Machining Center at the Forefront of Production

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Machining Centers are widely used for a variety of the latest machining processes. In 2002, Mitsubishi Heavy Industries, Ltd. (MHI) released the VΣ-series and HΣ-series machining centers that provide high-accuracy and high-efficiency part machining for the die/mold, power systems and aircraft industries. The operations are realized incorporating innovative technology such as high-speed low-vibration spindles, thermal displacement restriction, high-speed hydrostatic guide ways and high-speed high-accuracy servo drives. Σ series are at the forefront of advanced technologies.

1. Introduction

The progress of technology requires higher accuracy and higher efficiency for metal cutting. For example, in the die & mold industry, IT (Information Technology) requires smaller and much more precise machining details. Machines that can minimize the amount of hand finishing are in strong demand, to reduce cost and shorten delivery. In the power systems and aircraft industries, efficient machining of hard-to-cut materials such as Inconel or titanium is demanded.

To meet such needs, MHI has released vertical and horizontal machining centers called the Σ series, which incorporate MHI's state-of-the-art advanced technology.

High efficiency machining requires high-speed rotating spindles and high-speed motion feed mechanisms. To realize high accuracy, strong guide ways and restriction of thermal displacement are necessities. This thesis reports how Σ series realize high speed yet highly rigid spindles, high speed and high precision feed mechanisms, and thermal displacement restriction.

2. The latest technologies for our machining centers

The basic specifications of the Σ series vertical machining center M-V50-FM and the horizontal machining center M-H60 are shown on **Table 1**. The key technologies are discussed below.

Table 1 Σ series specifications

		M-V50-FM	M-H60
Travel	X-axis (mm)	800	1 050
	Y-axis (mm)	510	890
	Z-axis (mm)	450	890
Rapid feed speed	(m/min)	24	30/50* (XY only)
Maximum spindle speed	(min^{-1})	14 000/30 000*	6 000/3 200*/16 000*
Table size	(mm)	510 × 1 000	630 × 630
No. of tools	(tools)	15/24*/40*	40/80*/120*/238*

Note 1: Only representative models are shown. Σ series includes M-V50, M-V70, M-H80. Note 2: * option

2.1 High speed yet highly rigid spindle

In the die/mold industry, high speed, highly rigid, low vibration spindles are required in order to cut smooth 3D surfaces with higher efficiency. For the VΣ series, a 30 000 min^{-1} low vibration spindle has been developed.

With this spindle, high efficiency die & mold machining is realized thanks to higher rigidity at all speed ranges, obtained by optimum bearing layout and our automatically variable pre-load mechanism. Also, spindle nose end vibration within 3 μm^{P-P} can be maintained for long periods by utilizing coil springs in place of Belleville springs in the tool retention mechanism, and incorporating multi-phase dynamic balancing technology.

As a result, drilling of diameters as fine as 60 μm, which is hitherto almost impossible, is feasible as shown on **Fig. 1**.

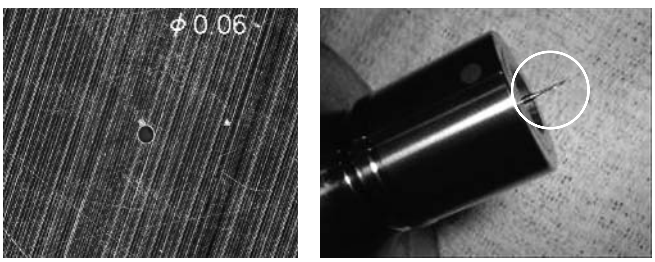

Fig. 1 φ60μm hole and drill

2.2 High speed high precision feed system

For higher efficiency of machining, higher feed speed is required in order to reduce both cutting time and non-cutting time. Furthermore, for higher accuracy, it is essential to enhance the rigidity of the guide way system. However, simply increasing feedrates will increase positioning error due to inertial force of the moving parts,

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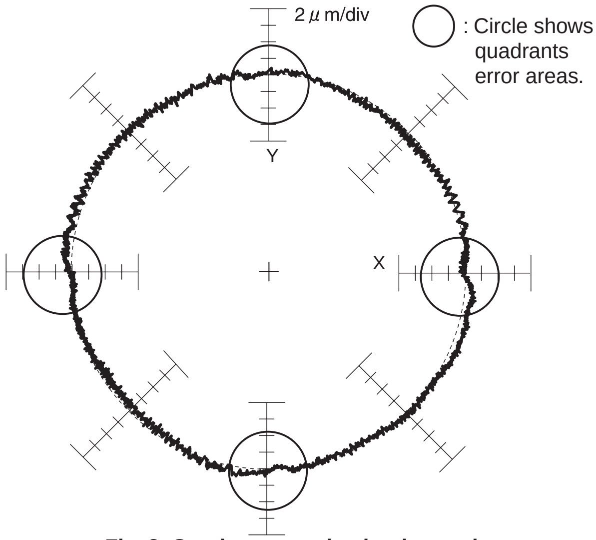

Fig. 2 Quadrant error in circular motion

and simply increasing rigidity of the guide ways will increase friction, thereby further increasing positioning error. The hydrostatic guide way technology was employed for the Σ series in order to satisfy these mutually contradictory demands. Rigid box ways combined with a thin film of incompressible hydrostatic oil results in tremendous dynamic rigidity yet extremely low friction of linear motion, with no stick-slip. As a result, when machining a circular motion at 50 m/min, which is the maximum feedrate of the class, the machining error occurring when reversing the moving direction, known as quadrant error, is held within 3 μm as shown in **Fig. 2**, and accurate circle machining is realized. Moreover, owing to the high rigidity of the guide ways, cutting performance for difficult-to-cut materials such as heat-resistant alloys like Inconel 718 is greatly improved, and chipping of tools experienced with conventional machines is eliminated, extending tool life by more than two times.

2.3 Measures against thermal distortion

Σ series machining centers have effective ways to eliminate thermal distortion, which is another major factor influencing machining accuracy. Basically, thermal distortion occurs when temperatures of parts are not uniform. For our Σ series, heat insulating covers are used to isolate the machine from environmental temperature fluctuations and major internal heat sources are cooled by an oil circulation system. Additionally, fans circulate air through ducts in the machine castings to maintain uniform temperature throughout the entire machine. This eliminates thermal deflection, which is difficult to compensate. In addition, the uniform thermal expansion and contraction of structural parts is compensated by use of temperature sensors and algorithms which correct for thermal displacement. As a result, for the machining accuracy for dowel pins, which is very important for automotive parts, 20 μm diameter true position can be obtained as shown in **Fig. 3**.

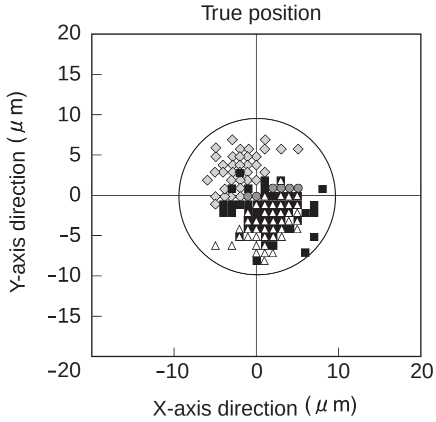

Fig. 3 True position of dowel pin holes

2.4 Innovation of design technique

The technologies described above are not only based on our experience and know how accumulated through decades as a machine tool manufacturer, but also are a by-product of research and development at the Aerospace and Power Systems Divisions of MHI. This engineering support system gives us a competitive advantage in advancing state-of-the-art technology in our machine tool designs.

The Σ series had been totally designed by using three dimensional CAD, with computer simulations developed through our engineering support system, such as structural analysis, spindle rotor dynamics analysis, characteristics analysis of non-linear element feed systems, thermal distortion analysis of machine structure, and cooling effect simulations by thermal fluid mechanics analysis.

To support these computer simulations, actual testing using full-scale models is frequently performed. Thus, reliable products are developed by a combination of digital models and real models.

3. Conclusions

MHI is determined to further advance of the latest technologies and will continue to introduce newly improved machining center designs which address the needs of our customers in meeting the increasing demands of a global economy.


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