DESIGN OF MOTORIZED PRECISION SPINDLE FOR CNC MACHINE APPLICATION

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The Mechanical tool spindle is the core of machine tool. The major performance features of the high speed motorized spindle for CNC machine includes speed and power that gives accuracy of the machining component. A precision spindle used in a machine tool must be designed to provide the required performance features. The static and dynamic stiffness of spindle is influenced by spindle shaft, bearing size, bearing preload, design by considering the bearing parameter. However spindle shaft shape and size is usually chosen constrained to the design consideration and dimensional restriction. The motorized spindle shaft contains rotating elements such as motor-stator rotor, bearing inner race, spacers, locknut and disc. Finally the spindle shaft dynamics will be optimized by varying the mass balancing and which will support for better high speed performance.

***Keywords*:** precision spindle, spindle shaft, tool clamping, integral motor spindle

• Introduction

The machine tool spindle provides the relative motion between the cutting tool and the work piece which is necessary to perform a material removal operation. In drilling, it is the physical link between the machine tool structure and the work piece, while in processes like milling, turning or grinding, it links the structure and the cutting tool. Therefore, the characteristics of the spindle, such as power, speed, stiffness, bearings, drive methods or thermal properties, amongst others, have a huge impact on machine tool performance and the quality of the end product. Machining requirements differ greatly from one sector to another in terms of materials, cutting tools, processes and parameters.

Spindle is the heart of the machine and basic spindle design is based on the machine capability and material is to be removed for the basic machining operations in CNC machine. A belt and pulley driven spindles are basically used in CNC Machines. Due to low speed, medium torque and high power transmission loss in the belt and pulley driven spindles lead to design of integral motor spindle.

1.2 Integral Motor Spindle

The integral motor-spindle shown Fig.1, consist the asynchronous motor element like stator and rotor which are assembled to spindle shaft and rotor is a rotating part in spindle rotates by external electric power. The spindle consists spindle shaft, bearing, bearing housing, disc spring, spindle motor, clamping and de-clamping system, proximity switch etc.,

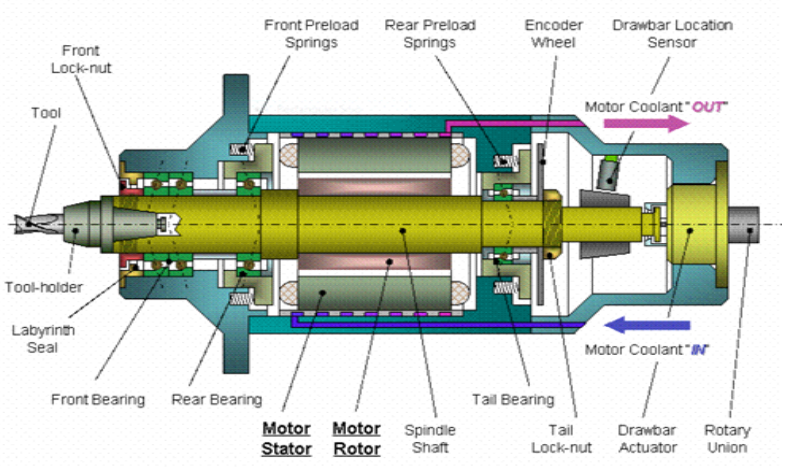


Fig.1.Schematic diagram of Integral Motor Spindle

2. Design Considerations

2.1 Power, Speed & Torque

Power, speed and torque are the important factors for the spindle design. The machining process is dependent on the three variables cutting speed (m/mim), feed(mm/rev), depth of cut (mm). The variables can be changed depending on the work piece material, tool material, condition & power of the machine. The three variables are interdependent and can be optimized to remove maximum material and extend the tool life. The preliminary design can be made by choosing the appropriate motor and bearings based on the speed, power and size limitations. In most cases spindle motor defines the maximum power and torque specifications of the spindle, unless there is a transmission system (belt, gear drive, etc.) without 1:1 ratio. Hence the calculations of the cutting forces and required motor power for the spindle will help to select the integral motor with correct specifications.

Before designing the spindle assembly further, preliminary mechanical design should be checked and verified through static and dynamic analyses. An analytical model will be created to understand the spindle static behavior under cutting forces. The analytical model results will be compared with FEM results to validate the models and the method. The spindle will be optimized in bearing span distances within the size limits through the model. The dynamic stiffness of the spindle is important to prevent vibration and any related problems which will eventually affect the spindle life and machining process quality. Therefore, the dynamic behavior of the spindle will be analyzed with FEM through its Eigen frequencies and harmonic response

Detail design and finalization

Spindle design can be finalized by the verification of the preliminary design and optimization of the bearing positions. There are more factors to consider for the further steps of spindle design such as design of other components in the arrangement, appropriate fits and mounting methods, design for manufacturing, sealing of the system, measurement system adaptation, mounting and dismounting methods, coolant circulation system design, type of lubrication etc.

2.2 CAD Model of Spindle Shaft and Spindle Housing

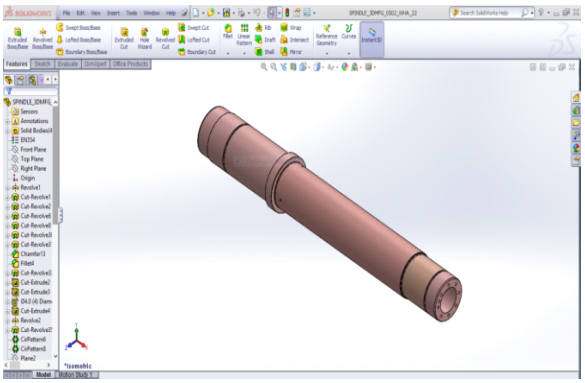


Fig.4 CAD Model of Spindle shaft

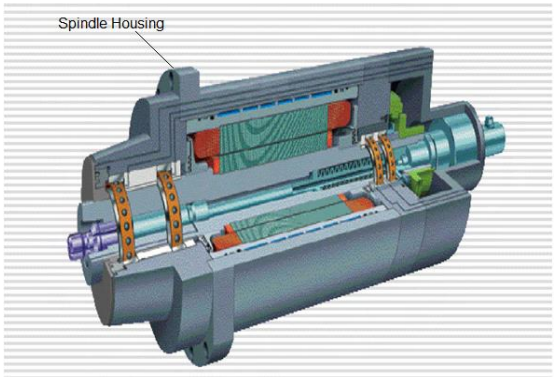


Fig 5. Spindle Housing

The Fig.4 shows the CAD model of spindle shaft and has the following characteristics

- Shaft material EN354 and EN 353
- Case harden to 55 – 58 HRC
- Case depth to 0.6 – 0.8 mm
- High speed, high strength for running speed.

The spindle housing shown in fig.5 provides the holding of spindle shaft bearing and motors in the hosing for location of spindle shaft and bearing.

- Material of spindle housing C45
- Toughen to 20 to 25 HRC
- High straight
- Medium carbon steels : 0.35% to 0.6%
- Resistance to withstand against load

2.3 Selection of Bearings for spindle application

Bearing is the one of the important component in the design of spindle it will be gives static motion to rotary motion with high rotational speed high stiffness with axial and radial loading of the rotation of the shaft it will desires. Their specifications define the speed, load carrying capacity and life span of the spindle. Also, analyze the static and dynamic performance of the spindle. The most common and simplest methodology of bearing lubrication is the grease lubrication.

Angular contact bearings are the one of the major and important part of the design that high speed spindle design need to design features such as high stiffness, high speed and high load carrying capacity. Angular contact bearing provides the maximum speed and taking the radial load and in some applications of axial load. Different arrangement of bearings is used to the different speed and load.

Bearing Contact Angle

Angular contact shown in fig.6 is the one of the important arrangement in the angle between ball-to-race contact lines that will be gives to the load carrying capacity to overall design of the spindle.

- The Contact Angle determines the magnitude relation of axial to radial loading capable
- Different Contact angle 15^0, 18^0, and 25^0
- The Contact angle 15^0 is used for high speed
- The Contact angle 18^0 is used for medium speed
- The Contact angle 25^0 is used for adjustable speed

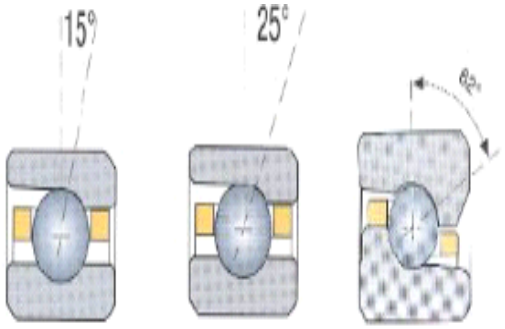


Fig. 6 Different contact angles

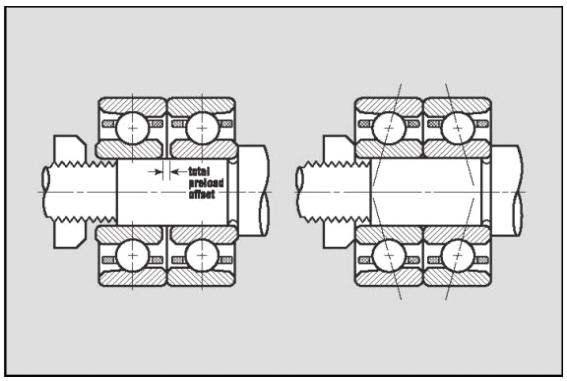


Fig. 7 Back-to-back bearing arrangement

Bearing Preload and Mounting Configurations

Bearing preload will be required for space between the bearing mounting race and bearing mounting place. There are different types bearing preload such as light preload, medium preload and high preload. The pre loading depends on cutting load and rpm

The most usually arrangement used back to back "O" or "DB" mounting within the configuration. The inner races are completely locked in the spacer or shaft face. The outer race locked in outer space or spindle housing. Spindle assembly is preloaded typically with solid-preload arrangement (between front and rear bearing).

Calculation of Bearing Life

Calculation of bearing life is the major and important design of any spindle design, below are the points that influence of bearing life calculation.

- Most Speed
- Bearing force, Axial and Radial
- Vibration levels
- Average Bearing Temperature
- Quality and amount of Lubrication

2.4 Tool Clamping and De-Clamping Unit

The clamping unit used is the HSK clamping unit and has face to face contact to the spindle face. It gives a high tool load carrying capacity. The de-clamping is done hydraulic cylinder arrangement with help of disc spring mounted on the draw bar shaft with spacers in between the spring stack.

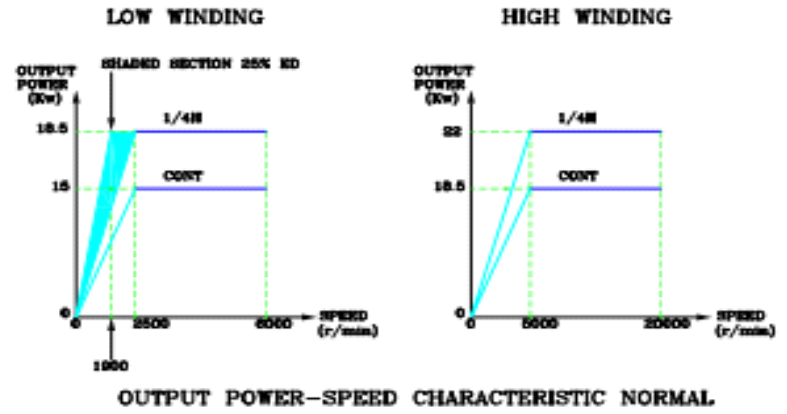
3. Result

Spindle specification

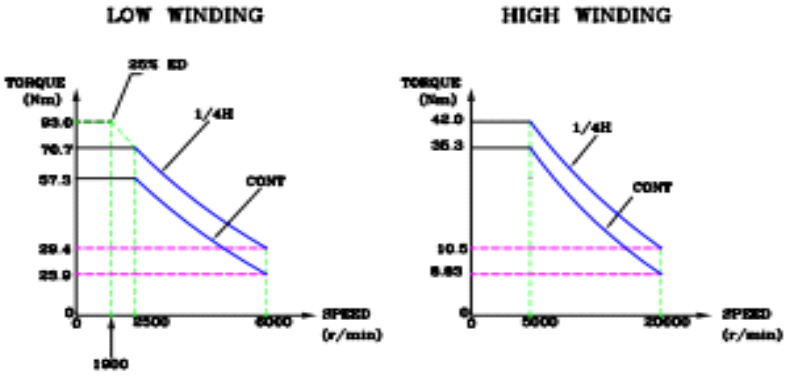
- Spindle type ; HSK 63A
- Tool Clamping force from disc spring = 400 KGF
- Force multiplication factor from the clamping set = 3
- Clamping force of the tool = 400*3 = 1200 kgf
- Tool de-clamping force =900 kgf
- Spindle maximum speed = 20000 rpm At 18.5 KW
- 18.5 KW (S1-Count) (5000 – 20000 rpm)
- 22 KW (S2-Count) (5000 RPM)

Table :1 Data sheet

Data Sheet		
Sl. No.	Description	Recommendation
1	Radial runout spindle	0 TO 0.003mm
2	Tightening torque of the bearing	
	2.1) Front bearing - 7014 A5 TR 2TB M P3	10*10 = 100 Nm
	2.1) Front bearing - 7012 A5 TR DB M P4	2*10=20 Nm
3	Grease quantity	
	3.1 Front bearing	8 cc/brg
	3.1 Rear bearing	5 cc/brg
4	Type of grease	Kluberisoflex Super LDS 18 or Kluberisoflex NBU 15
5	Face run out on spindle Face after assembly	0.0002 mm
6	Radial run out on spindle bore	0.0002 mm
7	Radial run out on mandrel at distance of 300 mm from spindle face	0.01 mm
8	Maximum spindle speed -Max	20000RPM
9	Continues power	18.5KW at 20000 rpm
10	Peak power	22KW at 5000 rpm
11	Temperature rise of spindle bearing w.r.t. ambient temperature	15+degree at Ambient temperature



OUTPUT POWER–SPEED CHARACTERISTIC NORMAL



TORQUE–SPEED CHARACTERISTIC NORMAL

4. Conclusion

With integral motor Spindle, there will be a consistent or efficient output of power, torque and speed compared to other type of spindle like belt drive and in-line spindle. It is subject to loss in transmission, vibration, repeat-ability, and accuracy, integral motor spindles are predominantly preferred for high speed application.

5. Scope for Future Work

A high speed spindle can develop by the different specifications like power, speed, torque, tooling system, accuracy and life from the design requirements by using motor spindle with different configuration of spindle and different speed. Improve the performance of the spindle with self balancing with the help of different disc and balancing system with good accuracy.

6. References

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