

The Next Spindle Generation for Ultra-High Precision Cutting

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Abstract

The miniaturization of parts in various industries continuously increases. Manufacturing methods and processes have to improve permanently to fulfill the requirements by the miniaturization of cutting tools and by the increasing of machine precision. This paper presents features in spindle design needed to increase precision, speed ability and reliability, describes steps needed to be taken in the fields of motor , bearing and cooling technology in order to successfully cover all needs.

1 Motor technology

In the past two years, synchronous motors gained more importance for spindles used for ultra-high precision cutting [1]. If a synchronous motor should be generally preferred for ultra-high precision applications, this question can only be answered when the requirements of the specific application have been analyzed accurately.

Asynchronous motors are considered being very robust. The same is true for synchronous motors. However, improper parameterization of the converter system driving the spindle can cause a fatal error. The consideration of the total mechatronical system (spindle including motor plus converter) is crucial for achieving ultra-high precision cutting requirements.

While asynchronous motors feature a high temperature resistance, at operating temperatures over 120°C/150°C the permanent magnets of a synchronous motor demagnetize and its rotor bandage is critically stressed.

The major advantage of a synchronous motor is its higher power density that is achieved even while having a greater centre bore and resulting in a greater static stiffness and a better dynamical spindle behavior. Generally, disadvantages of the synchronous motor are its smaller constant power range and the mandatory encoder

system. In ultra-high precision applications the smaller range of constant power is of minor importance since a linear power characteristic is common.

Due to lower operating rotor temperatures, which result in smaller thermal axial growth of the spindle shaft, spindles with synchronous motors achieve better TCP repeatability.

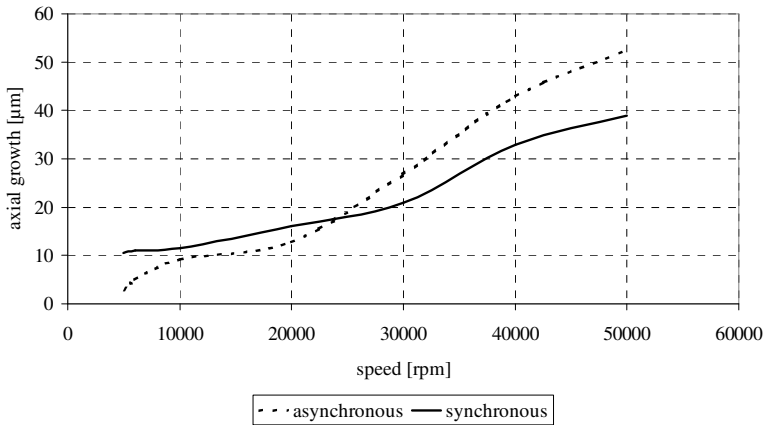


Figure 1: Axial growth of spindles with asynchronous and synchronous motors

Thermal expansion and the effects of centrifugal forces on the rolling elements of the ball bearings causes axial growth of a spindle. While the mechanical influence on axial growth remains constant for each speed chosen, the smaller rotor temperatures of synchronous motors have a beneficial influence on the axial growth. For a HSK-E25 spindle (grease lubricated) with a 100 mm OD and a maximum speed of 50,000 rpm, tests with a asynchronous and a synchronous motor have been performed to evaluate the influences of both technologies on spindle growth (figure 1). Using a synchronous motor, the rotor temperature of the spindle is approximately decreased by 20K. This decrease results in an axial growth reduction by 14 µm or 26%. Considering only the thermal expansion (subtracting the mechanical growth from the

total axial growth), the synchronous motor spindle growth amounts to only half of the asynchronous motor spindle growth.

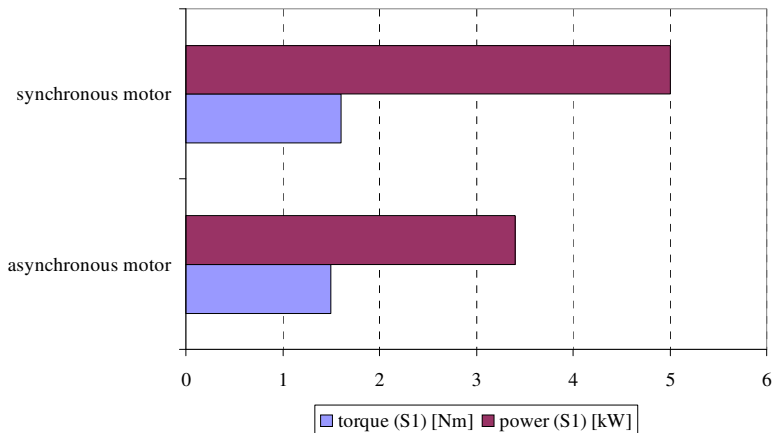


Figure 2: Comparison of torque and power (Fischer AG, test center measurements).

Additionally, the synchronous motor provides a higher power as displayed in figure 2.

2 Cooling systems

Addressing the requirements of accuracy, reliability, and durability, Fischer developed a shaft cooling system for motor spindles. The complete shaft assembly including rotor and bearing inner rings is liquid cooled through a series of channels. This became possible by developing a special three-channel rotary joint that allows supplying the channels with water or while keeping the additional option of a regular rotary joint, i.e. sending coolant through the centre of the shaft to the tool tip.

When major heat sources like the rotor and the bearings are cooled directly, tests showed that up to 1kW of electrical power losses can be removed from the shaft of the spindle.

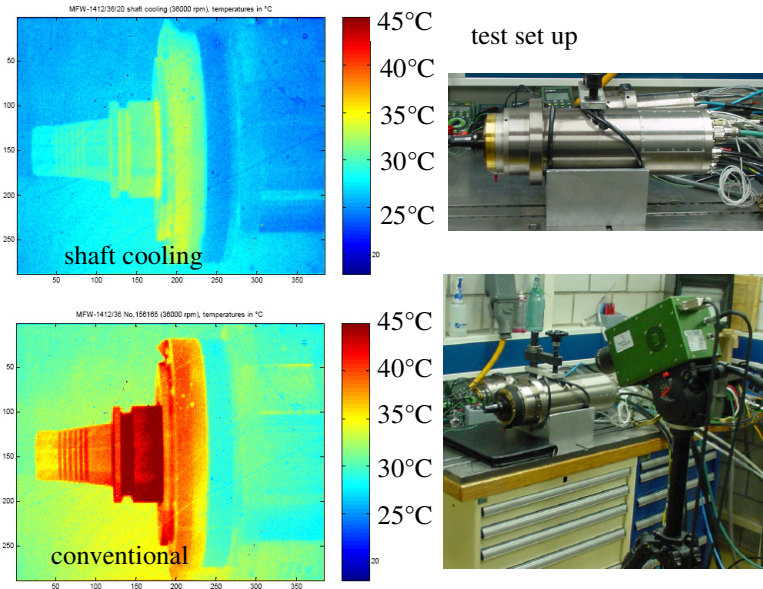


Figure 3: Influence the shaft cooling on the spindle temperature distribution.

(All tests have been performed with a Fischer MFW-1412/36, HSK-E50, $n_{\max}=36'000$ rpm, $P_N = 15$ kW, no loads applied.) Consequently, the warm-up time of the test spindle was reduced by 80% and less heat would migrate into the machine. The temperature distribution of the spindle has been changed as displayed in figure 3. Compared to a conventional cooling system, at the tool interface a temperature reduction of 25°C was achieved. We can literally claim: The Fischer spindle does not transfer heat losses to the tool. First tests show a very positive impact on bearing life. However, statistically proven data will be obtained in one or two years through various production trials. A positive influence on bearing life can be assumed because an elasto-hydrodynamic lubrication film that is needed to separate bearing's contact partners can be built up earlier, at lower speed. Consequently, the number of wear conditions during operation are reduced which prolongs bearing life.

3 Bearing technology

The bearings used influence the surface quality of the parts manufactured and play a significant role for the reliability of the spindle and its speed range. 90% of all

spindles used in ultra-high precision cutting use angular contact ball bearings. Although, with the requirement to increase precision, magnetic and aerostatic bearing systems find a wider consideration. This is mainly due to the higher spindle precision that can be achieved. A comparison of bearing systems is made in table 1.

Table 1: Comparison of bearing systems

	Rolling bearings	Aerostatic bearings	Magnetic bearings
Speedability	•••	••••	••••
Life time	••	••••	••••
Runout	••	••••	••••
Damping	-	••	••
Stiffness	•••	•	•••
Lubrication	••	••	-
Friction	••	••••	••••
Price	••••	••	-
- not good; • acceptable; •• medium; ••• good; •••• very good			

The capabilities of spindles using aerostatic and magnetic bearings are achieved by reducing the non synchronous radial error motion

(NRRO) of the system and by reducing overall spindle vibration. Since both systems are non-contacting (neglecting air between the rotating and stationary parts), the NRRO is almost perfect.

Due to higher damping, aerostatic bearings' vibration pattern show smaller amplitudes. Magnetic bearings can actively control and also damp vibrations and influence the vibration pattern of the spindle. Tests showed that surface qualities of < 0.1 µm have been achieved using those systems which fulfill latest requirements on spindles for ultra-high precision cutting.

4 Conclusion

In order to cope with the future requirements in ultra-high precision cutting, new motor concepts like synchronous motors, advanced cooling systems like the shaft cooling and different bearing technologies like aerostatic and magnetic bearings gain importance.

5 References

[1] Walter, R.; Beck, J.: Mikrozerspanung mit innovativen Spindelsystemen, Mikroproduktion 03/2007, Hanser-Verlag.