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Fatigue Analysis of VMC Spindle

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ABSTRACT

Spindle is an important component of a vertical machining center .The spindle has some slots, shape change, geometrical discontinuities that affect the stress concentration and the notch sensitivity. The results of the fatigue analysis of the spindle are greatly affected by factors such as type of loading, surface finish, surface treatment. Therefore, the analysis of the spindle for fatigue analysis is the basic objective of this dissertation. In this dissertation work, the significant parameters of the spindle like diameter, length, torque, etc., are considered while modeling the spindle. The modeling as well as the analysis of the the spindle is done by using ANSYSR15.0 software. The Fatigue analysis of the, plane shaft carrying same input conditions, and, spindle undertaken are compared to signify the effect of the each geometry change on the shaft.

Keywords— **Fatigue analysis, Notch sensitivity, stress concentration, surface treatment.**

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I. INTRODUCTION

Spindle is the main mechanical component in VMC. The spindle shaft rotates at various speeds and holds a tool, which machines a material attached to the work table. The Static and Dynamic stiffness of spindle directly affect the finish quality and machiningproductivity of work pieces. Spindle shaft is the weakest point in machine tool structure, increasing its stiffness will increase machine tools accuracy and machining product quality.

High productivity needs machine tools with high speed machining capability, which leads into unavoidable dynamic effects that occur in the machine tools spindle during production process such as regenerative chatter. Fatigue life of Spindle is greatly affected by factor such as type of loading, surface finish, Geometry of spindle, Bearing Arrangement. Therefore, the analysis of the Spindle for fatigue analysis is the basic objective of this dissertation.

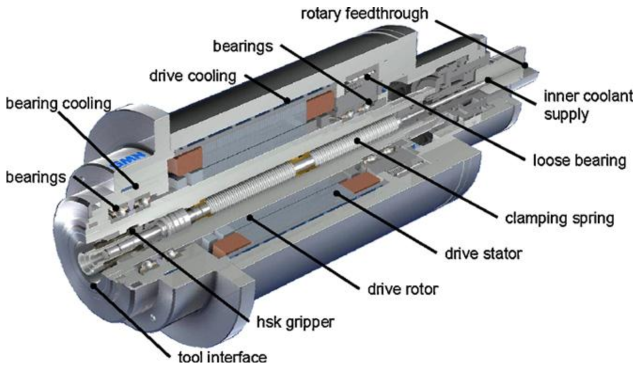

Fig.1. Sectional view of a motor spindle

The bearing arrangement is determined by the type of operation and the required cutting force and life of the bearings.

Rotational speed of spindle could only be varied by changing either the transmission ratio or the number of driven poles by electrical switches. The machine tool spindle is the most important mechanical component in removing metal during machining operations. The machine tool spindle leads to unstable vibrations, cutting forces and tensions in the belt and pulleys. The motorized spindle introduces huge amount of heat into the spindle systems as well as mass to the system.

High Rigidity of machine tool spindle is required to obtain efficient rough cutting and fine finishing capabilities .High speed spindle requires the preload control according to spindle rotation speed to prevent bearing from burning and to ensure sufficient rigidity for machining. Magnetic loading device used to measure Rigidity of machine tool spindle. The magnetic loading device is used to apply dynamic force to the spindle. The basic structure of a machine tool consists of base and column arrangement which serves as a balancing support for the entire machine. The machine is built of heavy steel and iron parts. The base of the machine is rigid and usually is of cast iron. For the analysis of structure the minimum deflection region near loading point is considered.

II. LITERATURE SURVEY

Many researchers had conducted analysis on Spindle of various type of machine. Anandkumar Telang [1] presented static stiffness analysis on high frequency milling spindle. The objective of this work was to optimize the parameters affecting the stiffness of the high frequency milling spindle running at 12000 rpm. Theoretical analysis has been carried out to evaluate the stiffness of spindle and to minimize deflection at the spindle nose by varying bearing a configuration, overhang of spindle nose from the front bearing and bearings span diameter. Finite element analysis result had shown that the diameter of the high speed spindle between the bearings has more influence on the rigidity.

Deping Liu *et al* [2] presented a method to investigate the characteristics of a high-speed motorized spindle system. The quality of high-precision parts was highly dependent on the dynamic behavior of the entire machining system.This paper taking the highspeed milling motorized spindle of CX8075 produced by Anyang Xinsheng Machine Tool Co. Ltd. [2] forFEA analysis.The support contact interface was established by using spring-damper element COMBIN 14. Furthermore, the static analysis, modal analysis, harmonic response analysis and thermal analysis were done by means of ANSYS software. The results show that the maximum rotating speed of the motorized spindle was smaller than the natural resonance speed, and the static stiffness of the spindle can complete the requirements of design.

V.V.Kulkarni [3] completed Analysis on CNC lathe spindle for maximum Cutting force condition and bearing life using FEM. This work deals with static, fatigue analysis of spindle structure for maximum cutting force condition and predicting life of bearings. Finite element result had shown that Stress obtained from the stress analysis was less than the yield strength of the material and deformation of the spindle was very less. Equivalent alternating stress, factor of safety and life of the spindle is found by fatigue analysis and results are closely matches with the analytical values.

A. Damodar *et al* [4] presented Static and Dynamic Analysis of Spindle of a CNC Machining Centre. This work, deals with study of static and dynamic behavior of spindle of a CNC horizontal machining center using FEA analysis. The geometric model of spindle is created in UNIGRAPHICS software as per the standard drawing. Spindle model is imported to HYPERMESH software through IGES format and Finite element model with converged mesh is developed. To this FEA model various loading conditions like dynamic andstaticanalysis and operating conditions are applied using ANSYS software to obtain the deflections and stresses. The max deflection of 64.3 microns is computed at tool cutting point which is 40mm away from spindle nose when 63 gear teeth acts likes a driver for 125 diameter cutter.

Dr. S. Shivakumar *et al* [5] investigated Analysis of lathe spindle using ANSYS. This work deals with design and analysis of Lathe Spindle in which the material used for the spindle was alloy steel. The spindle is supported by two bearings separated by different spans. Bearings consist of balls with certain stiffness, which acts as a cushioning effect for the spindle and hence can be considered as a spring in the software for analysis. Finite element result had shown that Optimum bearing span of 240 mm is considered for fixing distance between front and rear bearings. The vibration analysis showed that no resonance occurs predicted results are verified with analytical models.

CharnontMoolwan et al [6] investigated Failure Analysis of a Two High Gearbox Shaft. This paper deals with the results of fatigue failure analysis of a two high gearbox shaft in a hot steel rolling mill in Thailand [6] which fails prematurely after about 62 days of service. The results of analysis showed that the shaft failed by fatigue fracture. Beach marks on the fracture surface of shaft were clearly visible. Fatigue cracks were started at the corners of the wobbler of shaft. Small final fracture area indicated that the shaft was under a low stress at the time of fatigue failure. Gear box shaft failed by fatigue failure and that premature failure occurred due to high stress concentration at the discontinuities of the wobbler of the gear box shaft.

III. FATIGUE ANALYSIS

When a material is subjected to variable stresses, it fails at Stresses below the yield stresses. Such type of failure of a material is known as fatigue of material. The method of fatigue failure analysis involves a combination of engineering and science. The three fatigue life methods used in design and analysis are the stress-life method, the strain-life method, and the linear-elastic fracture mechanics method.

Life of $1 \leq N \leq 103$ cycles is a low-cycle fatigue, whereas high-cycle fatigue is $N > 103$ cycles. Stress Life method used to determine the strength of materials under the action of repeated loads, specimens is subjected to varying forces of specified magnitudes while the stress reversals are measured to destruction. The stress-life method is based on stress levels only. The stress Life method is the most traditional method and easiest to implementfor a wide range of design applications. The most commonly used fatigue-testing device is the R. R.Moore high-speed rotating-beam machine.

A. Cutting force in spindle

Milling is a cutting process that uses a milling cutter to remove material from the surface of a work piece. The milling cutter is a rotary cutting tool, often with multiple cutting points. The cutting action is shear deformation; the metal is pushed off the work piece in tiny clumps that hang together to more or less extent (depending on the metal type) to form chips.

Maximum cutting force is given by following equation,

$$Pz = \frac{6120 \times N \times 9.81}{v} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

Where,

N Power of the motor

v Cutting speed

B. *Modelling of spindle*

A 3-D model of VMC spindle is created by using ANSYSR15.0software as shown in fig. 2. 3-D model that has been generated from 2-D drawing provided by TAL .The filets and chamfers of the spindle are removed in the models used for the analysis in order to reduce the complexity of the models and the runtime.

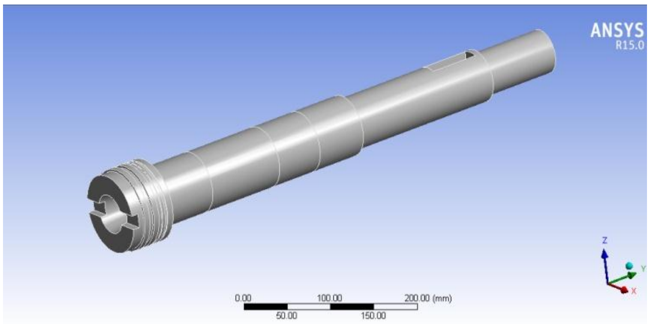

Fig. 2.3D Model of VMCspindle

C. *Material of spindle*

The raw material for the VMC spindle is $20MnCr_5$. $20MnCr_5$ has good wearing resistance property compared to another material. The property of the material is presented in Table1.

Table.1. Material properties

Physical Properties	Values
Ultimate Strength	**682 MPa (N/mm^2)**
Yield Strength	**375 MPa**
Young's Modulus	**190×103 N/mm^2**
Poisson's Ratio	**0.27-0.3**
Density	**8030 kg/m^3**

D. *Meshing*

The first step in Meshing is to select an element which closely represents the physical behaviour of the structure. A finite element model can be constructed out of several types of elements-spring, spar, beam, plate, shell, membrane, pipe, solid etc.

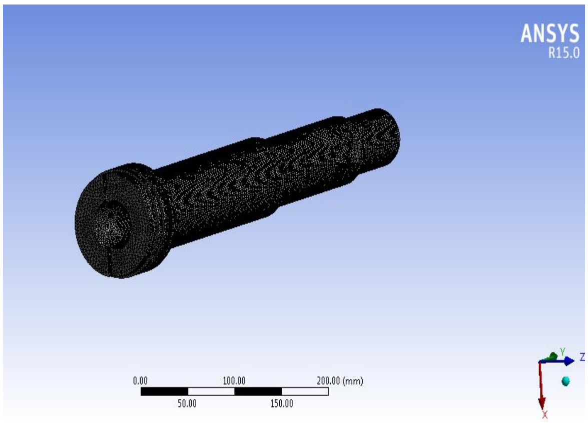

Fig. 3.Mesh Model of VMC spindle

The model is meshed as the SOLID 187 element type as shown in Fig. The size of each element is set to 3 mm. Patch Conforming mesh method is used in software to mesh the VMC spindle. SOLID187 is defined by eight nodes having 3 DOF at each nodes .The element have plasticity, stress stiffening, creep and strain capabilities. SOLID 187 have mixed formulation capability for simulating deformations of nearly incompressible elasto plastic materials.

E. *Boundary conditions*

Two cylindrical supports are provided at bearing location in FEA model. Total bearing span of spindle is173 mm and total overhang of spindle is 55 mm.

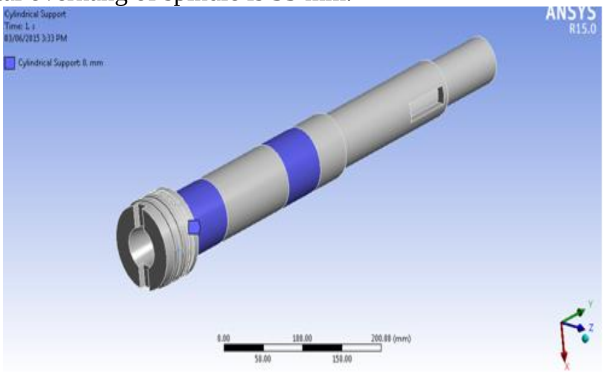

Fig. 4.Boundary condition

F. *Loading*

Maximum cutting load for the spindle are applied on the F_z negative direction shown in fig.6.one torque is applied on end of the spindle in the clockwise direction.

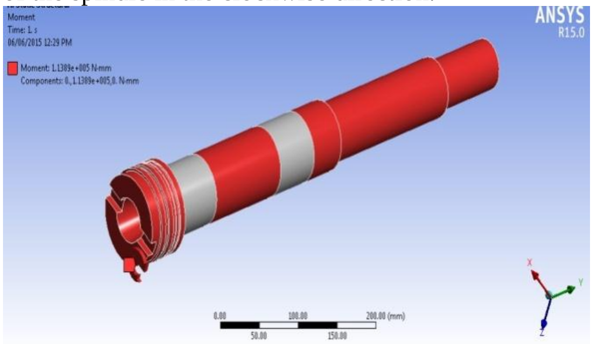

Fig.5 Torque on VMC spindle

Loading is of constant amplitude because only one set of FE stress results along with a loading ratio is required to calculate the alternating and mean values.

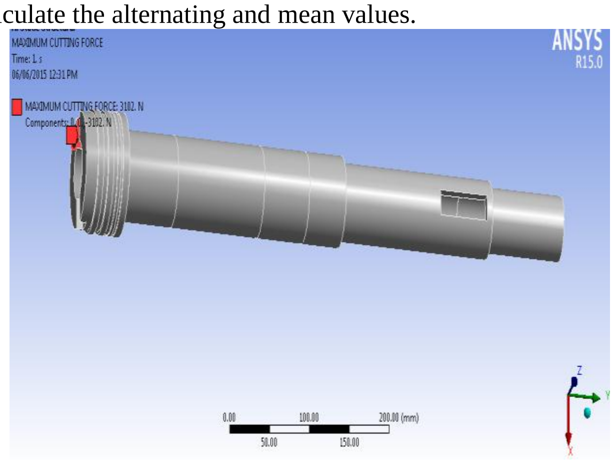

Fig.6. Load on VMC spindle

The loading ratio is defined a ratio of the second loads to first the load. Torque applied on spindle is 113.986 N-M and total maximum force is 3102 N

IV. RESULT & DISCUSSION

A. *Equivalent alternating stress*

The equivalent alternating stress is calculated only in stress life fatigue analysis. The equivalent alternating stress can be determined before determining the fatigue life of component. The Usefulness of this result is that in general it involves all of the fatigue related calculations Independent of any fatigue material properties.The Fatigue analysis of the, plane shaft carrying same input conditions, are compared with VMC spindle Analysis to signify the effect of the geometry change on the shaft.

Table 2.comparision of alternating stress

Case	VMC Spindle Shaft		Plane Shaft	
Equivalent alternating stress in (MPa)	Maximum	Minimum	Maximum	Minimum
	33.768	0.000347	23.887	0.0004142

Fig.7 & Fig.8 shows equivalent alternating stress intensity in two different cases (one actual vertical machining center spindle and plane spindle shaft).

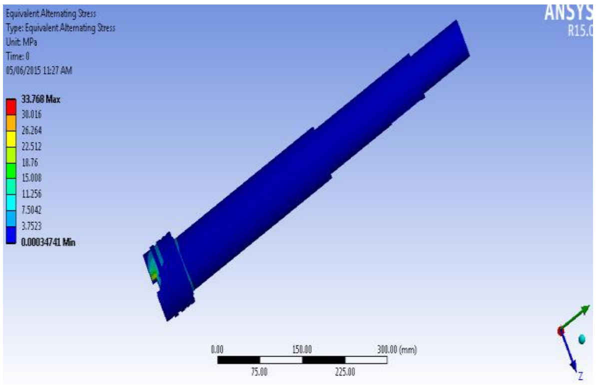

Fig. 7. Equivalent alternating stress on VMC spindle

Fig.7 and Fig.8 clearly shows that the equivalent alternating stress in the case of actual vertical machining center spindle shaft is greater than the equivalent alternating stress of planeshaft. [Max. equivalent alternating stress for vertical machining center spindle shaft = 33.768Mpa and max. Stress intensity for plane shaft =0.000347 Mpa].

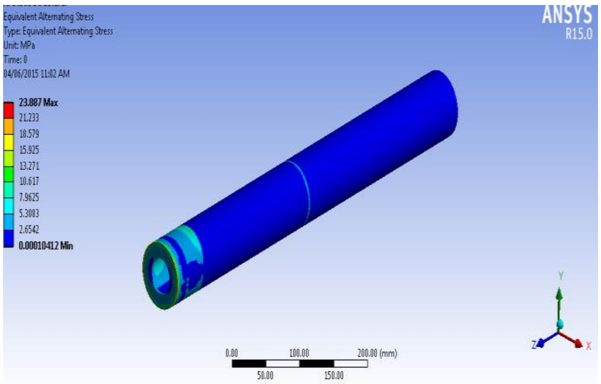

Fig. 8. Equivalent alternating stresson plane shaft

Maximum equivalent alternating stress for vertical machining spindle occurred at front end with magnitude 33.768 MPa and minimum at the rear end with magnitude 0.00034741 MPa. Maximum equivalent alternating stress for plane shaft occurred at front end with magnitude 23.887 MPa and minimum at the rear end with magnitude 0.0001041 MPa.

B. *Factor of safety*

Fatigue Safety Factor is a contour plot of the factor of safety of component with respect to a fatigue failure in a component at a given design life.

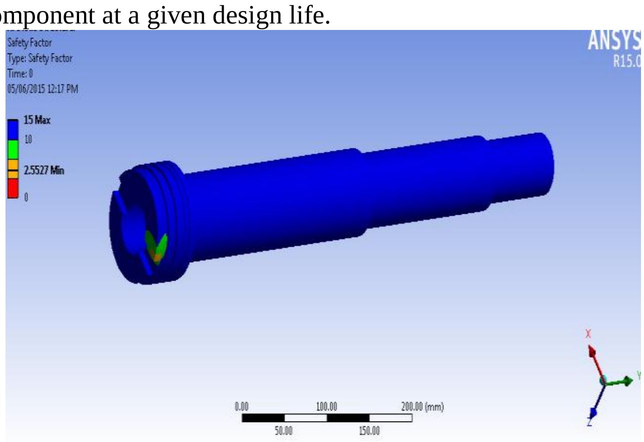

Fig.9. Factor of safety of VMC spindle

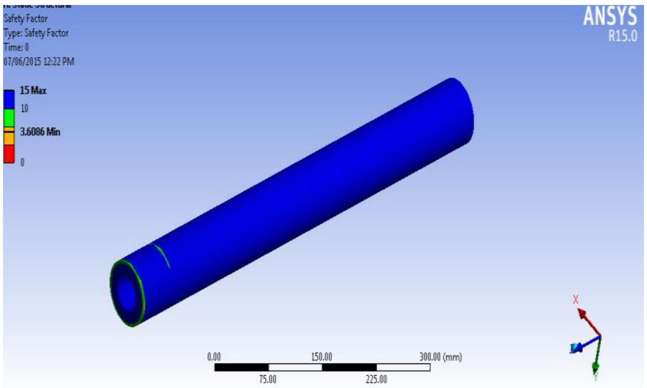

Fig. 10.Factor of safety of plane shaft

The maximum Factor of Safety for fatigue analysis is 15.
For Fatigue Safety Factor, values less than one indicates failure of component before the design life is reached. MaximumFatigue Safety Factor for vertical machining spindle occurred at rear end with magnitude 15 and minimum at the front end with magnitude 2.5. Maximum Fatigue Safety Factor for plane shaft occurred at rear end with magnitude 15 and minimum at the front end with magnitude 2.5.

V. CONCLUSION

Maximum equivalent alternating stress for vertical machining spindle occurred at front end. The Geometry of spindle at the front end has more influence on the alternating stress of spindle as is evident from the results. The equivalent alternating stress in the case of actual vertical machining center spindle shaft is greater than the equivalent alternating stress of plane shaft.

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