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THE APPLICATION OF ACTIVE MAGNETIC BEARING SPINDLE ON HIGH-SPEED AND PRECISE GRINDING MACHINE

Shuqin Liu
Dept. of Electric Eng., Shandong Univ., Jinan, Shandong 250061 China
Lshuqin@sdu.edu.cn

Zhongguo Bian
Dept. of Electric Eng., Shandong Univ., Jinan, Shandong 250061 China
zxning@sdu.edu.cn

Wentao Yu
Dept. of Electric Eng., Shandong Univ., Jinan, Shandong 250061 China
bianbin@gmail.com

Eric Maslen
Dept. of Mechanical Eng., Univ. of Virginia, USA

ABSTRACT

High-speed precision grinding requires that the spindle reaches a very high rotation speed and increasingly requires high precision of the workpiece at the same time. The active magnetic bearing (AMB) spindle meets the demands of high-speed and super high-speed grinding with its own advantages. In order to test AMB spindle grinding performance, we designed and modified a high-speed precision CNC grinding system, and tested the AMB spindle installed on the grinding machine. We introduced the controlling of electric spindle, furthermore, the superiority of the application of AMB spindle on the high-speed precision grinding machine was demonstrated by the grinding experiment.

The results showed that the precision grinding meet the requirements of a similar grinder and the AMB spindle can be long-term, stable operated. Test results also showed that the wheel speed higher, the accuracy of the grinded workpiece higher. At the same time, in this grinder for processing can be relatively high accuracy, roughness less than 0.4um, roundness error less than 4um, and the wheel speed higher the workpiece roundness error smaller.

INTRODUCTION

At present, high-speed grinding technology is developing very rapidly because it provides the advantages of high efficiency, small grinding force, and high quality of the workpiece. This technology can also be implemented in the ductility domain of hard and brittle materials. If it can be implemented for high plasticity materials, it also produces good grinding quality.

To achieve high-speed grinding, the grinding wheel requires a high surface speed. For internal grinding, the main method of increasing wheel surface speed is to increase the wheel rotation speed. To achieve this aim, the machine tools need grinding wheel spindle components capable of high-speed operation. At the same time, the spindle also requires sufficient rigidity, rotary high precision, good thermal stability, reliability, low power consumption, long life, and so on[1].

One of the core elements of a high-speed spindle unit is its high-speed precision bearings. The advantages of a high-speed spindle system which is supported by AMB are high-speed, high precision, active control and many other advantages, so for a high-speed grinder, and AMB spindle is the best form of support. AMB as a sophisticated product of the integration of the mechanics, electromagnetics, and computer control has its unique advantages in the design of a high-speed spindle system, so its applications are growing steadily.

A grinding machine often performs the final step in a machining process. Relative to the precision requirements of high-precision machining, a grinding machine with a cutting tool used for grinding wheel has a lot of uncertainties. Because of the rapid development of computer technology, NC technology is also steadily improving and this promotes structural changes in the CNC grinding machine, not only in

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accuracy, efficiency, and reliability, but also in flexibility, ease of operation and ease of maintenance.

GRINDING SYSTEM CONSTITUTION AND DESIGN MEASURES

Because a Computerized Numerical Control machine tool is completely controlled by the numerical control devices and processes automatically without human intervention, the mechanical structure of a CNC machine tool must be better than the traditional machine tool in terms of static stiffness, dynamic stiffness and thermal stability. Improving the geometric precision of CNC machine tools, using a sufficiently rigid feed transmission chain and a transmission gap elimination device, and using a rolling ball screw drive to eliminate low-speed rail shudder, fine local control of feed can be used to guarantee highly repeatable positioning precision. Therefore, in order to enhance machining accuracy of the magnetic suspension electric spindle in the J4K-095 numerical control inner-outer round AMB spindle composite grinder which is designed and developed with Jinan four-CNC Limited Company, we mainly rely on the following design measures.

- The feed machine uses a servo motor to drive rolling ball screws, and coupled with a rolling rails so that the feed precision can reach 0.25 um.
- A tapered roller bearing used in the workpiece spindle brings the accuracy of the rotary motion to 1 μm.
- The wheel shaft uses a high-speed AMB spindle with a rotary accuracy of 0.5 μm.

Machine control is provided by a Siemens 810D CNC system and the feed control uses a double closed-loop system. The inner loop is a speed speed while the outer loop is a position loop. The position feedback detection device is raster ruler, and the resolution is 0.1 μm. This device is installed in the machine moving parts. It measures the actual displacement, and feeds it back for comparison by the NC system which compares the value with the target trajectory and adjust the feed motion until the error margin diminishes to zero. This process can eliminate error caused by the machine table and the mechanical transmission chain: the closed-loop control system has good dynamic characteristics, ensuring the realization of high-precision machining.

The magnetic bearing spindle uses digital control. Compared to digital control, the general analog control is realized by entirely by the hardware and is fast, but it is not flexible in that the control parameters cannot be adjusted once determined. With the rapid development of electronics technology, digital control is now able to meet the high speed demands of magnetic bearings. The dynamic characteristics of digital control are realized by software so that its control strategy can be flexible, easy to implement detection, control integration, and other forms intelligent control. We use a DSP digital control to achieve the control of the multi-variable, non-linear, open-loop unstable magnetic bearing device.

The power amplifier is also an important component of the magnetic bearing spindle system: its function is to transform the control signals into the corresponding current in the coil, to achieve the objective of the rotor suspension stability. We use a three-level switching power amplifier, with swift current response speed (better than 2.5 kHz bandwidth), small current ripple (less than 4 mA) and high efficiency. The Dominate chip uses a field programmable gate array chip (FPGA Field-Programmable Gate Array), and digital signal interface with digital control system, eliminating DA and AD converter circuits, improving data transmission speed and greatly reducing noise in the transmission.

We carefully designed the main structure of AMB spindle, including the carrying capacity (radial and axial), the stator and rotor, sensors acquiring the rotor position signals, to realize the high stiffness and high precision of magnetic bearing spindle required by the practical application[2,4,5].

Solving the thermal problem in high-speed, high efficiency, high-precision working conditions is a key technology of AMB spindles. In addition to the cutting heat of the spindle, the stator and rotor of the motor and the AMB are the main heat sources. The structural characteristics of the spindle require that the stator is installed directly in the shell, which is not good for the cooling of the motor and bearings. Distortion caused by heat will lead to loss of the machine tool's precision, so the spindle needs a cooling system to ensure constant temperature. We designed a water-cooled structure and chose a water chilling system that relies on a pump to circulate cooling water (or cooling oil) with an anti-rust additive to provide sufficient cooling to the stator and rotor of motor and magnetic bearings[3,6].

AMB and motor heating will produce significant thermal expansion in the spindle system. Thermal expansion will cause relative displacement of the grinding head and the workpiece, which can seriously affect the repeatability of spindle positioning. Temperature compensation for thermal expansion in the spindle system is critical for precision grinding. In addition, displacement sensor temperature drift error is also an important factor affecting the spindle position repeatability, so it is necessary to provide correction for this drift. We installed heat sensors at primary locations of heat source in the spindle, so that temperature changes and the distribution of heat within the spindle can be monitored continuously.

In contrast to the traditional spindle, the AMB spindle provides continuous active control of the grinding head position so that the relative position of the grinding head and the workpiece can be adjusted according to temperature data to minimize the impact of temperature rise. We have established a mathematical model of the temperature rise and expansion of the magnetic bearing spindle and also constructed a correction procedure for

position sensor temperature drift.

Following on the basis of the preceding discussion, to provide real-time technical error compensation, the specific process is:

1. acquire the real-time internal temperature signal of the spindle with temperature sensors,
2. scale these signals, A/D convert, deliver to the compensation,
3. compute the compensation value by the prior error mathematical model f (computing the thermal error through temperature),
4. send the compensation value to the spindle control system through the input/output interface,
5. the control system corrects error by adjusting the rotor position

This system has the characteristics of real-time compensation of error and it also has real-time signal acquisition and integrates real-time compensation into the magnetic suspension control system, which is economic and convenient. We also introduced a temperature drift compensation for the rotor displacement eddy sensors, to improve the system of control accuracy.

The AMB spindle that we designed uses intelligent control. The spindle can not only maintain the high precision and high speed, and the stiffness and damping properties can be adjusted automatically during operation, but the control also provide for imbalance compensation. In addition, the spindle provides direct monitoring of the grinding process with the help of AMB: the control output current of each bearing is directly proportional to the magnetic force so that, by measuring the output control, the cutting force in grinding process can be measured up without any additional equipment. And by measuring the tool offset with with the AMB spindle position sensor, it is also possible to determine transients in the cutting force, for example: when the cutting tool just begins to engage the workpiece, cutting tool wear or damage can easily be identified.

With the wheel spindle rotating at high speed, tremendous centrifugal forces can quickly destroy the wheel in high-speed grinding, so it is necessary to adopt a proprietary matrix providing extremely high mechanical and abrasive base of strength for the grinding wheel. For the work reported here, we have used a combination ceramic grinding wheel: CBN, granularity 60, speed limit of 70m/s, and diameter of 25mm.

The grinding fluid was a water-in-oil emulsion, which offers high performance to this application. In high-speed grinding, we use high-pressure liquid (7 Mpa) and a large flow volume so that it is able to penetrate the strong airflow surrounding the high-speed rotating wheel. The grinding fluid was sprayed on the wheel peripheral face vertically through special nozzles: the nozzle has a front deflection plate to shear off the wheel's surface air flow. In the other side, it also has washing nozzles, which can be used to provide strong airflow through the layer of high pressure (3.5 ~ 5.5 Mpa) on the traffic flow to remove plug wheel wear debris from the surface.

TEST AND ANALYSIS

We installed sensors at the main hot spots of AMB spindle and conducted an extended temperature rise experiment. For the temperature sensor installation locations, see Figure 1. At 20,000 rpm spindle speed, see Figure 2 for a comparison of the temperature history with and without the experimental cooling system.

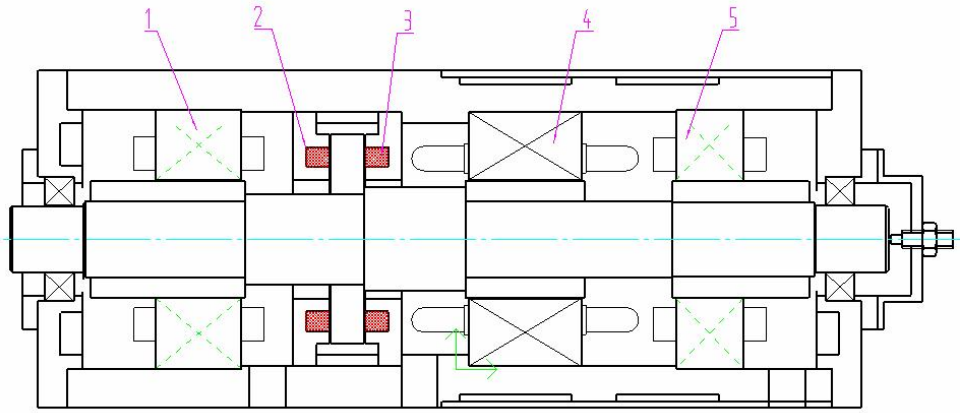

FIGURE 1: Locations of temperature sensors.

As can be seen from Figure 2, without cooling system, the spindle temperature at location five rose continuously for 75 minutes, soon reaching 70 degrees. This behavior will not only affect the rotor suspended position, but also may result in damage to the eddy current sensors. When coupled with the water cooling system, the temperature rise at location five reached a steady state value of 45 degrees in about 90 minutes:

the impact to the whole spindle system of this modest temperature rise is very small.

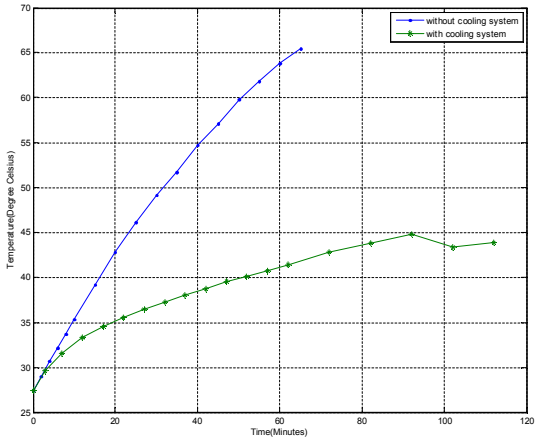

FIGURE 2: Temperature rise comparison with and without the cooling system.

We conducted a grinding spindle dynamic performance test on the grinding machine, through a number of different speeds and feed rates of the different holes in the grinding experiments on the cast iron QT600, 45 steel and steel quenching 45. The results shown below in Tables 1 through 3.

Table 1: QT600 cast iron

Speed (rpm)	Feed rate (μm)	Hole in the accuracy of workpiece (μm)	Parts of the Kongyuan (μm)
18,000	1	0.397	3.841
	2	0.397	3.846
	4	0.398	3.857
25,000	1	0.395	3.781
	2	0.396	3.799
	4	0.396	3.804
30,000	1	0.384	3.764
	2	0.388	3.777
	4	0.389	3.789

Table 2: Material for the 45 steel

Speed (rpm)	Feed rate (μm)	Hole in the accuracy of workpiece (μm)	Parts of the Kongyuan (μm)
18,000	1	0.396	3.845
	2	0.396	3.850
	4	0.397	3.859
25,000	1	0.389	3.783
	2	0.388	3.801
	4	0.391	3.807
30,000	1	0.380	3.768
	2	0.381	3.781
	4	0.381	3.790

Table 3: 45 steel materials for quenching

Speed (rpm)	Feed rate (μm)	Hole in the accuracy of workpiece (μm)	Parts of the Kongyuan (μm)
18,000	1	0.385	3.844
	2	0.386	3.851
	4	0.388	3.857
25,000	1	0.381	3.782
	2	0.382	3.804
	4	0.384	3.809
30,000	1	0.376	3.767
	2	0.376	3.780
	4	0.378	3.792

Figure 3 shows the active magnetic bearing spindle grinder. After grinding, the workpiece roundness

FIGURE 3: active magnetic bearing spindle grinder

quality produced by this grinder exhibits roughness of less than 0.4 um, a circular error of less than 4 um: the higher the speed of workpiece rotation, the smaller the error. The results showed that the precision grinding meets the requirements of a similar grinder, and the

magnetic suspension spindle can provide long-term stable operation. The results also showed that at the same time, using high-speed grinding, the higher the grinding wheel higher the speed, the higher is the precision of grinding of the workpiece.

FIGURE 4: The workpiece finished using the active magnetic bearings spindle grinder

Unfortunately, due to time constraints, only a narrow range of grinding test conditions have been explored: a batter of tests at different grinding feed rates remains for further research.

CONCLUDING REMARKS

In China, throughout the machinery, military, aerospace and other industries, particularly for vehicles such as motorcycles, mass production of factory grinding technology research shows that there are a many parts with a short axis disk form with a hole bored in the end, such as gears. The conical or cylindrical accuracy requirements of these parts are high, introducing the need for grinding. The above-mentioned industries require considerable economies of scale to be profitable in the market: to improve quality and also lower costs are pressing issues that they now face. The grinder is a core element in a class of finishing equipment subject to recent harsh demands: the industry needs a grinder with high reliability, high flexibility, high precision and high efficiency. Up to now, Chinese made products can not fully meet the requirements of the market: therefore since August 5, 1995, Chinese industries of imported a large number of grinders from foreign suppliers. In particular, these are high-performance, high-profile, high-grade, high value-added NC products, but the high prices of such imported products have seriously hampered the development of the national economy.

The CNC grinding machines with AMB spindle which we have studied are entirely independent of foreign intellectual property claims, ending the situation that the high-speed magnetic bearing technology has been a foreign monopoly, thereby transforming and upgrading our traditional industries, and laying the foundation for research and development of high-speed, high-precision, digital, intelligent, high-grade machines. In the future, this equipment can be widely used in military, aerospace, automobile and motorcycle industries: its market potential is enormous.

In addition, the magnetic bearing technology applications offer broader prospects because of their elimination of the lubrication system. This means a reduction in environmental pollution because they do not require environmentally harmful lubricants, so these machines can be widely applied to meet stringent environmental requirements and enable green production as the mainstay. By providing minimal environmental impact, the industrialization prospects for this technology are even brighter and offer many valuable social benefits.

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