Application of High-speed Spindle in Intelligent High-speed Drilling and Tapping Center Machine Tool

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Abstract. The Concept of intelligent manufacturing has brought about the rapid development of intelligent machine tools, and the development of manufacturing industry has been deeply influenced by such functional components as high-speed spindle. High-speed spindle is the important part of machining center. This article expounds the application of high-speed spindle on intelligent high-speed drilling and tapping center from the aspects of main driving mode and structure of high-speed spindle, and verifies the feasibility of application by means of measurement of temperature rise, measurement of vibration and processing effect of parts.

Key words. Intelligent manufacturing High-speed spindle Drilling and tapping center Measurement of temperature rise Measurement of vibration.

1. Introduction
Since the state proposed “Made in China 2025” in 2015, various industries have been studying intelligent manufacturing. Some experts say that “Intelligent Manufacturing (IM)” is a kind of human-computer integrated intelligent system composed of intelligent machines and human experts. It can carry out intelligent activities in the manufacturing process, such as analysis, reasoning, judgment, conception and decision-making. Through the cooperation between human and intelligent machines, it extends and partially replaces the mental work of human experts in the manufacturing process. As a working machine of manufacturing industry, it is a necessary condition for manufacturing industry to apply information technology to numerical control equipment and realize high intelligence. As the main functional part of the CNC machine tool, the high-speed spindle is just like the heart of the machine tool. This article will focus on the application of high-speed spindle with a speed of 24000r/min in intelligent high-speed drilling and tapping center machine tool.

2. Main transmission scheme
There are two main transmission systems in vertical Machining center. One is belt drive, another is direct transmitted by the servo motor and the main spindle. The two methods have their own advantages and disadvantages. Through analysis and comparison of transmission chain, installation, debugging and performance, the method of direct motor_spindle connection is often adopted.

The drive chain of belt drive (see Figure 1) is composed of motor→expansion sleeve→belt wheel→belt →belt wheel and main spindle. The supporting of the motor and the main spindle is the
motor seat and the main spindle box. There are many factors influencing the performance of the whole system of transmission. Its advantage is the elastic connection of belt, it can effectively separate the vibration of the motor and the spindle, and the precision of parts is relatively low. When driving at high speed, the design, manufacture and installation of belt and belt pulley are much higher than those of low-speed transmission. The noise of vibration and wind cutting often occur, and the fault point is difficult to judge. Therefore, the application of belt drive in high-speed drive requires greater efforts from the technical system and manufacturing system, which is more common in low-speed cutting machine tools, especially those whose rotating speed is less than 10000 r/min.

Figure 1. belt drive 1. Motor 2. Motor base 3. Main spindle box 4. Expansion sleeve 5. Main spindle 6. Pulley

Figure 2. direct transmission of motor 1. Column 2. Z axis servo motor (3) colliding of block 4. 5. sword arm 6. Main motor 7. Motor base 8. Elastic coupling 9. Main spindle box 10. main spindle

The transmission chain of the direct connection transmission of the motor (see Figure 2) is composed of the motor→the coupling and the main spindle. The supporting frame is the motor base and the main spindle box. The disadvantage is that the processing and assembly precision of related parts are high, and the problem of thermal deformation and dynamic balance needs to be solved well, otherwise it will easily cause spindle damage. Through analysis and testing, we found that the above disadvantages can be overcome in the installation. Only two aspects affect the operation performance of installation accuracy, the coaxiality of the motor and the inclination of the motor and the spindle, these two precisions are converted into the coaxiality of the inner bore of the motor base to the spindle and the verticality of the motor base end to the spindle when it is installed. These two items can be mounted by scraping or grinding to ensure assembly accuracy. Second, the detachable gearless coupling is selected for the coupling, and a certain amount of thermal deformation space can be reserved during installation, that is, the upper and lower parts of the coupling have gap requirements to prevent interference of the motor shaft and main spindle due to thermal elongation. Finally, on the basis of accurate dynamic balance
and installation of rotating parts, the dynamic balance is calibrated again after assembly to ensure the vibration standard. In addition, when cutting at high speed, the required torque is small, and the transmission mode of direct motor is suitable for the case of small torque and high speed.

Based on the above factors, the high-speed spindle system with direct motor connection is decided on this type of high-speed machining center machine tool.

3. Structure and technical indicators of high-speed spindle
The maximum speed of the spindle is 24000r/min, and the DN value is 1.44x10^6. The low-speed spindle generally adopts metal ball bearings with advanced technology, reliable performance and contemporary international advanced level. However, it is not suitable for the high-speed spindle. In order to meet the need of high-speed rotation of the spindle, ceramic ball bearings are finally selected. Ceramic ball bearings are characterized by good wear resistance, good self-lubrication and small thermal expansion coefficient. Compared with metal ball bearings, they can maintain better operation accuracy and longer working life at higher temperatures. The front and rear bearings of the main spindle are supported back-to-back by two rows of angular contact ball bearings. The bearing is pre-tightened by positioning pre-tightness and the degree of pre-tightness by moderate pre-tightness. This compound mode enables the bearing to withstand both large radial and axial loads at the same time and obtain high spindle dynamic and static stiffness. In addition, compared with the low-speed spindle, the dynamic balance precision grade of each part of the spindle is improved from the original G6.3 to G1, so as to effectively reduce the unbalance measurement of the spindle. Technical indicators of spindle is shown in attached Tab 1.

| Measurement of spindle accuracy |
|-------------------------------|
| Static stiffness (400KG)       |
| Radial runout                 |
| Radial wobble                 |
| Axial wobble                  |
| bore-hole wobble              |
| Nose wobble                   |
| 25mm place                    |
| 300mm place                   |
| 0.001 mm                      |
| 0.002 mm                      |
| 0.001 mm                      |
| 0.002 mm                      |
| 0.003 mm                      |
| 0.001 mm                      |
| 0.002 mm                      |

It is well known that in high-speed processing, cutting fluid is all over the place, and metal chips are generally very small. In order to avoid foreign matter entering the front bearing of the spindle, the front end of the spindle is sealed with the structure of mechanical return lattice and high-pressure gas seal. During the operation of the spindle, high-pressure gas always flows through the bearing chamber, forming an internal high pressure, which effectively prevents the entry of external cutting fluid and other sundries, ensures the normal operation of the bearing at the front end of the spindle and improves the stability of the machine tool.

4. Intelligent numerical control system
The current popular system have Fanuc NC system, Siemens system, and i5 intelligent system has big influence in recent years, it belongs to “Shenyang Machine Tool company ltd.”. This article focuses on the i5 intelligence system, the system has the function of network intelligence, complete with independent intellectual rights, the digital control Ethercat bus, carrying WIS intelligent workshop management system, and the cloud platform can realize collection and analysis of data, using today's popular touch-screen operation mode, can realize the friendly human-computer interaction. The operation panel is shown in Figure 3.
I5 is an effective integration of industrialization, informatization, networking, intelligence and integration (industry, information, Internet, intelligent and integrate). The i5 system is based on advanced motion control technology and network technology, giving birth to internet-based intelligent terminals, realizing intelligent operation, programming, maintenance and management functions.

**Intelligent operation:** It simplifies the operation through technologies such as graphics guidance, automatic mode matching and full touch screen interaction, enabling users to "Go Directly by One Key"; The integrated function of interface customization can customize different interfaces according to user needs and quickly switch in the NC system.

**Intelligentization of programming:** By graphical guidance programming, using the graphical interface can complete the compilation of loop; The system has the function of 3D simulation, and supports the trajectory previewing during machining. Meanwhile, the system can also recommend cutting parameters to users by selecting ways to reduce the process requirements for workers.

**Intelligent maintenance:** Graphical diagnosis and remote diagnosis can help users to quickly find and troubleshoot faults, reduce the skill requirements for maintenance personnel and reduce user downtime. And the system can be easily and quickly updated to keep the machine in sync with the latest technology.

**Intelligent management:** IF intelligent workshop has WIS, it can provide internet-based device query function, and use cloud management method to monitor and analyze the processing status, order completion status and other information of the machine through the browser.

5. Effect verification

5.1. Spindle running test
The test equipment uses the i5M4.1 intelligent high-speed drilling and tapping center machine tool produced by Shenyang Machine Tool. The operation test of the spindle is mainly to test the temperature rise and vibration of the spindle during operation. It is required to measure one by one from low speed to high speed, with a step length of 1,000r/min, and measure once every hour. Request bearing temperature below 15 °C, using infrared thermometer to measure temperature. The amplitude is below 0.002mm and the vibration meter is used to measure the amplitude of the bearing. The temperature variation curve is shown in Figure 4 and the amplitude curve is shown in Figure 5. By Figure 4 to know that the maximum temperature rise to 37.5-24 = 13.5 °C, Through the Figure 5, the maximum amplitude of 0.0018 mm, all meet the design requirements.
5.2. Validation of machining effect

According to the machine tool main processing object, in order to process the surface roughness and tool to determine the actual application effect, high-speed spindle design a specimen, the cutting speed of 18 000 r/min, the surface roughness Ra = 0.6 μm, surface have no obvious marks, prove the high-speed spindle can meet the requirements of high speed machining, the actual effect is shown in Figure 6.
6. Summary
Since “2015 Intelligent Manufacturing” concept, the development of intelligent machine tools is very fast, equipped with robot flexible processing unit in the enterprise application is more and more widely, machine to replace artificial concept by the rising popularity of the enterprise managers can be ordered on the development of intelligent machine met with important development opportunities, with the development of intelligence function of forming a complete set of machine parts also encountered great challenge. Compared with the high-speed vertical machining center machine tools abroad, there are still some deficiencies. For example, the spindle speed is not high, and the high-speed machine tools abroad are usually over 40000r/min. At present, domestic vertical machining center is still in the middle and low level development stage. In the future, the machining center will develop into an intelligent aspect, such as automatically suppressing vibration, automatically adjusting cutting speed and acceleration, automatically adjusting cutting speed and cutting feed quantity. In the next 5 to 10 years, further improving the spindle speed, dynamic performance and feeding speed are still the development focus of the high-speed machining center.

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