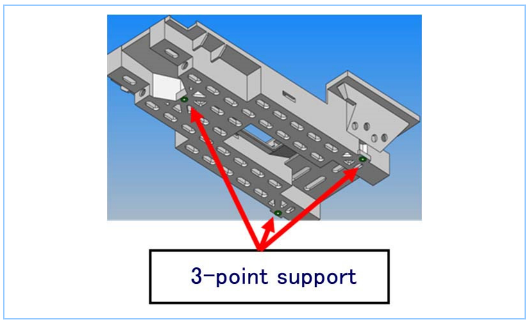

Figure 7 3-point supported bed

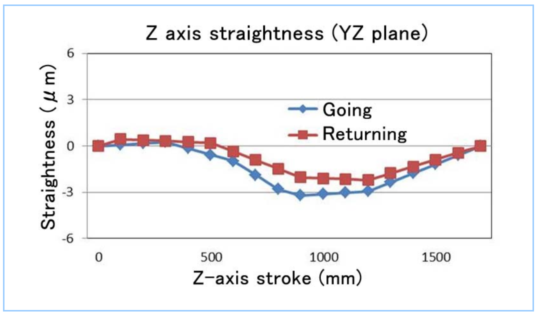

Figure 8 Changes in Z axis straightness (YZ plane)

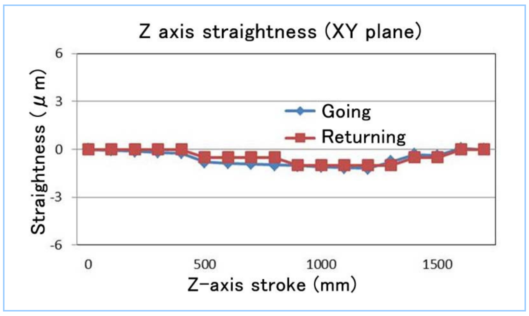

Figure 9 Changes in Z axis straightness (XZ plane)

2.3 Efforts for automation/high productivity

(1) Issue

A processing line well responsive to different kinds/different volumes must ensure high productivity for multiple workpieces. But the aforementioned line with special purpose machines has the issue of having been forced to replace the setup for different workpiece machining after once bringing the production line to a halt. For medium-/large-sized engine parts, a heavy workpiece/fixture setup (workpiece mass of 500 kg, fixture mass of 1,500 kg and pallet mass of 500 kg, totaling 2,500 kg) is required to be replaced in a short time. In addition, workpieces/fixtures are not always the same and changes in size or mass dependent upon the situation must be properly complied with.

(2) Solution

In this machine, the 2APC method (method of allowing two pallets to turn for automatic replacement) shown in **Figure 10** to automatically replace the setup containing fixtures as-is (including pallets) was employed, thus proposing a measure in favor of automation and high productivity. By means of FEM analysis, a level of rigidity that can withstand the supposed load was secured, and at the same time, supposed workpiece and fixture models were prepared to simulate the state where pallets were actually exchanged for arm shape and stand rigidity optimization, thereby realizing a maximum loading mass of 2,500 kg and APC exchange time of 30 seconds. Changing workpiece and fixture masses were to be coped with by servo motor driving which changes the speed, depending upon the mass, for the permitted quickest operation, to come up with a structure that contributes to time saving. Moreover, the adopted method of replacing the setup containing fixtures as-is (including pallets) also facilitates the development of an automatic guided vehicle (AGV)-based palletized shipment-type flexible manufacturing system (FMS).

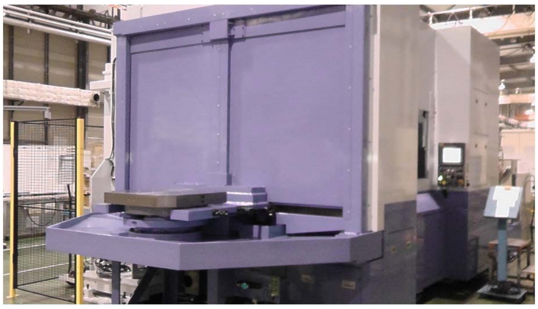

Figure 10 2APC method

2.4 Efforts for labor saving

(1) Issue

Labor saving at and around processing equipment faces the problem of the need to optimize the line composition for line operation with the lowest possible personnel allocation, as well as to alleviate short-term breakdowns (moment stops) on the order of minutes for a decrease in man-hours for equipment restoration. Many moment stops are caused by shavings. Heated shavings bring about machine accuracy deterioration, deposited shavings induce the malfunction of fixtures and sensor failure, and the splashing of shavings result in on-board equipment damage and other problems.

(2) Solution

This machine employs a stainless chute which prevents shavings from directly contacting the bed as shown in the internal structure of the M-CM5BG in **Figure 11**, structuring it in such a way as not to conduct the heat of the shavings to the bed and thereby suppressing thermal displacement. Inside the machine, metal covers (ATC shutter and XY-/Z-axis slide covers) were employed and have improved durability against direct hits from shavings. The center-trough bed structure and the employment of a stainless chute have prevented shavings from depositing within the machine and enabled them to be quickly discharged outside the machine. Further consideration is given to prevent shavings from being deposited by the washing of the inside of the machine using MHI's uniquely designed coolant curtain as shown in **Figure 12**.

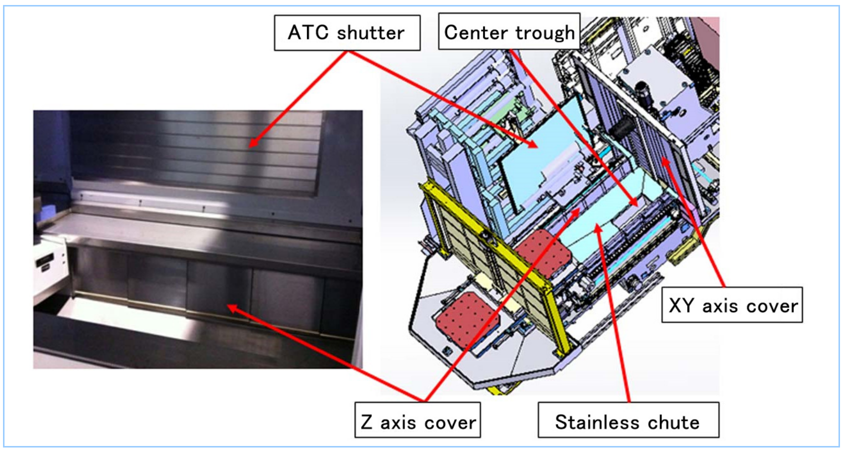

Figure 11 Internal structure of the M-CM5BG

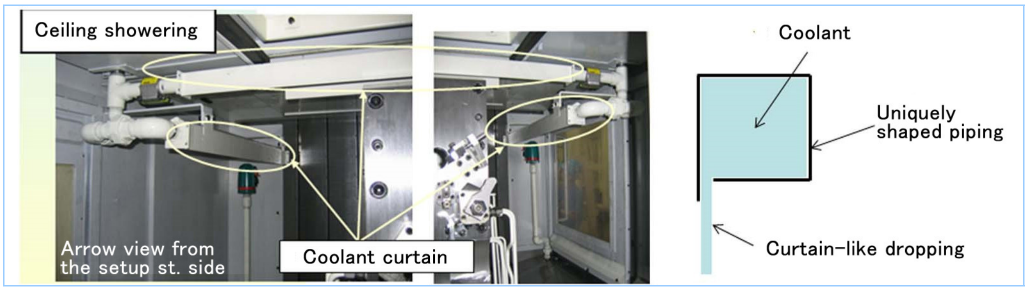

Figure 12 Coolant curtain

2.5 Future efforts

(1) Issue

For truck/bus engine parts as well, it is necessary to cope with the trend toward aluminum for lighter-weight parts to prospectively improve fuel efficiency. This raises additional needs to make both high-load processing and high-speed processing compatible. Nevertheless, the greatest problem with an increase in speed in a #50 taper spindle is the need to prevent bearing seizure due to heat generation and minimize thermal displacement.

(2) Solution

By adopting MHI's own jet lubrication and circulating coolant of the temperature synchronously controlled to that of the machine body through the spindle inside and casing, both the minimization of thermal displacement and the maximization of pre-loads on the bearing in the low speed zone were made compatible. Further total recovery and recycling of bearing lubricant amounts have lengthened coolant life by eliminating unnecessary oiling, reducing running costs and using a smaller amount of lubricants mixed in the coolant.[1] This achieved the 15,000 min^{-1} specification in a #50 taper spindle, enabling high-efficiency high-accuracy machining in the whole rotating area.

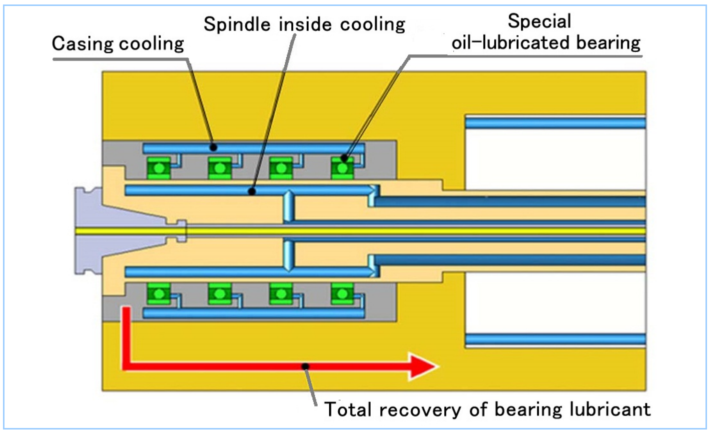

Figure 13 Internal cooling structure of spindle

3. Conclusion

The technologies mounted on the M-CM5BG horizontal machining cell were featured above. They have been finished into a machine capable of handling the stages where medium-/large-sized engine parts were processed by special purpose machines and this machine can perform all kinds of processing by itself. Through the replacement of existing special purpose machines with the M-CM5BG, MHI will propose a more flexible and capable multiproduct variable quantity production method, thereby maintaining its contribution to higher productivity at large parts production sites. MHI further intends to understand the needs of various industries and provide unprecedented solutions in an effort to contribute to the extensive development of the manufacturing industry.

Reference

1. Omokawa, H. et al., High-precision Machining Technology for Large Machining Centers Special Jet Lubrication and Advanced Thermal Displacement Suppression System, Mitsubishi Heavy Industries Technical Review Vol. 49 No. 3 (2012) pp.35-38