Accuracy Improvement Technology of MAF-C Floor-type Horizontal Boring Mills

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Horizontal boring mills, which have a protruding boring spindle and ram, have an inherent problem: deflection due to their own weight and changes in the barycentric position causing deformation of the machine body, and as a result the straightness and perpendicularity of each axis vary. Although existing machines have accuracy compensation mechanisms, deformation increases further in processing with an attachment. In such cases, deformation is resolved by operating methods when accurate machining is required: for example, table feeding is used instead of ram feeding. However, some machines have no table feeding function. Thus we have developed new movement accuracy compensation technology in order to increase the machining accuracy of horizontal boring mills to a level nearly equal to that of double column boring mills.

1. Introduction

Infrastructure industries are growing worldwide, in particular in China and India. Along with this trend, demand for construction machines, power systems, industrial machines and pressing machines is increasing. A horizontal boring machine is required for machining medium and large parts, and the enhancement of cutting ability and accuracy is called for in order to improve productivity.

MHI has been responding to such requests by offering the MAF-RSC series. Reflecting the current increase in demand, however, the development of a machine with higher productivity that can lead the industry further is required. So we have enhanced cutting ability and pursued the realization of a machine that deforms little, even when an attachment is mounted, through the installation of new accuracy compensation mechanisms. Accordingly, we have created the MAF-C floor-type horizontal boring mill, which attains the highest performance level in the world.

This document describes the details of the technology that resulted in the accuracy improvement described above.

2. Machine configuration and problems of horizontal boring machines

2.1 Machine configuration

A horizontal boring machine consists basically of a bed, column, saddle, ram and spindle as shown in **Figure 1**. The X axis is the longitudinal travel of the machine on the bed. The Y axis is the vertical travel of the saddle moving along the column. The Z axis and the W axis are the inward and outward travel of the ram and the boring spindle, respectively. The saddle is connected by a wire to the balance weight placed in the column through the pulley on the top of the column to cancel its own weight. Each axis is accurately driven by a ball screw or rack and pinion.

The workpiece is set on the floor plate installed on the front side of the machine and cut by each axis operation. When a rotary table is mounted, the workpiece can be turned and then its back side, etc., can be cut.

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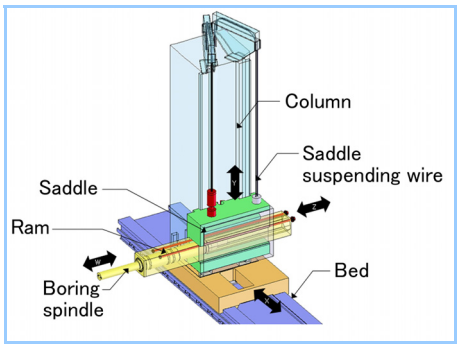

Figure 1 Configuration of horizontal boring machine

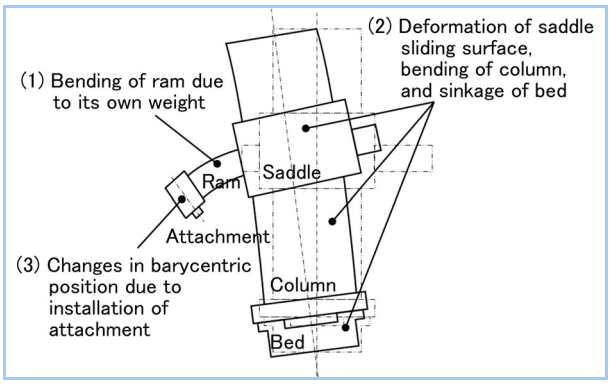

Figure 2 Problems of horizontal boring machine

2.2 Problems of horizontal boring machines

Because horizontal boring machines have the spindle positioned horizontally, the jutting out movement of the ram causes accuracy degradation due to the following factors as shown in **Figure 2**.

(1) Bending of the ram due to its own weight

(2) Deformation of the saddle sliding surface, bending of the column, and sinkage of the bed caused by changes in the barycentric position due to the movement of the ram

(3) Leaning caused by changes in the barycentric position when an attachment is mounted

Horizontal feeding without compensation will experience degradation of finished surface accuracy and perpendicularity between the Z axis and the Y axis as described above. Accordingly, the accuracy compensation function is essential.

3. Conventional accuracy compensation method

Our existing MAF-RSC machine uses a full balancing function as a countermeasure to the problem. This function consists of the three compensation mechanisms shown in **Figure 3**: the moment balance weight for canceling changes in the barycentric position due to the movement of the ram, the ram barycenter suspending mechanism for maintaining a certain bending of the ram regardless of the protrusion of the ram, and the ram suspending position moving device for canceling changes of moment when an attachment is mounted. These conventional compensation methods have the advantage that they can fully cancel even changes of moment on the base and the bed, and consequently accuracy stabilizes regardless of the positions of the Y axis and the Z axis. However, the ram cannot be made smaller and fine compensation specific to each attachment is difficult.

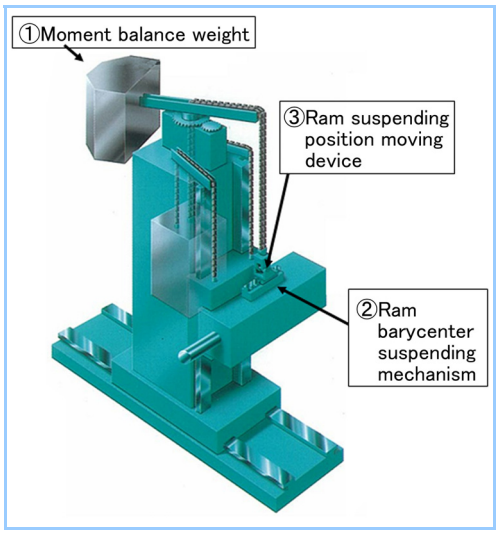

Figure 3 Current compensation mechanisms

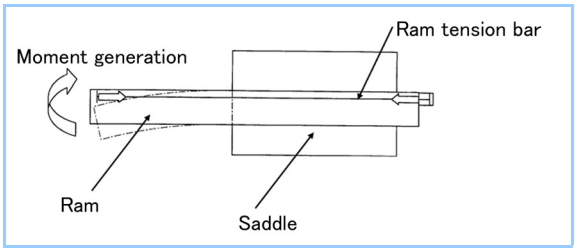

Figure 4 Ram tension bar

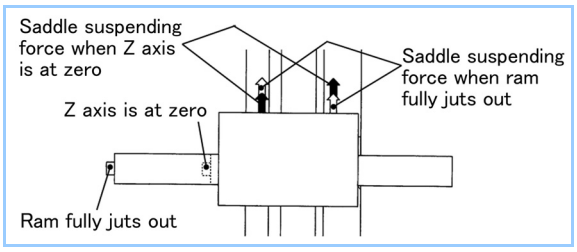

Figure 5 Compensation for saddle suspending force

On the other hand, typical floor-type horizontal boring machines use the ram tension bar compensation shown in **Figure 4** and the saddle suspending force compensation shown in **Figure 5** as compensation mechanisms. Ram tension bar compensation is a mechanism that cancels the

bending of the ram due to its own weight, using moment generated by the tension bar located at the upper part of the ram. Saddle suspending force compensation maintains the saddle horizontally, changing saddle suspending force in response to changes in the barycentric position of the entire ram and saddle due to the movement of the ram.

When these mechanisms are used, however, the bending of the column changes in principle depending on the position of the Z axis, and accordingly the straightness of the Y axis fluctuates in response to the position of the Z axis. In addition, accuracy degradation caused by sinkage of the base and the bed due to barycentric changes in the entire machine during the movement of the ram cannot be compensated. So these mechanisms have the problem where the straightness of the Y axis and perpendicularity between the Y axis and the Z axis vary and the swing accuracy of the spindle degrades depending on the position of the Z axis.

4. New compensation system and its effect

The MAF-C aims to make possible a compact ram that cannot be realized by the full balancing function and attain the same or higher accuracy. Previously, degradation of accuracy due to bending of the column and sinkage of the base and the bed could not be compensated for by ram tension bar compensation and/or saddle suspending force compensation. The MAF-C takes advantage of our FEM analysis technology to eliminate such a weak point using the following methods.

4.1 Compensation for bending of the column (column tension bar compensation)

As shown in **Figure 6**, changes in the barycentric position due to the leftward and rightward movement of the ram is balanced by changing the suspending force of the right and left sides of the saddle. Because the balancing wire connecting the saddle and the balance weight runs through the pulley on the top of the column, however, the force on the top of the column varies when the suspending force of the column is changed. This bends the column, causing accuracy degradation. To compensate for such bending of the column, we have developed and employed for MAF-C a column bending prevention mechanism, installing a tension bar in the column to cancel the moment generated by changes in the saddle suspending force.

This mechanism reduces the bending of the column depending on the position of the Z axis, and accordingly the straightness of the Y axis and swing accuracy of the spindle are stabilized regardless of the positions of the Z axis and the Y axis.

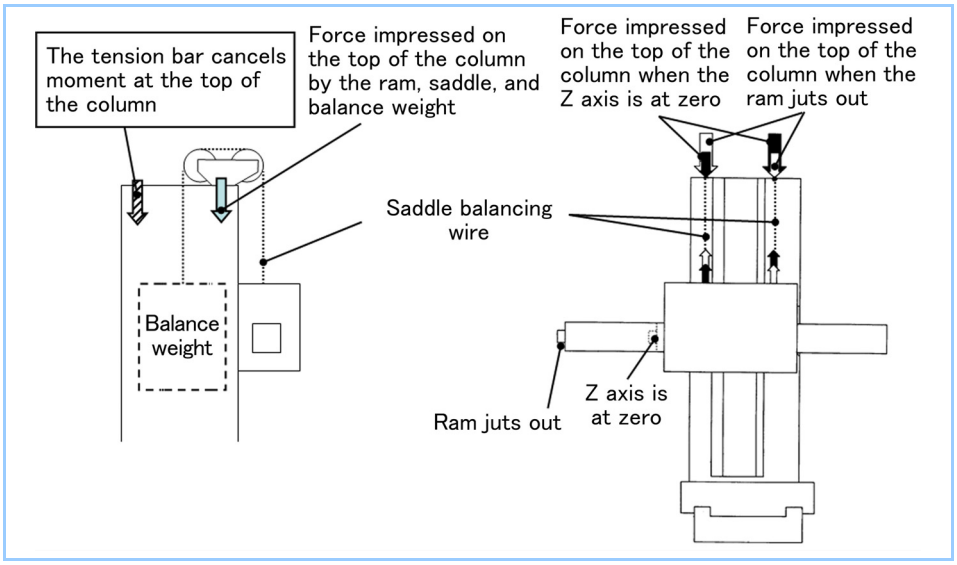

Figure 6 Force impressed on top of column

4.2 Compensation for sinkage of the bed and the base (spatial accuracy compensation)

When the ram moves leftward and rightward, the barycentric position of the machine body changes, causing the bed and the base to sink. As a result, the Y axis leans from the reference horizontal line depending of the position of the Z axis. In spite of the employment of a design with a higher rigidity for the minimization of such sinkage, complete elimination is difficult. Because

this accuracy degradation can be compensated for easily by measuring the error vector on the Y-Z plane, however, we use spatial accuracy compensation, which performs measurement and compensation with NC, to ensure higher accuracy.

Spatial accuracy compensation enables accurate cutting, even with an attachment mounted, because the force on each tension bar and spatial compensation amount are controlled depending on the machine coordinates and the tension amount and spatial compensation amount are set for each attachment mounted.

4.3 Effect of new compensation system

Figure 7 shows the measurement of displacement in the direction of the Y axis using the compensation method described above. The displacement shown is 3 μm/1000 mm for the protruding ram without an attachment and 6 μm/1000 mm for that with an attachment. So the variation is very small (3 μm/1000 mm).

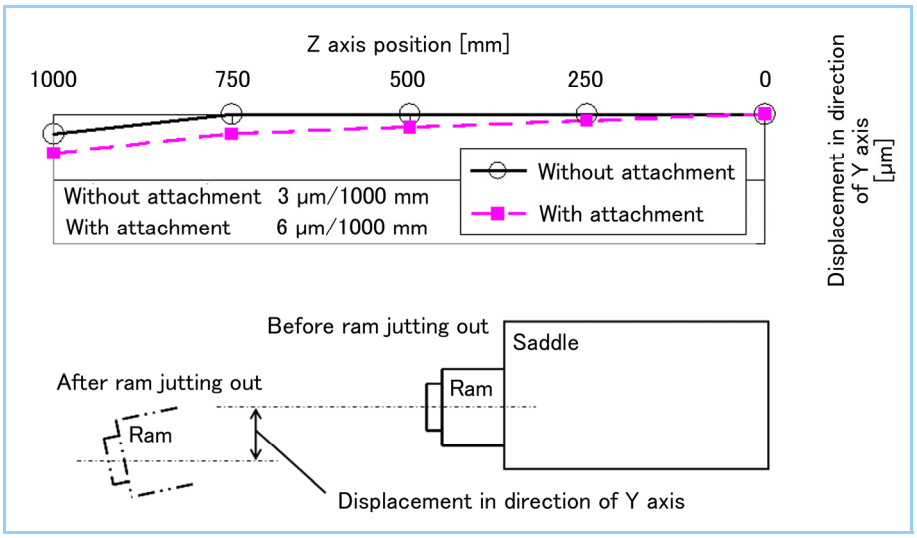

Figure 7 Measurement of displacement in direction of Y axis

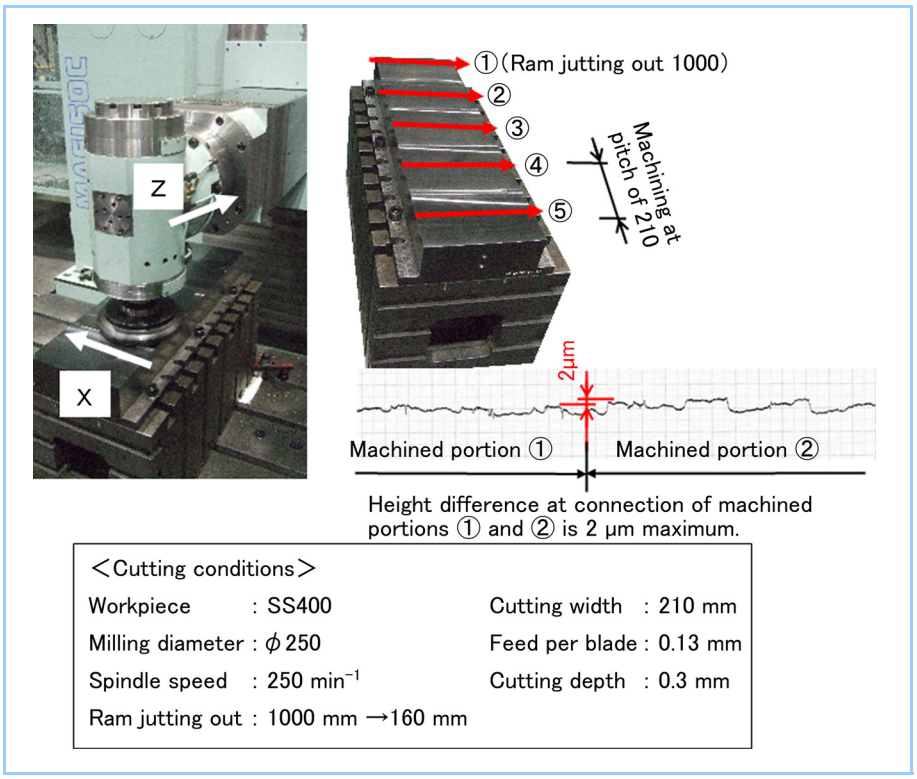

Figure 8 Right angle head finish machining

Figure 8 shows an actual workpiece finish-machined with a right angle head. The machine cut the workpiece in the direction of the X axis, moving the Z axis at a pitch of 210 mm from the position where the Z axis juts out 1000 mm (the distance from the gauge line is 1550 mm). The

unevenness of pitch height was 2 μm at the most, so the effect of the new system was demonstrated.

5. Conclusion

The MAF-C has accuracy compensation mechanisms that represent a different approach to the status quo. We have realized such a machine due to our extensive analysis technologies. The MAF-C is a world-leading machine that has improved accuracy, cutting ability and rigidity, enabling even deeper cuts. We will continue to offer horizontal boring machines that provide for customer productivity improvement using the expertise obtained in the development of this machine. **Table 1** compares the specifications of the MAF-C with those of competing machines as a reference. We have set specifications that can respond to any customer needs: the stroke of the X axis is 5000 to 21000 mm, and that of the Y axis is 3000 to 5000 mm.

To make it possible to cut deeply in a small bore, the overall stroke of the Z axis and the W axis is extended to 2250 mm, and the ram size is reduced from 600-mm-square to 420-mm-square. Although the ram is more compact, its rigidity is increased from previous models using a ductile cast iron material and four-plane static pressure support. As a result, this machine can take full advantage of the spindle output of 55/75 kW. In addition, the thermal displacement in the Z axis direction caused by the rotation of the spindle can be compensated for using ATDS (Advanced Thermal Displacement Suppression System) thermal deformation compensation technology.

When compared to competitors, this machine has attained the best specifications in its class. In addition, we have obtained an advantage over competitors due to the compensation system described above.

Table 1 Specifications comparison table

		MAF-C	MAF-RSC (existing machine)	Japanese competitor A	Foreign competitor B
Boring spindle diameter	mm	ϕ 150 * ϕ 180	ϕ 150 * ϕ 180	ϕ 160	ϕ 180
Ram size	mm	420×420	600×600	420×420	400×440
Spindle output	kW	*55/75* **80/100*	30/37 *37/45	45/55	60/84
Spindle speed	min^{-1}	2500	2000	2000	2500
X axis travel (column longitudinal)	mm	5000-21000	3000-20000	6000-18000	4000-
Y axis travel (saddle vertical)	mm	3000-5000	2500-4500	3000-5000	2500-3500
Z axis travel (ram in/out)	mm	*1250*	1100	1100	1200
W axis travel (boring spindle in/out)	mm	1000	900	900	1000
Rapid traverse X	mm/min	*20000*	15000	10000	20000
Y	mm/min	*20000*	15000	10000	20000
Z, W	mm/min	*15000* **20000*	10000	6000	20000

* Optional