STATIC AND DYNAMIC ANALYSIS OF HIGH SPEED MOTORIZED SPINDLE

P. ANJANI DEVI [1], G. LAXMAIAH [2], V. JAIPAL REDDY [3]

[1,3] *Assistant Professor Chaitanya Bharathi Institute of Technology*
[2] *Professor Chaitanya Bharathi Institute of Technology*

Abstract - *In any machining center the spindle forms a vital component as it holds and rotates the cutting tool. As such, the modelling and analysis of this part of the machining center is crucial for successful design and subsequently manufacturing them. The dimensional accuracy and surface finish of the work piece in machining operation are of particular interest and the way the machine tool spindle influences these parameters is of great concern to the user. In the present work, the static and dynamic behavior of horizontal CNC machining center spindle is studied. The spindle is modelled in ANSYS and is analyzed for static and dynamic loading. The deflection curves and mode shapes are obtained at different cutting forces for EN24 and H13 materials.*

Key Words: M***achining center*****, dynamic behavior**

1.INTRODUCTION

The state of art computer numerical control (CNC) machine tool needs higher speed, higher precision, and good efficiency, the high-speed motorized spindle has become the most important part of metal cutting machine tool. High speed motorized spindle influences the overall technical performance of the machine tools, [1,2]. Hence it is important to analyze the dynamic characteristics of spindle. Bearings carry a great significance as quality, accuracy of machine depends on them. The operating history of spindle - Operating speed, Type of lubrication, Estimating the workloads, Torque, Spindle material must know parameters. Spindles are mostly hollow and contains the draw bar which decreases its weight. To maintain the accuracy under the influence of cutting forces and the moving weight of the machine tool elements, the spindle structure should possess high static and dynamic stiffness, this is to ensure it withstands various forces acting on it [3]. Al-Shareef et al. [4] suggested a quasi-static method of analyzing machine tool spindles. They worked by taking the amplitude of the dynamic forces and applies them to a static model of the spindle-bearing system.

Wang and Chang [5] analyzed a spindle-bearing system with a finite-element model and compared with the result of their experiment which had Radial and tilting springs and dashpots in angular contact spindle ball bearings. Their analysis showed a significant effect on higher-order vibration modes. Zhao Haitao et.al.[6] suggested a method for computing the coefficient of convection heat transfer of the spindle surface by referencing the theory on computing the coefficient of convection heat transfer of a flat plate when air flows along it. Yuzhong Cao and Altintas [7] integrated the model of the spindle bearing and machine tool system, which consists of a rotating shaft, tool holder, angular contact ball bearings, housing, and the machine tool mounting. Chi-Wei Lin. et al. [8] proposed a model with experimental validation and sensitivity analysis for studying various thermo-mechanical-dynamic spindle behaviors at high speeds. Spindle is usually made of case-hardened Ni-Cr steel and their configurations depend on how it holds the cutting tools, the fit of drive element and type of its bearings. They are made hollow to contain draw bar and decrease the spindle weight. High-Speed Machining (HSM) is widely used in the manufacturing industry. The premature failure without alarming signs leads the development of spindle technology to be strategically critical for the HSM implementation.

2. MATERIALS AND METHODOLOGY

The structure of the spindle is shown in Figure 1. The spindle is supported by two sets of angular contact ball bearings for reducing the axial run out of the spindle and improving the axial stiffness of the spindle. The two sets of angular contact ball bearings are installed back-to-back.

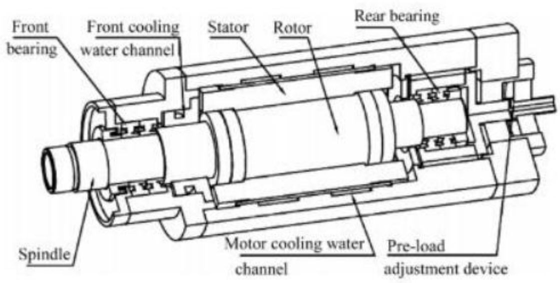

Figure1. Typical Motorized spindle assembly

A motorized spindle assembly is composed of different parts and subassemblies, many of which are complex. The spindle can be modelled as a shaft, supported at each end by a set of bearings. Fig. 2 shows a diagram of the simplified representation of the spindle system. The model of the high-speed motorized milling spindle is made using ANSYS software. Spring-damper element is applied to simulate the elastic support of the two sets of bearings.

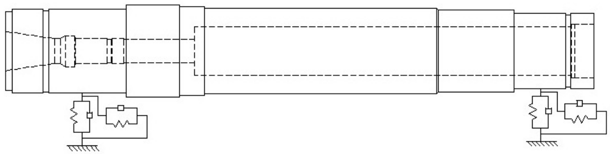

Figure2. Equivalent dynamic model of a spindle.

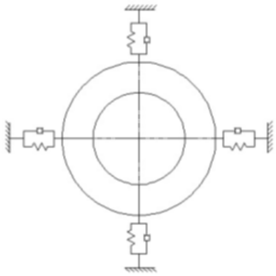

Figure 3. Layout of spring damper unit.

COMBIN14 element which can be applied to simulate springs and dampers is provided by ANSYS. The Solid 92 element which is a tetrahedral element with ten nodes is used to simulate spindle part. The finite element model of spindle is shown in Fig. 4 The total numbers of nodes and elements are 17303and 9533 respectively. The material used for the spindle are EN24 and H13. When assigned material is EN24 to the model in ANSYS, the weight of the spindle is 20.523 kg. and for that of H13 is 18.349 kg. The bearing used are XCB7017C.T.P4S andXCB7018C.T.P4S. The spring stiffness of each set of bearings is 310.3N/μm and 274.3N/μm. Since the damper has little influence on the natural frequency of the transversal vibrations, the damper element can be ignored.

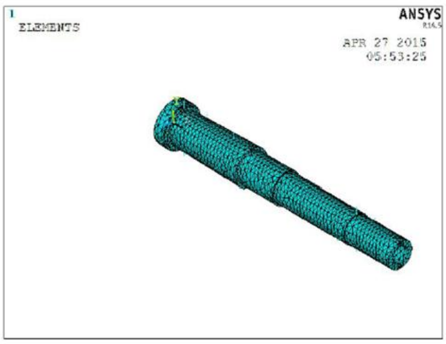

Fig 4 Finite element Model of spindle

3. ANALYSIS OF THE SPINDLE

3.1 STATIC ANALYSIS OF THE SPINDLE

The spindle stiffness is closely related with the load capacity and vibration resistance, which is an important performance index of the motorized spindle. The spindle stiffness includes the axial and bending stiffness. In normal operating condition, the bending stiffness is more important than axial stiffness. The bending stiffness (K) of the spindle unit is defined as follows: if the front part of the spindle generates unit radial displacement δ, and the force in the direction of the displacement is Fr :

$K = Fr/\delta$ (N/μm)

In the study of the static load analysis of spindle, the rotating speed loading analysis is done at first, and the maximum rotating speed of the motorized spindle is greater than or equal to 12000rpm. The maximum deformation is only 3.67 micron, which basically does not affect the precision of the spindle

3.2 MODAL ANALYSIS OF THE SPINDLE

During milling, the vibration cannot be avoided, and this changes the relative position of work pieces and milling cutters and also accelerates the wears of milling cutter. Therefore, the Modal analysis of spindle is the primary problem of dynamic characteristics analysis.

3.3 HARMONIC RESPONSE ANALYSIS OF THESPINDLE

Modal analysis is basis of Harmonic response analysis. The computing time is effectively reduced based on the completed modal analysis. For harmonic response, the cutting force is applied on the end of the spindle taper to analyze the 10 order frequency, whose range is from 0Hz to 1400Hz with step 400Hz. Analysis is done by selecting a node from the cone part of spindle.

3.4 Machining load calculations

ANGULAR CONTACT BEARINGS

Radial stiffness of angular contact ball bearings
Kr = 1.77236Km(Z2Dw)1/3cos2/sin1/3(fao)1/3 N/M

Bending stiffness (K) = fr/δ
δ = radial displacement.
fr = force required to be imposed in the direction of displacement.

MILLING CUTTING FORCE FORMULAE

Cutting Speed (m/min) $V_c = \frac{\Pi * Dc * n}{1000}$

Spindle Speed (rev/min) $\eta = \frac{Vc * 1000}{\Pi * Dc}$

Feed Speed $V_f = f_z * n * z_n$

Feed per revolution $f_z = \frac{Vf}{\eta}$

Feed per tooth $f_z = \frac{Vf}{\eta * Zn}$

Removal rate (cm^3) $Q = \frac{ap*ac*Vf}{1000}$

Specific Cutting force (N/mm^2) $K_c = K_{C1} * \eta_m^{-mc}$

Average chip thickness

(if $a_e/D_c \leq 0.1$) $h_m = f_z \sqrt{\frac{ae}{Dc}}$

(if $a_e/D_e \geq 0.1$) $h_m = \frac{sinkr*180*ae*fz}{\Pi*Dc*\arcsin(\frac{ae}{De})}$

Net Power $K_w = \frac{ap*ae*Vf*Kc}{60*1000000}$

For work piece material ALUMINIUM

Cutting parameters 1

Feed $f_z = 0.4$ mm

$a_e = 0.2$

Cutter diameter $D_c = 150$ mm

$a_e = 30$ mm
$a_p = 100$ mm
Entry angle $K_r = 45^0$
No.of Inserts Z = 8
Average chip thickness $h_m = \frac{180*sinkr*ae*fz}{\Pi*Dc*\arcsin(\frac{ae}{Dc})}$

$= \frac{180*sin45*0.2*0.4}{\Pi*\arcsin(0.2)}$

$= \frac{180*0.707*0.08}{\Pi*0.201}$

= 16.123

Specific cutting force $K_c = 960\ N/mm^2$

4. RESULTS

4.1 Spindle material EN24

For the workpiece material Al, with cutting parameters P1,below are the rotational speed and cutting force analysis results.

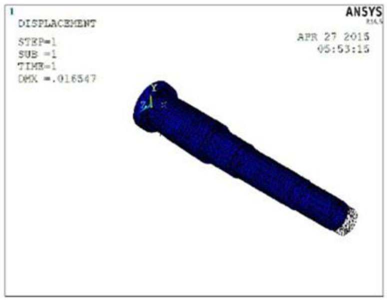

Fig5 Deflection of spindle for En 24

Fig 5 shows the spindle deflection under the rotational speed analysis and cutting force analysis where the deflection is 0.016 mm and 0.005mm respectively.

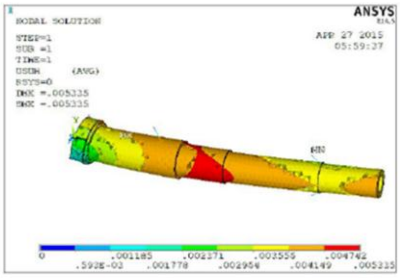

Fig 6 Delection of spindle under cutting force

Fig 7 shows the spindle deflection under the rotational speed analysis and cutting force analysis where the deflection is 0.016 mm and 0.005mm respectively.

4.1.2 MODAL ANALYSIS

For the same Aluminium material and with cutting parameters P1 , the table below shows the natural frequencies of the spindle and its mode shapes.

Table :1 Natural frequencies of spindle

1	**0**
2	**0**
3	556.28
4	1143.5
5	1321.2
6	1553.5
7	1564.3
8	2124.8
9	2326
10	2754.1

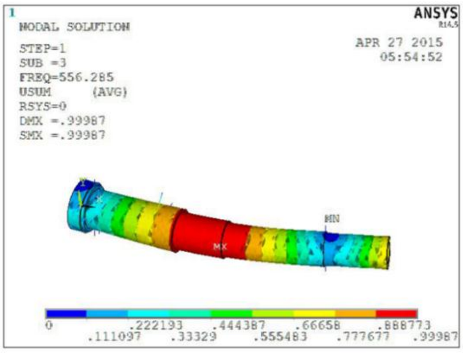

Fig7 3rd Mode Shape of the spindle

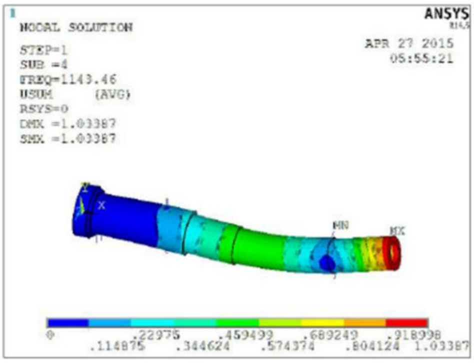

Fig8 :4th Mode Shape of the spindle

Figure 7 and fig 8 shows the mode shapes of the spindle with material EN24. 3rd mode shape and 4th shape are shown with natural frequency at that mode of vibration is 556.28 and 1143.5 respectively. Of 10 mode shapes ,3rd and 4th shapes are illustrated

4.1.3 Harmonic Analysis

The harmonic Analysis is performed on the spindle by applying Radial Force = 2305N at Frequency Range 0-1400Hz with Sub steps 140

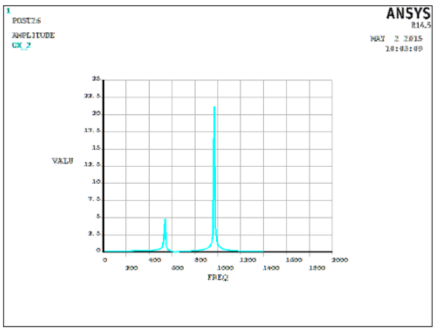

Fig 9 :Frequency response under external loading

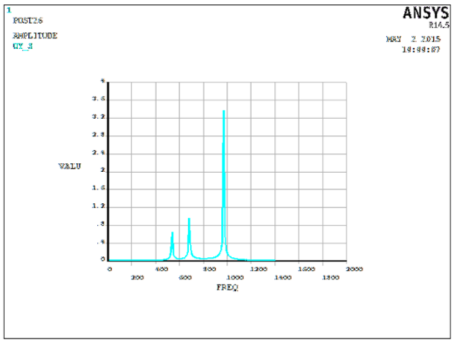

Fig 10 :Frequency response under external loading

Figure 9 and 10 shows the frequency response analysis and the peak amplitude of vibration at node 7 and 2 respectively

4.2 Spindle MATERIAL: H13

For the workpiece material Al, with cutting parameters P1,below are the rotational speed and cutting force analysis results

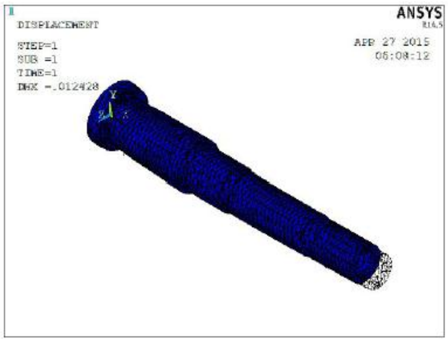

Fig 10 Deflection of spindle under rotational speed

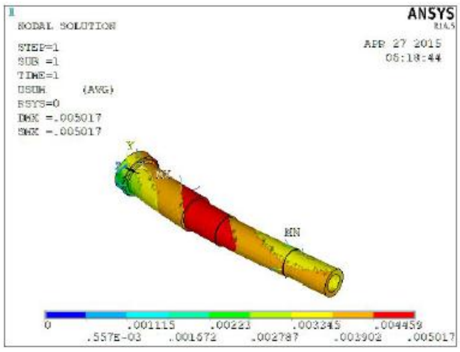

Fig 11 Deflection of spindle under cutting force

Fig 10 and fig 11 shows the spindle deflection under the rotational speed analysis and cutting force analysis where the deflection is 0.0124mm mm and 0.005mm respectively

4.2.1MODAL ANALYSIS

For the same Aluminum material and with cutting parameters P1 , the table below shows the natural frequencies of the spindle and its mode shapes.

Table 2 : Natural Frequency values

1	2	3	4	5	6	7	8	9	10	
0	0	602.5	1237.9	1414.4	1675.9	1676.8	2338	2514.8	2975	

The above table is the listing of the first 10 natural frequencies of the spindle under the action of free vibration.

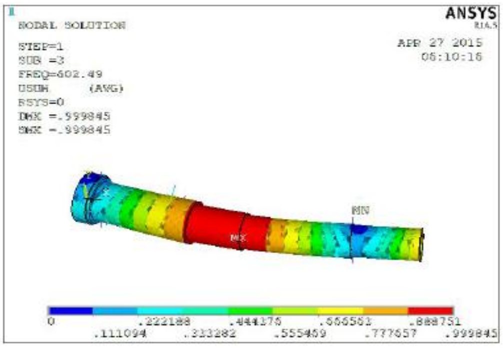

Fig 11 3rd Mode shape of the spindle with H13 material

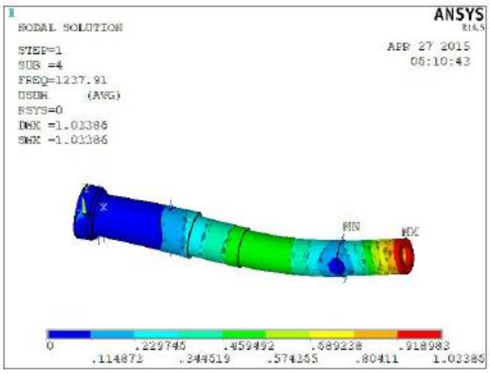

Fig 11 4 th Mode shapes of the spindle with H13 material

Figure 7 shows the mode shapes of the spindle with material H13.out of 10 3rd mode shape and 4th shape are shown with natural frequency at that mode of vibration is 602.5Hz and 1237.9respectively

4.2.3 Harmonic Analysis:

The harmonic analysis is performed on the spindle by applying Radial Force = 2305N at Frequency Range 0-1400Hz with number of Substeps 140

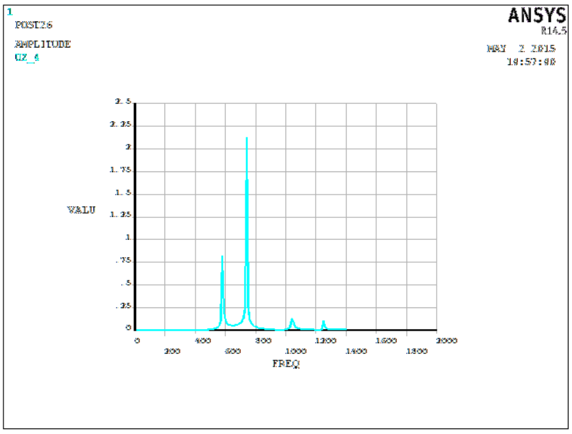

Fig 12 Frequency response under external loading

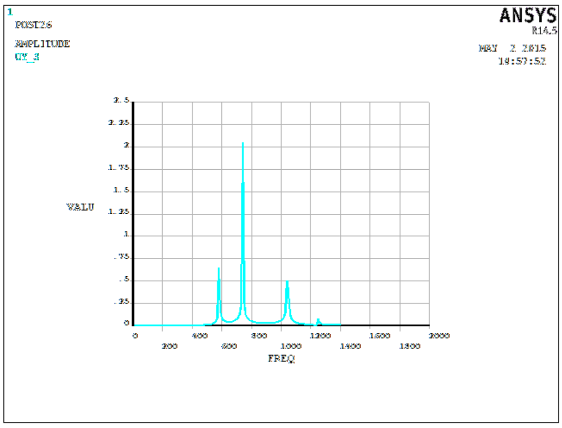

Fig 13 Frequency response under external loading

Figure12 and 13 shows the frequency response analysis and the peak amplitude of vibration is shown at node 7 and 2 respectively

5 CONCLUSIONS

1. The static analysis, the modal analysis and harmonic response for motorized milling spindle is done by means of ANSYS. The method to establish the finite element model of the bearing support by spring-damper element COMBIN 14 was investigated and tested.

2. The above analysis are performed on two different materials to optimize the design. It was found that the deflection of H13 was lesser than that of EN24.

3. The modal analysis was performed on both the material combinations and the first natural frequency of H13 was slightly higher when compared to EN24.

4. The amplitude of vibration in EN24 was more that if H13 in harmonic analysis Hence EN24 is subjected to more vibration.

REFERENCES

1. Machine Tool Design By N. Acherkan,Isbn-10: 0898750474, Univ Pr Of The Pacific, (April 2000)

2. Design And Construction Of Machine Tools By -H.C. Town, Iliffe Books, 1971

3. Central Machine Tool Institute Hand Book By -CMTI Bangalore

4. Al-Shareef, K.J.H, Brandon, J.A., "On the Applicability of Modal and Response Representations in the Dynamic

5. Wang, W. R., Chang, C. N., Dynamic analysis and design of a machine tool spindle-bearing system, Journal of
Vibration and Acoustics, Transactions of the ASME (ISSN 1048-9002), vol. 116, no. 3, p. 280-285.

6. Zhao Haitao, Yang Jianguo, Shen Jinhua, Simulation of thermal behavior of a CNC machine tool spindle,International Journal of Machine Tools and Manufacture, Volume 47, Issue 6, May 2007, Pages 1003–1010.

7. Yuzhong Cao Y. Altintas, Modeling of spindle-bearing and machine tool systems for virtual simulation of milling operations, International Journal of Machine Tools and Manufacture, Volume 47, Issue 9, July 2007, Pages 1342–1350.

8. Chi-Wei Lin, Jay F. Tu, Joe Kamman, An integrated thermo-mechanical-dynamic model to characterize motorized machine tool spindles during very high speed rotation, International Journal of Machine Tools and Manufacture, Volume 43, Issue 10, August 2003, Pages 1035–1050.

9. Z.-C. Lin, and J.-S. Chang, “The building of spindle thermal displacement model of high speed machine center”, *Int. J. Adv.Manuf. Technol.*, vol. 34, pp. 556-566, Sept. 2007.