Latest Trend of Main Spindle for NC Machine Tool

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This paper overviews today’s technologies and future trends in high-speed spindles for machine tools. High-speed machine tools have been popularized in order to meet the progress of machining technologies led by the technical progress in tools and in workpiece materials. We consider that such progress will continue for a while, and that spindle systems will get faster. The \( \text{dmn} \) value may reach as high as 4 million in the near future.

1. Introduction

The machine tool manufacturers today are excited about good business for the first time in several years and are loaded with an unprecedented amount of orders. The order amount for this year appears to surpass that of the previous year by more than 160%. The orders include not only compound machine tools, 5-axis control machining centers, or other multi-axis control, complex, and high-end machine tools, but also such popular equipment as common 2-axis NC lathes and vertical machining centers. The primary reason for this huge order volume is that the domestic manufacturers have finally rebounded from the recent spell of low market demands and begun their full capital investment drives.

When business is good, manufacturers tend to tone down technology development and place priority on the production of easy-to-manufacture equipment. Nevertheless, the technological innovation in the NC machine tools was staggering up until a year ago. It all began with the pursuit for high-speed main spindles, and then came the high-speed feeding systems. Soon, the high-speed feeding systems caught up with and passed the high-speed main spindles, creating a situation where they are pushing the main spindles to even higher speeds.

In the following sections, we will review the changes that have taken place in the machining technology, which are the true cause for this pursuit of high speeds. We will then look at the today’s status of the high-speed trend in the main spindle and feeding systems.

2. Changes in machining technology

Progress in machining technology is generally triggered by development of new cutting tool material (lately including new coating technologies) and, indirectly, by the changes in the workpiece materials and profiles at the end users. The fabrication method for hardened dies, for example, has suddenly changed to the past 10 years. In the past, the raw material of about HRC25 was machined and hardened by heat treatment. Since the material was too hard to machine, it was finished with electrical discharge machining.

With the advent of (Al, Ti) N-coated ultra hard end mill cutting tools, machining of the hardened materials was made possible. High-speed machining technology that cuts hardened SKD61 die steel of about HRC53 at an amazing 200m/min was developed, which brought a big change in the configuration of the die machining processes and machine tools. Furthermore, there has been a rapid transition in the complex, free-form finishing process from the use of electrical discharge machining to small bore ball end mill cutting tools. This change accelerated a shift towards high-speed main spindles in the machining centers for die fabrication.

In the parts fabrication works, a major change took place in the workpiece material for energy conservation from steel to aluminum, which could be machined at high speeds. These two developments brought significantly fast main spindles and high-speed, high-acceleration feeding system to medium and small size machining centers.
These changes may be described as changes "from low-speed, heavy cutting to high-speed, light cutting." Fig. 1 shows the historical transition in the machining speeds of various materials, which depicts the compound effects of the above developments.

Fig. 1 Improvement of cutting speed

(a) Carbon steel

(b) Aluminum alloy
3. Evolution of main spindle speed

The $d_{mn}$ values are often used as an index to indicate high-speed performance of the main spindle. $d_{mn}$ represents the ball pitch circle diameter of the bearing rollers in millimeters, and $n$ is a product of a realizable maximum revolution of the main spindle represented by /min. The limit of the $d_{mn}$ value naturally varies with the methods of lubrication and the types of bearings.

Fig. 2 shows the history of the bearing speeds for NTN's main spindle bearings in the past 20 years. Around 1990, the maximum $d_{mn}$ value of the air-oil lubricated bearings was about 2 million. Today, with advancement in optimization of the bearings internal specifications, the $d_{mn}$ value has reached 3 million. Since, as mentioned above, heavy cutting has declined, demands for rolling bearings of high rigidity, which can be used at low-speeds only, have not increased much. Instead, more and more ball bearings, especially those using Si3N4 ceramic balls of smaller specific gravity, are used very frequently. In the past, the ceramic balls were considered more expensive and less accurate as compared to the steel balls. Now, with increased production, the quality of the ceramic balls has stabilized and the price has come down. As a result, more bearings with the ceramic balls are being used. It is not an overstatement when they say that almost all the rolling bearings rated for 1.5 million in the $d_{mn}$ value use the ceramic balls.

Another recent trend is the customer’s preference for environmentally friendly lubrication methods. The environmentally friendly lubrication methods are often low-cost lubrication methods, too. For this reason, this trend appears to proliferate faster. NTN re-evaluated grease lubrication in preference to the relatively popular air-oil lubrication method and successfully made the grease-lubricated sealed angular contact ball bearings available for service at up to 1.4 million in the $d_{mn}$ value. This speed is often sufficient for use in steel parts fabrication, and bearings of this type are increasing their applications.

Leading the race for faster bearing speed, the air-oil lubrication method has been improved by NTN for low noise and less consumption of air and oil. Eco-conscious type bearings are contributing to reduction in environmental burdens.

Fig. 2 Improvement of NTN bearing speed for main spindle
4. Faster feeding speed

As mentioned above, it is desirable for the main spindles and the feeding systems to advance hand-in-hand in the race for faster speeds in view of fabrication technology. However, they do not always progress in synchronization subject to the status of the technological development. Recently, more significant advancement is visible in high-speed, high-acceleration feeding systems. This progress was led by the introduction of linear motors into machine tools, and then followed by the use of high-lead ball screws. Fig. 3 shows the status of development. There are machining centers in the market that utilize the parallel mechanisms without the use of guides.

Thanks to these technologies, the maximum feeding speed of 60m/min and the maximum acceleration of 1G in the machining centers no longer draw special attention. (Nevertheless, in many actual applications, this performance is sufficient.) The maximum speed of over 100m/min and acceleration reaching 2G have already been achieved on actual equipment. Considering that 24m/min and 0.1G were the standards some 10 years ago, there has been great progress. On the other hand, the speed of the corresponding main spindle for BT40 is 40,000/min, though is still in the testing stage and has not proven to be service worthy.

5. Conclusion

As mentioned above, it is desirable for the main spindles and the feeding systems to advance hand-in-hand in the race for faster speeds. Lately, achievement in making faster main spindles is somewhat behind that of the feeding systems. I hope that NTN will develop a high-speed technology for main spindles to break this cycle, and become the leader of the world's machine tool industry.