

The MAF150R: A Floor Type Horizontal Boring Mill Providing the Highest Machining Efficiency in its Class



HIROYUKI YAMAMURA SATOSHI FURUTATE

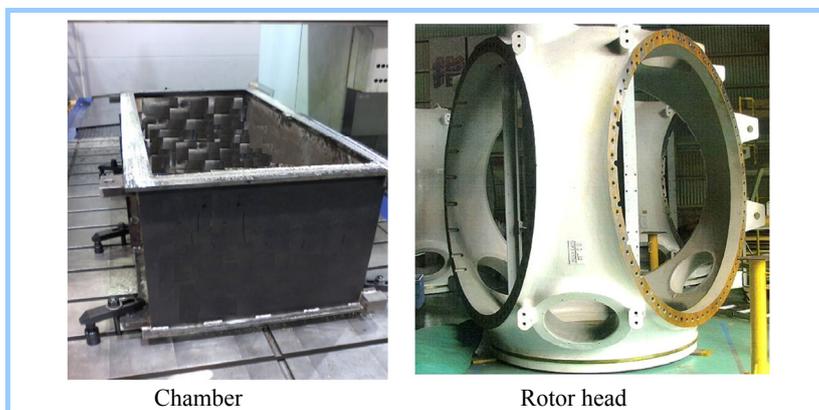
HIROYUKI DOMARU TOMOHARU HASEGAWA

MAKOTO EGUSA

In recent years, customer demand has been increasing for machining tools that offer higher cutting performance and productivity with reduced non-cutting periods for medium- and large-part machining processes. To address such machining needs in manufacturing facilities, Mitsubishi Heavy Industries Ltd. (MHI) developed the MAF150R, a floor type horizontal boring mill that provides both heavy-cutting performance and short non-cutting times. MHI designed this machine by making full use of its FEM analysis technology. In this paper, we describe the technologies used for this machining tool and present actual machining examples.

1. Introduction

With the expansion of wind and solar power and the increased use of motors in other energy-generation industries, an upsurge has occurred in demand for medium- to large-size parts that need be produced using a horizontal boring mill. **Figure 1** shows an example reference workpiece used in this field.



Chamber

Rotor head

Figure 1 Example workpiece

This surge in demand appears to be spreading worldwide. Manufacturers of these parts now expect heavy-cutting, high-speed, and high-productivity machining tools.

MHI tried to address these needs with the MAF-RS series. To meet the demand for even faster machining, however, we developed the MAF150R, the best floor type horizontal boring mill in its class in Japan, which pursues the reduction of non-cutting times by speeding up and automating processes without sacrificing heavy-cutting performance. In developing the MAF150R,

MHI optimized the structural shapes and the coupling rigidity between parts by utilizing FEM analysis and simulating anticipated cutting in actual machining postures. This resulted in a high-productivity boring mill that offers heavy-cutting performance that is not influenced by the height and protrusion of the spindle, as well as the highest speed and acceleration/deceleration characteristics in its class.

We discuss the technologies used to realize the above functions in this technical review.

2. Development concept of the MAF150R

The MAF150R was developed with the concept of realizing a high-performance horizontal boring mill. The aim was to provide benefits to our customers with higher productivity compared to competitors' products. Thus, a machine was required that reduced both its cutting and non-cutting times in a well-balanced manner.

Figure 2 compares the cycle time of the MAF150R versus a domestic competitor's machine in the same class when machining a construction machine part (or workpiece). In this example, the cycle time was reduced approximately 35% by decreasing the axis feed time through more rapid traverse rates and decreasing the attachment changing and indexing and the tool changing times. The cutting time was also decreased by improving the heavy-cutting performance of the machine.

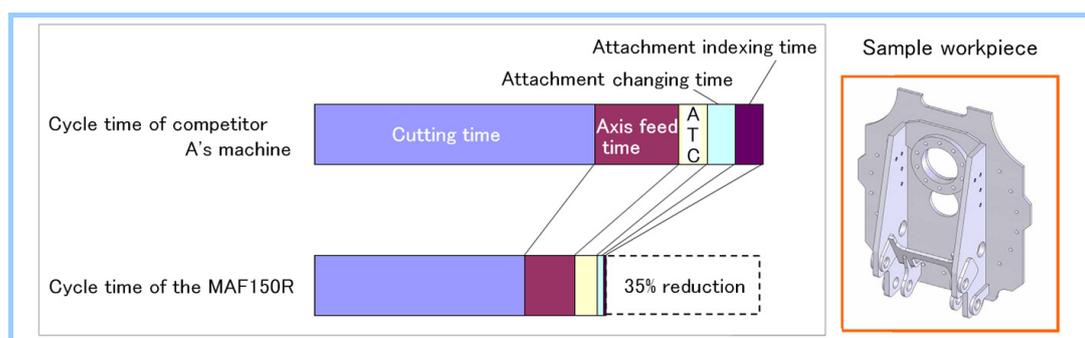


Figure 2 Comparison of cycle time

3. Technologies for realizing high productivity

3.1 Machine construction

Figure 3 shows the construction of the MAF150R. To meet the needs for high-speed machining, the MAF150R was developed as a new series product that is slightly smaller than the current MAF-RS series. Therefore, its ram (Z-axis), which extends and retracts while supporting the main spindle, is somewhat smaller but has a 400-mm square shape to ensure optimal rigidity. This construction enables the machine to bore the deepest holes in its class in a flexible manner, even in a narrow workspace. In addition to this, the MAF150R also has a W-axis for boring spindle longitudinal in/out, a Y-axis for the vertical movement of its saddle along the column, and an X-axis for cross-feeding its column along the bed.

3.2 High heavy-cutting capacity

The high rigidity of the machine body achieved by utilizing FEM analysis enables full-power cutting at 37 kW, the maximum output capacity of the spindle motor, across all the machining ranges. The MAF150R can offer the same heavy-cutting performance even when the main spindle is at a high position or has a long protrusion, improving the overall machining efficiency. In the following description, we introduce the technologies for optimizing the structural shapes and the coupling rigidity between parts to achieve high rigidity.

(1) Selection of materials for an optimal structure

To realize high rigidity, we first reviewed the selection of materials used for the main structures. Although welded steel, which offers a high static rigidity, has been used conventionally as the structure material, we adopted castings for the MAF150R because they have advantages in forming the complex logical structure shapes derived from the FEM analysis. The result was an increase in sectional rigidity, which not only led to higher static rigidity, but also improved dynamic rigidity, affecting the machining accuracy. Moreover, for the ram located nearest to the cutting point, ductile cast iron (FCD600) with a high elastic modulus equivalent to iron steel was used because it has particularly high rigidity and damping characteristics.

(2) Optimization of the structural shapes

The rigidity of the column was very important in order to realize heavy cutting at a high position, which effectively improves productivity. The column also must be as light as possible to ensure fast movement. For these reasons, we adopted a double-walled rib structure for the MAF150R.

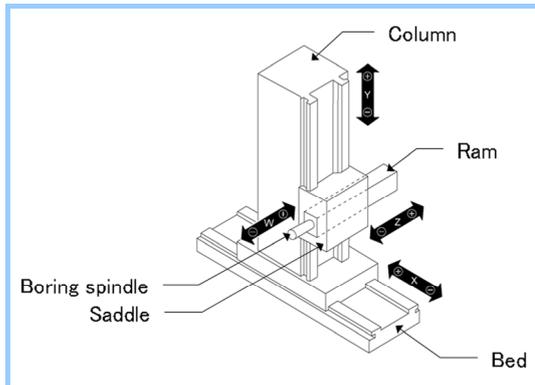


Figure 3 Construction of horizontal boring mill

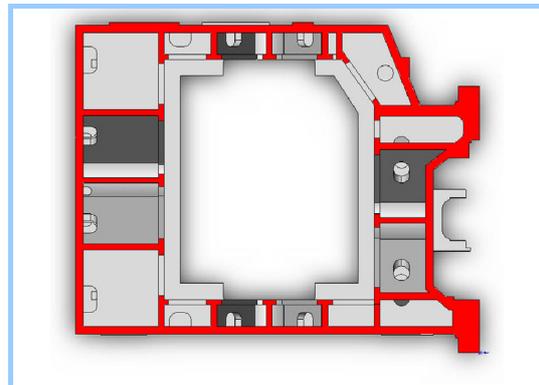


Figure 4 Double-walled structure of the column

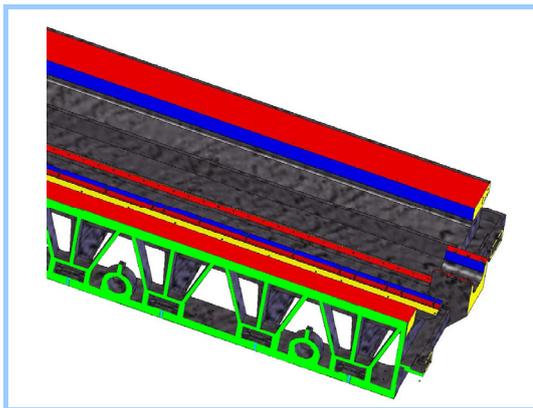


Figure 5 Honeycomb structure of the machine bed

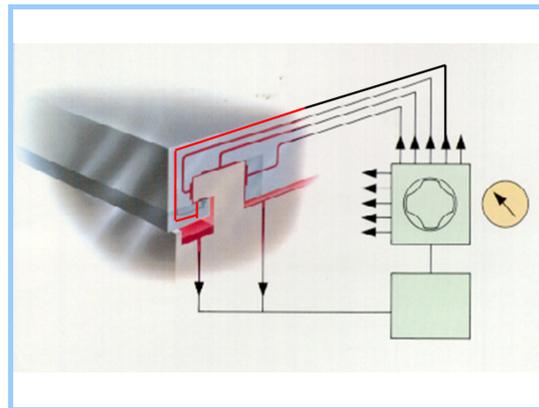


Figure 6 Opposed hydrostatic bearing

Figure 4 shows a model of the double-walled column. It is a well-known fact that providing double walls with a rib between them improves the rigidity of a structure. However, relying on this technique only not only results in a substantial increase in mass, but also makes the casting forming extremely difficult. Therefore, we partially removed the internal walls, as shown in the model, to facilitate the casting forming process and minimize the increase in mass. This construction provided sectional rigidity 1.6 times higher than that of a conventional simple rib structure.

Next, a model of the machine bed is shown in **Figure 5**. By providing a honeycomb structure just under the sliding surface that can support the entire moving mass, we enabled the machine bed to maintain a high rigidity without increasing its mass. Thus, by means of FEM analysis, we balanced the competing design elements "mass reduction" and "rigidity improvement" in a sophisticated manner.

(3) Optimization of coupling rigidity between parts

The MAF150R adopted opposed hydrostatic bearings (**Figure 6**) for the X- and Y-axes that support a large mass of the structure and a slide-guide mechanism that holds the four faces of the ram for the Z-axis. This enabled each of these axes to provide smooth rapid traverse across all speed ranges while maintaining a high level of support rigidity.

3.3 Increased productivity by reducing the non-cutting times

(1) Increased rapid traverse rate

The aim of increasing the rapid traverse rate for each axis was to reduce the time required for positioning the axis during the feed operation. The rapid traverse rate was increased to 24000 mm/min for the X-axis, approximately twice as fast as that of domestic competitors' products in the same class, and 20000 mm/min for the Y- and Z-axes.

(2) Increased spindle speed

The spindle speed of the MAF150R was set to 3000 min⁻¹, approximately twice as fast as that of competitors' products in the same class. In addition, to suppress the heat emitted from the drive system, we adopted a cooling system for the MAF150R that cools the spline shaft

from inside by injecting temperature-controlled oil. We also adopted an automatic mist lubrication for all bearings in the drive system (8 points) and the main spindle bearings that supplies temperature-controlled oil to the outer case of each bearing to prevent thermal deformation. The main spindle bearings have temperature-monitoring functionality that detects the occurrence of a failure at an early stage and reminds the operator of required maintenance to prevent sudden machine stoppage.

3.4 High accuracy through compensation for variations in the center of gravity and thermal displacement

(1) Saddle balancer

This balancer offers balance compensation functionality intended to reduce the drooping of the main spindle nose when the boring spindle and/or ram is extended horizontally. Specifically, if the spindle end bends or hangs down under its own weight when the workpiece is machined with the boring spindle or the ram extended horizontally, the finished surface accuracy is badly affected. Such bending or hanging of the spindle nose can be minimized by using this compensation function.

The balancer controls the degree of drooping of the spindle nose by adjusting the suspension force at the front and back of the saddle so that the bending angle (swinging or hanging) of the main spindle is minimized. For this purpose, a cylinder was built into the suspended portion in front of the saddle that compensates for the pressure through linear compensation based on the Z-axis position. A similar compensation technique is also used for the W-axis to compensate for the variation in the center of gravity of the moving body.

(2) Thermal displacement suppression

The MAF150R was provided with the following four improvements to suppress thermal displacement.

- To suppress the deformation (thermal expansion) of the column due to fluctuations in the outside air temperature, the volume (thickness) of the front and back ends of each column member varying in shape were made equivalent in heat capacity through a thermal analysis to minimize the variation in the degree of rise or fall of the column at different ambient temperatures.
- Temperature controlled oil was designed to circulate inside the main spindle bearings and in the drive gearbox to suppress the temperature rise and thermal displacement that occurs when the main spindle is rotating at a high speed.
- For the opposed hydrostatic bearings used for the X- and Y-axes, which have high support rigidity, the variation of the center of gravity was minimized to realize high-accuracy movement, and the temperature of the hydrostatic lubricating oil was controlled to the temperature of the machine to suppress the thermal displacement caused by the axis feed.
- Compensation functionality was added to compensate for the thermal displacement of the machine in the Y- and Z-axis directions that occurs when the main spindle rotates.

3.5 User friendliness

With recent improvements in productivity, customer demand for easy maintenance and operation has been increasing. To improve maintainability, the MAF150R adopted a centralized arrangement of all lubrication devices to facilitate the refilling and draining of lubricating oil, the servicing of these devices, and other maintenance tasks. In addition, for periodic maintenance items, the machine was designed to alert the operator by displaying maintenance information on the machine operation panel when required.

For improved operability, we developed five-face machining software based on the technique of machining surface-coordinate expansion. This software facilitates the creation of programs for complex surface machining in a short period of time because any inclined surface (at any degree) can be programmed as XY planes, and tetrahedral shapes can be defined with four sides crossing at right angles. The software also has sixteen patterned subprograms for bolt-hole circles, etc. The software was developed based on numerical control (NC) functions and does not require any special programming device, which also enhances its user-friendliness. It was designed to yield the best performance from a rich variety of attachments, such as a right angle head, universal head, boring-tool head, and spindle support.

4. Machining example

To verify that the machine performs as anticipated, we test-cut a sample workpiece. The test was conducted using the machining conditions shown in **Figure 7**, with the Y-axis set to a height of 2,700 mm and the Z-axis (ram) extended 700 mm. For these conditions, the actual output indicated by the spindle load meter was 37 kW, which demonstrates that the MAF150R offers heavy-cutting performance at a high spindle position as initially intended. Compared with the machining data for Competitor A's machine, this resulted in a cutting capacity improvement of 1.6 times, which demonstrates that the cycle time is reduced for heavy-cutting applications. This means that the workpiece can be machined with a motor output of 37 kW, the highest in its class, regardless of the extension distance of the Z-axis along the Y-axis up to a height of 2,700 mm.

The test results are compared with those obtained Competitor A's machine in **Figure 8**. The graph shows the Y–Z machining area of both machines. The MAF150R had an obvious advantage in machining capacity because a motor output of 37 kW was available over the entire range, unlike in Competitor A's machine.

Machining data for the right angle head, one of the main attachments, is shown in **Figure 9**. **Figure 10** shows its external appearance. This test was conducted with the Z-axis (ram) extended to 550 mm, meaning that the machining point was as far as 1,000 mm including the length of right angle head itself from the original Z-axis zero position. The test demonstrated that the workpiece could be machined with a motor output of 30 kW, the maximum output of the right angle head, in this machining position, and highlighted the high rigidity of this attachment. The motor output was three times that of Competitor A's angle head (max. 10 kW), which shows the excellent performance of the MAF150R as a five-face cutting machine.

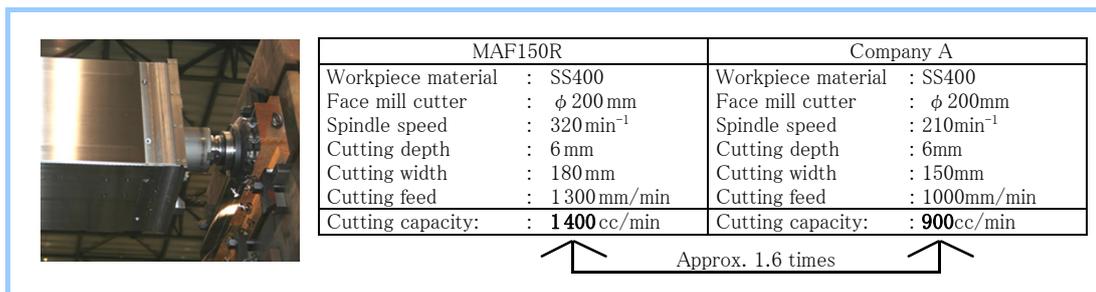


Figure 7 Machining data for the MAF150R

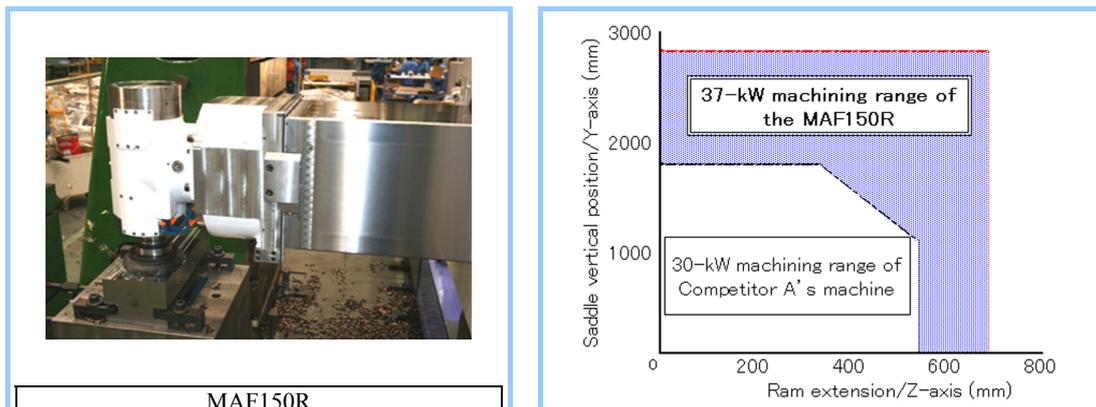


Figure 8 Comparison of cutting range

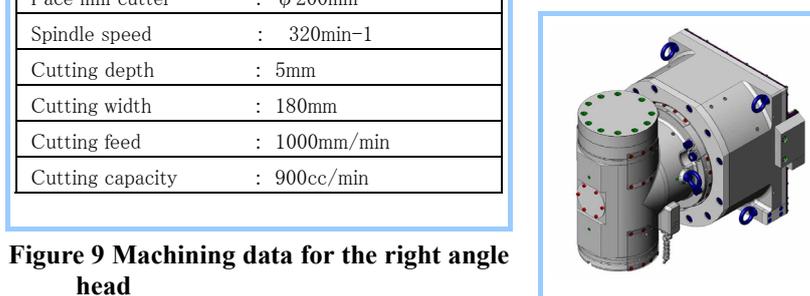


Figure 9 Machining data for the right angle head

Figure 10 External appearance of the right angle head

5. Machine Specifications

The specifications of the MAF150R were determined to support the machining of large-diameter and long workpieces with the X-axis stroke set between 5000 and 21000 mm, the Y-axis stroke set between 2500 and 3500 mm, and the total stroke of the Z- and W-axes set to 1400 mm. Despite these extensive specifications, the adoption of a modular design approach enables a short delivery period. Table 1 lists the main specifications of the MAF150R and compares them with those of competitors' products. The capacity of the MAF150R is prominent in its class.

Table 1 Main specifications

| | MAF150R | Company A | Company B |
|---|------------------------------------|-------------------|--|
| Boring spindle diameter (mm) | φ150 | φ150 | φ150 |
| Spindle taper | 7/24 taper ISO 50 | 7/24 taper ISO 50 | 7/24 taper ISO 50 |
| Spindle motor output (kW) | 30/37 | 22/26 | 22/30 |
| Spindle rotation speed (min ⁻¹) | 7 to 3000 | 5 to 1500 | 16 to 1600 |
| X-axis stroke [Column, cross feed] (mm) | 5000 to 21000 | 6000 to 10000 | 4500 to 9000 |
| Y-axis stroke [Saddle, vertical] (mm) | 2500 to 3500 | 2000 to 3500 | 2500 to 3500 |
| Z-axis stroke [Ram, longitudinal] (mm) | 700 | 750 | 450 |
| W-axis stroke [Boring spindle, longitudinal] (mm) | 700 | 900 | 1000 The total stroke of the W- and Z-axes is 1000 mm or less |
| Rapid traverse rate: X-axis (mm/min) | 24000 (X-axis stroke = 5 · 6 m) | 10000 | 10000 |
| Rapid traverse rate: Y-axis (mm/min) | 20000 | 10000 | 10000 |
| Rapid traverse rate: Z-axis (mm/min) | 20000 | 6000 | 8000 |
| Rapid traverse rate: W-axis (mm/min) | 10000 | 6000 | 8000 |
| Cutting feed rate (mm/min) | 1 to 10000 | 1 to 4000 | 1 to 4000 |
| Automatic tool changer (ATC): # of tools | 60, 80, 100 | 60, 80 | 50 |

6. Conclusion

In developing the MAF150R, we combined MHI's abundant analysis know-how and pursued an optimal structural construction. As a result, we successfully built our envisioned product on our first attempt. This achievement was due to our improved analytical capacity. We will accelerate the development of new products in the future using similar techniques.

Authors



Hiroyuki Yamamura
Manager,
Engineering Department,
Machine Tool Division



Satoshi Furutate
Manager,
Engineering Department,
Machine Tool Division



Hiroyuki Domaru
Engineering Department,
Machine Tool Division



Tomoharu Hasegawa
Engineering Department,
Machine Tool Division



Makoto Egusa
Engineering Department,
Machine Tool Division