Developments in High Precision Machining Center Spindles

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INSTRUCTIONS

Recently, there has been an increasing tendency throughout the market toward machining centers being used for production of general components and die & mold components. As complex-functionalization and multi-functionalization of machining centers progress, the market is increasingly demanding ever more sophisticated levels of performance. What is required of machining centers is minimization of dimensional errors, profile errors and machined surface roughness. These are all closely related to improvements in efficient machining of all kinds of components as well as reductions in lead times.

The realization of these machining center performance demands is considered to depend on the performance of the feed drive system, system control and spindle unit system, which are the main component units of the machine, and therefore these units need to be improved. Especially, with high precision machining centers used for machining high accuracy workpieces, the performance of the spindle unit, which is located nearest to the machining point and significantly influences machining, must be improved.

PERFORMANCES REQUIRED FOR THE SPINDLE UNIT

The spindle unit of the machining center is a very simple structure composed of a drive motor section, rotating spindle section, cutting/grinding tool holding section and spindle support section. The drive motor section generally employs an AC servo motor. The rotating spindle section made of heat-treated alloy steel is finished by grinding. The spindle support section uses hydrostatic bearings, aerostatic bearings, ball or roller bearings or hybrid bearings, according to the DN value and usage applications. As the structure using ball bearings has a wide variety of machining applications, it is generally used for grinding by the machining center. The required performances for the spindle unit are, as shown in Table 1, heavy cutting performance (mainly static rigidity) and finish cutting/grinding performance (mainly dynamic rigidity and thermal distortion error of the spindle unit). What controls these performances and factors are considered to be the magnitude of preload given to the bearings, change in preload according to revolution change, change in dynamic unbalance and control of heat generation from the bearings and motor.

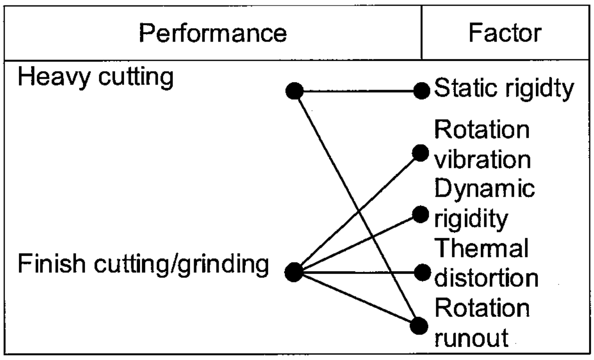
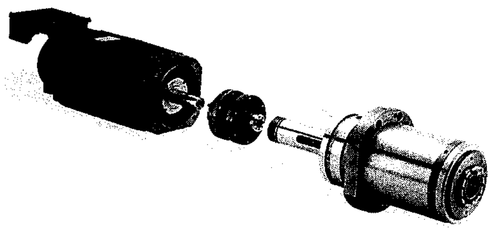


Table 1
Required performance for spindle unit

STRUCTURE OF THE DEVELOPED SPINDLE UNIT

Fig. 1 shows the structure of the developed spindle unit. Figure 2 shows its section view, and Figure 3 shows the structure concept for further understanding.



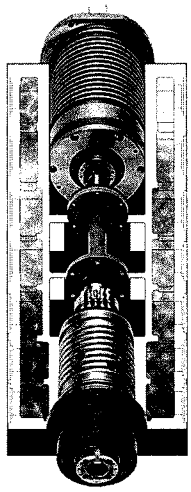


Figure 1
Appearance of spindle unit structure

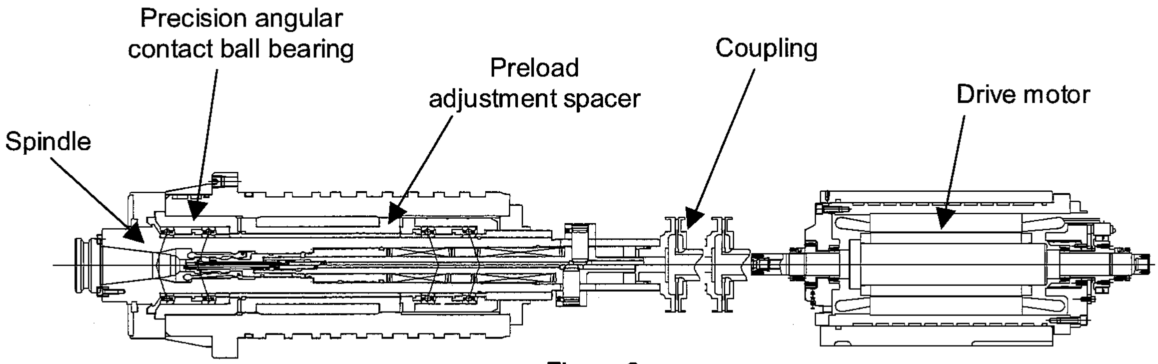


Figure 2
Entire spindle unit structure

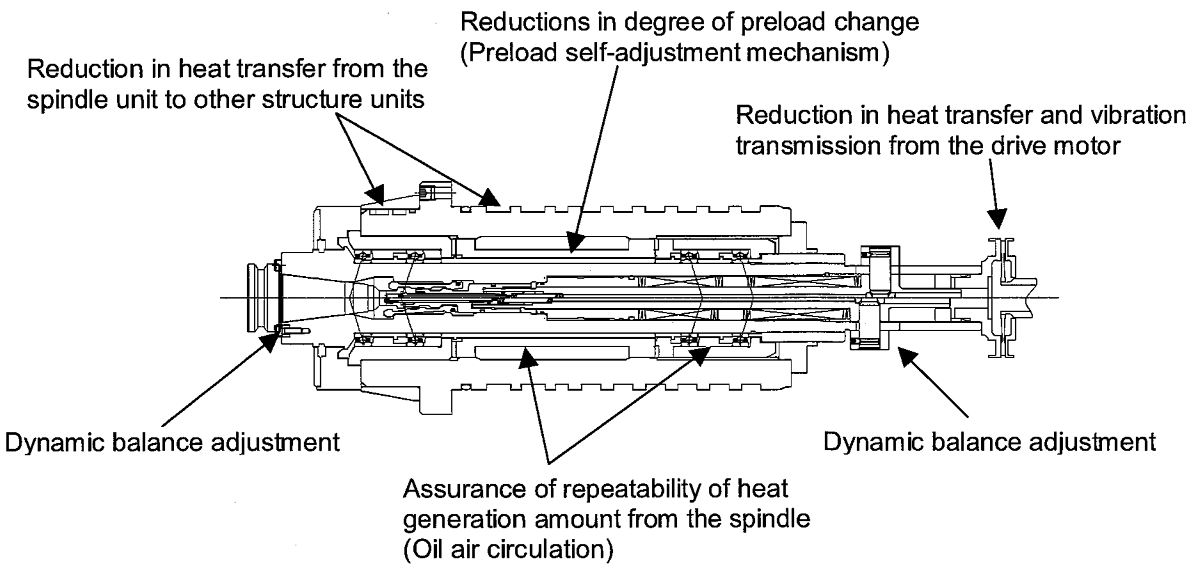


Figure 3
Spindle unit component structure

The reason for this structure being adopted is based on the following factors:
1) reduction in the degree of preload change,
2) reduction in heat transfer and vibration transmission from the spindle motor,
3) assurance of repeatability of heat generation amount from the spindle,
4) reduction in the degree of heat transfer from the spindle unit to other structure units and
5) simplicity of dynamic unbalance adjustment.

1)Reduction in the degree of preload change
The methods to apply preload to the bearings which support the spindle include a solid preload type, constant-pressure preload type and variable position preload type. With the solid preload type, a stable spindle rotation is achieved across the entire spindle rotation range. However, differences occur in thermal distribution on the bearing inner ring side and outer ring side due to heat generation from the spindle bearings, which cause a phenomena where the preload changes depending on the spindle revolution. As a result, we have focused on the difference in heat generation between the bearing inner ring and outer ring and adopted a preload self-adjustment mechanism which applies different materials to the preload spacers on the bearing inner ring side and bearing outer ring side and utilizes the heat generation from the bearing. This reduces the degree of preload changes.

2)Reduction in heat transfer and vibration transmission from the spindle motor
With increased spindle revolutions, an AC servo motor, or inductive motor, has been widely used for a drive motor. In the AC servo motor rotor, silicon steel plates are fixed by aluminum. For this reason, it is difficult to adjust the dynamic unbalance amount and therefore impossible to achieve perfect balance. As a result, vibration is generated by the spindle rotation and this transmits to the cutting tool, which deteriorates machined surface properties as well as shortens tool life.
The AC servo motor rotation transfers heat to the rotor support axis. This heat is then transferred to the bearing. However, the heat quantity received by the bearing differs depending on the rotor revolution, which causes a change in preload amounts to the bearing.
To reduce the instability of the spindle rotation mentioned above, we have employed use of separate units for the spindle unit and spindle motor and to connect them by coupling.

3)Assurance of repeatability of heat generation from the spindle
Heat generation at the bearings and motor rotor caused by the spindle and drive motor rotations is mainly derived from the bearing components. As it is presumed impossible to avoid this phenomenon, the common practice has been to enable prediction of the thermal distortion amounts due to heat generation by ensuring the repeatability of heat generation and to use software for correction.
To put this idea into practice, we have adopted a preload self-adjustment mechanism which reduces the change in preload given to the bearing.

4)Reduction in the degree of heat transfer from the spindle unit to other structure units
If heat transfers from the spindle unit, which is a main heat generating section of the machining center, to other structure units, thermal distortion of the machine itself increases, which negatively affects the stability of high-precision machining.
To reduce this phenomenon, we have adopted a jacket cleaning method at points where heat transfer is predicted.

5)Simplicity of dynamic unbalance adjustment
The spindle, or rotating body, maintaining a good dynamic balance is an important factor in considering tool life, machining accuracy and machined surface properties in cutting and grinding. Adoption of a structure which ensures simple adjustment of dynamic unbalance is another important factor in designing the spindle unit. So, we have developed a structure where dynamic unbalance can be adjusted at four points of the spindle unit without removing the spindle unit from the machining center.

The basic performances of the spindle unit developed and assembled based on the concept and structure mentioned above are verified for dynamic rigidity and degree of heat generation change.

PERFORMANCE VERIFICATION OF THE DEVELOPED SPINDLE UNIT

Spindle unit performances consist of inherent performance and machining performance and are verified by testing these performances.
Inherent performance includes
1) heat generation,
2) rotation runout,
3) vibration,

4) noise and
5) static rigidity.
Table 2 shows the rotation runout measurements.

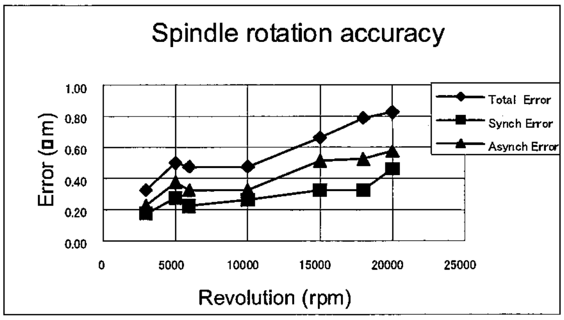


Table 2
Spindle rotation runout measurement results

On the other hand, machining performance includes
1) heavy cutting performance,
2) finish cutting performance and
3) finish grinding performance.
Table 3 shows the verification results of heavy cutting performance and Table 4 shows those of grinding performance.

Work material	Tool steel
Hardness	HRC50
Tool	□ 10 carbide end mill
Cutting feedrate	157 m/min
Feedrate	3000 mm/min
Axial cutting depth	10 mm
Radial cutting depth	1 mm
Cutting fluid	Mist
Tool life	71 m

Table 3
Heavy cutting results

Work material	Cemented carbide
Hardness	HRA76
Tool	□ 6 electroplated diamond tool (#140)
Cutting feedrate	560 m/min
Feedrate	600 mm/min
Grinding depth	10 □m
Grinding fluid	Soluble cutting fluid
Finished surface roughness Feed direction (Pick direction)	Ra 0.4 nm (Ra 1.3 nm)

Table 4
Finish grinding results

ACKNOWLEDGEMENT
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