

## THERMAL AND DYNAMIC ANALYSIS OF HIGH SPEED MOTORIZED SPINDLE USING FEA

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### ABSTRACT

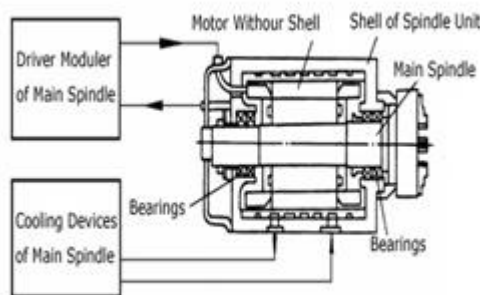
Motorized spindle is one of the core parts of high-speed machine tool, to a great extent, its thermal characteristics determine the thermal stress and thermal deformations, and therefore the research on thermal characteristics is of great significance to increase the accuracy of high-speed machine tool. The motorized spindle is modeled and its thermal characteristics analysis by finite element method is done using ANSYS software, in the foundation of analyzing its configuration and heat transfer. The variation regularity of its temperature-rise and temperature field is also summarized. Thereby it provides a powerful theoretical basis for reducing temperature-rise, calculating thermal deformations and improving working conditions. The Development of high-speed spindle technology is strategically critical to the implementation of high speed machining. However, the built-in motor introduces additional mass to the spindle shaft, besides, since it's very high working speed, some high-speed rotational effects, including centrifugal forces and gyroscopic moments on the spindle shaft can't be neglected in the analysis as is done in conventional spindle, thus complicating its mechanical-dynamic behaviors. Thus an review is given in this paper

**Keyword:** Element method, Thermal deformation, Mechanical-Dynamic

### INTRODUCTION

In today's prosperous industrial development, with the multifarious design of products and reduction of production cycle, high speed machining technology has been widely adopted by manufacturers. With the development of the science and technology, the high frequency spindles has been taken place of the normal mechanical spindles more and more, and also be used of the numerical control machine with great effects.

High speed, precision, ultra-precise machining technology is an important trend of advanced manufacturing engineering, and high speed machining is a promising advanced manufacturing technology for increasing productivity and reducing production costs dramatically. High speed machine tool is the precondition for realizing high speed machining. The high speed motorized spindle is the technical precondition and foundation, and the improvement of its speed and rigidity is very hot to research, thus high speed motorized spindle technology is of great significance to the research and development of high - speed machine tool. Compared with conventional spindle motorized spindle is equipped with a built-in motor, so that power transmission devices such as gears and belts are eliminated and "zero transmission" is realized.



**Fig.1.High Speed spindle**

**Functions of high speed spindles:** Numerous industries use high-speed spindles to Deliver high speed, Maximize application performance, Deliver high power, Better accuracy

**Design factors to consider are as follows:**

**Requirement of high speed spindle:** High Stiffness, High Speed, Radial Loading, Axial Loading

**Best Bearing Type:** High Contact Angle, Low Contact Angle, Small Angular Contact

**Structure of the hsm spindle:** The spindle parts are supported by two sets of angular contact ceramic ball bearing in front and one set of angular contact ceramic ball bearing in rear which is installed back to back. The motor is set between front second set and rear bearings. As one whole body, the stator and coolant jacket are installed to the shell of spindle. Front and rear bearing housings are placed over the bearing systems. The coolant jacket is placed over the stator-rotor system and outer body is placed over the coolant jacket. The main spindle, front and back

bearing systems, stator-rotor system coolant jacket and the outer body are only considered in the high speed motorized spindle in both thermal and vibration analysis.

**Dynamics analysis:** The dynamics of a structure are physically decomposed by frequency and position. Modal analysis is based upon the fact that the vibration response of a linear time-invariant dynamic system can be expressed as the linear combination of a set of simple harmonic motions called the natural modes of vibration. The mode shape may be real or complex. Each corresponds to a natural frequency. The degree of participation of each natural mode in the overall vibration is determined both by properties of the excitation source and by the mode shapes of the system. The FEM model of motorized spindle is set up to research on its dynamic characteristics in theory with an eye to high-speed rotational effects, including centrifugal forces and gyroscopic moments on the motorized spindle shaft. The motorized spindle's natural frequencies and corresponding vibration shapes are got through the nodal analysis, and the effect of the axial preload on the natural frequency.

**Problem definition:** The motorized spindles are equipped with built-in motors for better power transmission and balance to achieve high-speed operation. The heat generated due to power loss in the motor and friction in the bearings is significant during high speed machining, and it makes bearing's temperature-rise high. Thus the thermal deformation of the spindle owe to the heat decreases the accuracy of high-speed machine tool greatly. The dynamic characteristics are affected by thermal load, preload. Finite element analysis is important to characteristics the thermal and dynamic characteristics of the high speed motorized spindle.

**Thermal analysis:** To conduct thermal analysis for finding temperature distribution in high speed Motorized spindle using ANSYS. To conduct thermal-structural analysis for finding axial and radial deflection due to thermal load. Thermal analysis is conducted for both grease and oil to select the appropriate bearing lubricant which gives low heat generation. Elements Plane55 and plane182 are used for thermal and thermal-structural analysis. Bearing and motor heat generation and convection loads are calculated separately for both the grease and oil lubrication. High speed motorized spindle has to be created as 2D axis symmetric model and meshed by triangular element. Transient analysis has to be done for heat generation and convection loads using plane55 to get temperature at each node for different time. Thermal structural analysis has to be done for temperature loads to get axial and thermal deflection. The thermally induced preload is estimated from temperature, axial and radial deflection which is taken from thermal analysis. Bearing lubricant has to be selected based on the results of these two analyses.

**Vibration analysis:** To perform a modal analysis for finding natural frequencies and corresponding mode shapes of the high speed motorized spindle using ANSYS. To analyze the effect of the axial preload, centrifugal and gyroscopic effects on the natural frequency using ANSYS. The radial stiffness of the bearing and spindle shearing stiffness are given as major inputs for dynamic behaviors of the spindle bearing system. Coriolis and the gyroscopic effects of the spindle are available in the element BEAM 188. COMBI214 is simulating the bearing as radial compression spring. The influence of these effects on natural frequencies is analyzed. The effect of thermally induced preload on natural frequencies also is analyzed.

**Plane55 assumptions and restrictions:** The element must not have a negative or a zero area. The element must lie in an X-Y plane as shown in Figure "PLANE55 Geometry" and the Y-axis must be the axis of symmetry for ax symmetric analyses. An ax symmetric structure should be modeled in the +X quadrants. A triangular element may be formed by defining duplicate K and L node numbers as described in Triangle, Prism and Tetrahedral Elements

#### THERMAL ANALYSIS-FEA MODEL

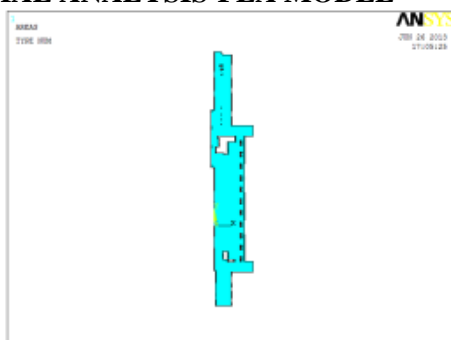


Fig.2.Finite Element Model

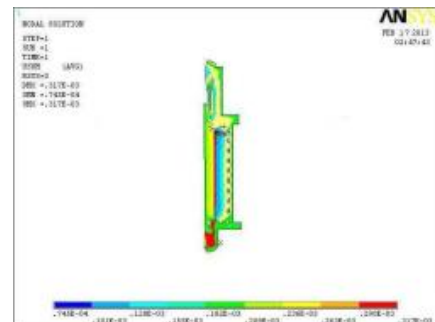


Fig.3.Radial thermal deflection

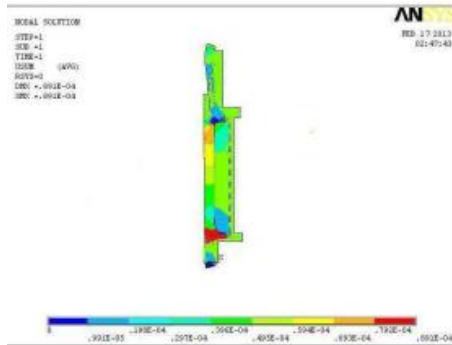


Fig.4.Axial thermal deflection

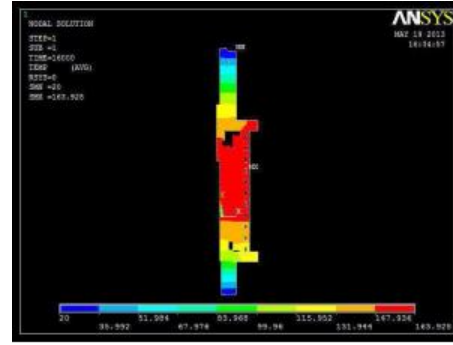


Fig.5.Thermal analysis for 16000 RPM

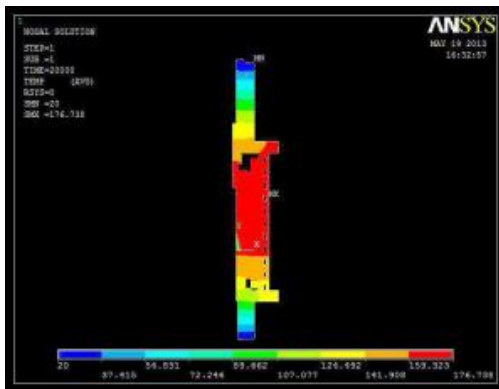


Fig.6.Thermal analysis for 20000 RPM

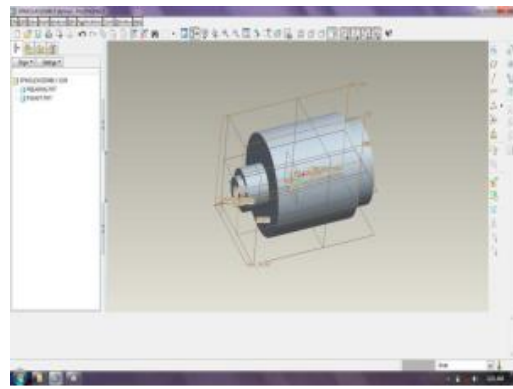


Fig.7.High speed motorized spindle assembly model

#### DYNAMIC ANALYSIS

**Beam 188:** Nodes I,J Degrees of freedom, Three translations, Three rotation, It includes bending and shearing effects, It allows gyroscopic effects, includes in mode extraction damped and QR, damped methods.

**Vibration shapes and characteristics of natural frequencies:**

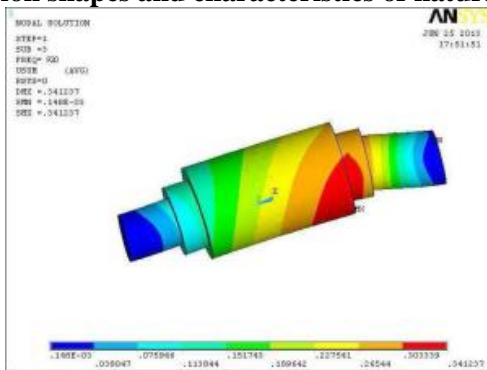


Fig.8.First-order vibration shape

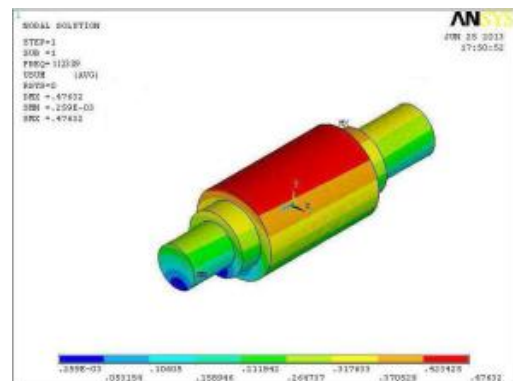


Fig.9.Second-order vibration shape

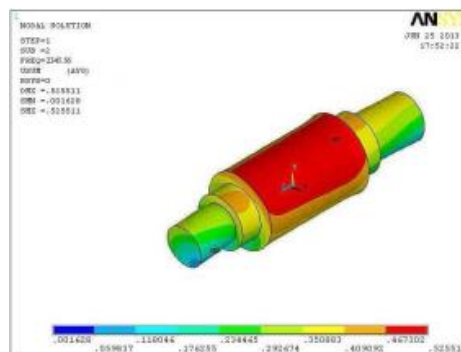


Fig.10.Third-order vibration shape

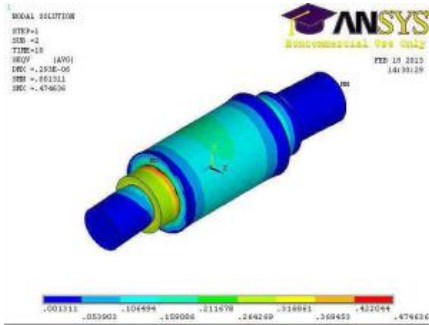


Fig.11.Displace of the motorized spindle first set

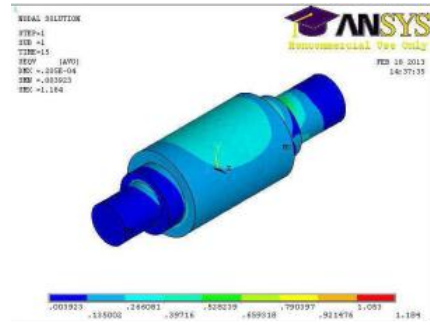


Fig.12.Displace of the motorized spindle second set

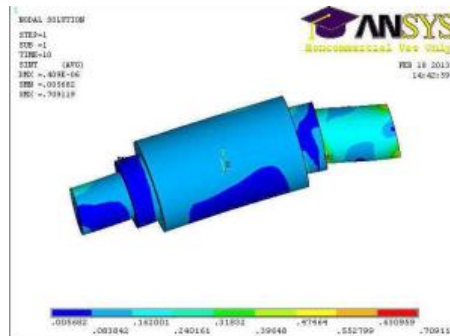


Fig.13.Displace of the motorized spindle third set

## CONCLUSION

The Thermal and Dynamic analysis of the high speed motorized spindle has been performed the effects of the initial preload, thermally induced preload, centrifugal force and gyroscopic moments on the natural frequencies are analyzed. The natural frequencies are extracted by considering stiffness and mass of the body will not be sufficient to find critical speed for high speed spindle. Because the stiffness of the rotating body will be varying depends on the speed .so the speed effects like centrifugal and gyroscopic effects of the spindle bearing system have been considered.

The centrifugal and the gyroscopic effects are damping the natural frequencies significantly. The gyroscopic effects are damping the natural frequencies little than the centrifugal effects and this effects can be minimized by keeping same shaft cross-section and placing motor in the middle position to have mass balance .

## REFERENCES

- Y. Lu Y.X. Yao and R.H. Hong (2008) "Finite Element Analysis of Thermal Characteristics of High-speed Motorized Spindle" Applied Mechanics and Materials
- Y. Lu Y.X. Yao and W.Z. Xie (2008) "Finite Element Analysis of Dynamic Characteristics of High-speed Motorized Spindle" Applied Mechanics and Materials
- Jenq-Shyong Chen Wei-Yao Hsu (2003) "Characterizations and models for the thermal growth of a motorized high speed spindle" International Journal of Machine Tools & Manufacture 43 1163–1170
- Chi-Wei Lin a, Jay F. Tua, Joe Kamman (2003) "An integrated thermo-mechanicaldynamic model to characterize motorized machine tool spindles during very high speed rotation "International Journal of Machine Tools & Manufacture 43 1035–1050
- Bernd Bossmanns, Jay F. Tu (1999) "A thermal model for high speed motorized spindles" International Journal of Machine Tools & Manufacture 39 1345–1366
- Deping Liu, Hang Zhang, Zheng Tao and YufengSu(2011)"Finite Element Analysis of High-Speed Motorized Spindle Based on ANSYS" School of Mechanical Engineering, Zhengzhou University, Zhengzhou 450001, China, Vols. 10-12 pp 258-262, Vols. 10-12 pp 900-904