Fatigue Analysis of VMC 450 Spindle

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Abstract -*Spindle is an important component of a vertical machining center 450.The VMC spindle has some slots, geometrical discontinuities, shape change 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 modelling the VMC spindle. The modelling as well as the analysis of the spindle is done by using ANSYS ® 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.*

Key Words: Fatigue analysis, Notch sensitivity, stress concentration, surface treatment, surface finish, Torque**.**

1. INTRODUCTION

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

A high productivity needs machine tools with high speed machining capability, which leads into unavoidable dynamic effects that occur in the machine tool spindle during production process such as regenerative chatter. The fatigue failure is caused by means of a progressive crack formation. The failure in the material may occur even without any initial indication. The fatigue of material is affected by the size of the component, relative magnitude of loads and the number of repeated loads. The fatigue life of the spindle is greatly affected by factor such as type of loading, surface finish, geometry of the spindle, bearing arrangement. Therefore, the analysis of the spindle for fatigue analysis is the basic objective of this dissertation. The high speed spindle requires the preload control, according to spindle rotation speed to prevent bears from burning and to ensure sufficient rigidity for machining.

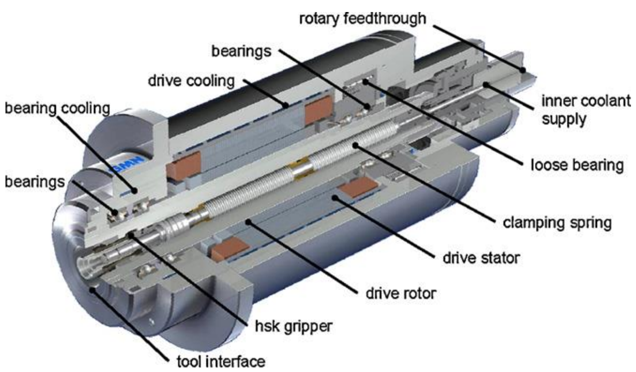

Fig -1: Sectional view of a motor spindle

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.

2. LITERATURE REVIEW

Many researchers had conducted an analysis on the spindle of various types of machine. Anandkumar Telang [1] has presented static stiffness analysis on a high frequency milling spindle. The author has optimized the parameters influencing the stiffness of the high frequency milling spindle running at 12000 RPM with a power rating of 10 KW. Theoretical analysis has been carried out to evaluate the spindle stiffness and to minimize deflection at the nose by varying bearing arrangement, bearing span length of spindle. The finite element analysis results show that the diameter of the spindle between the bearings has more influence on the rigidity.

Deping Liu *et. al.* [2] has presented finite element analysis of high-speed motorized spindle based on ANSYS®. The author has investigated the characteristics of a high-speed motorized spindle system. The geometric quality of high-precision parts was highly dependent on the dynamic performance of the entire machining system. In this publication the static analysis, modal analysis, harmonic response analysis and thermal analysis were carried out on high-speed milling motorized spindle. The results show that the maximum rotating speed of the spindle was smaller than the natural resonance region speed, and the static stiffness of the spindle can meet the requirements of the design.

V. V. Kulkarni *et. al.* [3] has presented analysis on CNC lathe spindle for maximum cutting force condition and bearing life using FEM. The author has completed static, fatigue analysis on the spindle structure for maximum cutting force condition and predicting life of bearings. The spindle holds the cutting tool, which cuts the material attached to worktable. The finite element results show that stress obtained from the stress analysis was less than the yield strength of the material and deformation of the spindle was very less.

A. Damodar *et. al.* [4] has presented static and dynamic analysis of spindle of a CNC machining center. The author has studied the static and dynamic behavior of spindle of a CNC horizontal machining center using finite element analysis. The UNIGRAPHICS® software is used to create the geometric model of spindle. The geometric model is imported to the HYPERMESH® software through IGES format to develop a mesh model of spindle. The ANSYS® software is used to apply the boundary condition. The analysis results show that the max deflection of 64.3 microns is computed at cutting point which is 40 mm away from spindle nose.

Dr. S. Shivakumar *et. al.* [5] has investigated analysis of lathe spindle using ANSYS® software. The author has completed design and analysis of the lathe spindle. The spindle is supported by two bearings of different types. The bearings consist of balls with certain stiffness, which act as a cushioning effect for the spindle. The finite element analysis results show that optimum bearing span of 240 mm is considered for fixing the distance between the front end and rear end bearings.

SumitRaut *et. al.* [6] has investigated failure analysis and redesign of shaft of overhead crane. The shaft failed due to dynamic, alternating low tensile– compressive stresses and simultaneous torsional load. An overhead crane is mechanical equipment for lifting and lowering the load. The CATIA® software is used to create a geometrical model of the shaft. Then author completed the analysis of existing shaft by ANSYS® software. The analysis results show that the failure of shaft occurs due to the corrosion, fatigue, overload, creep, wear, abrasion, erosion.

CharnontMoolwan *et. al.* [7] has investigated failure analysis of a two high gearbox shaft. The high gearbox shaft of a gearbox failed prematurely after about 15,000 hours of service. The beach marks on the fracture surface were clearly visible. The fatigue cracks were initiated at the corners of the wobbler of the shaft. The fracture area of the fracture surface indicated that the shaft was under a low stress at the time of failure. The gear box shaft failed by fatigue fracture and that premature failure occurs due to high stress concentration at the corners of the wobbler of the gearbox shaft.

E. Abele *et. al.* [8] has presented machine tool spindle units. The author has presented the state-of the art in machine tool spindle units. The author mainly focused on motorized spindle units for high speed and high performance cutting. The author presented information about the main components of high speed spindle units regarding historical development, recent challenges and future trends in the spindle. An overview of recent research projects in spindle development is also given in the publication. The current methods of modeling the thermal and dynamical behavior of spindle units are presented in the publication.

3. FATIGUE ANALYSIS

The finite element method is a computational technique used to obtain approximate solutions of boundary value problems in engineering. The fatigue analysis has three main methods, strain life, stress life, and fracture mechanics method. The stress life method is used for the fatigue analysis of the VMC spindle. The stress life is based on S-N curves (Stress – Cycle curves). The stress life approach is related with total life and not distinguishes between initiation and propagation of cracks. The stain life method is widely used for high cycle fatigue .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.

Life of 1 ≤ N ≤ 103 cycles is a low-cycle fatigue, whereas high-cycle fatigue is N >103 cycles. The stress Life method is the most traditional method and easiest to implement for a wide range of design applications. The most commonly used fatigue-testing device is the R. R.Moore high-speed rotating-beam machine.

3.1 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,

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

Where,
N =Power of the motor
v =Cutting speed

3.2 Modelling of spindle

The model of the VMC 450 spindle is created using the ANSYS® software as shown in figure 2. The filets and chamfers are removed from the VMC 450 spindle model used for the analysis in order to reduce the complexity of the model and the runtime. The length of the VMC 450 spindle model is 618 mm and maximum diameter of the VMC spindle model is 90 mm.

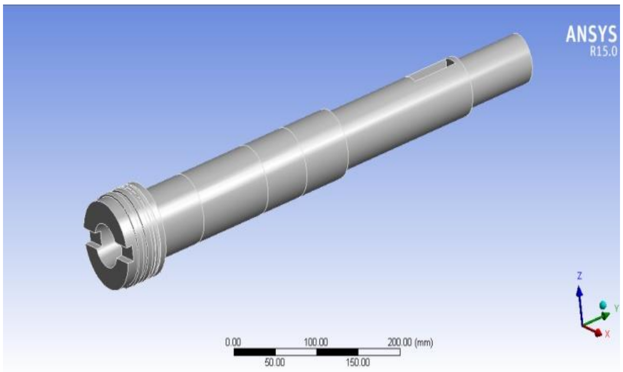

Fig -2: 3D Model of VMC spindle

3.3 Material of spindle

The raw material for the VMC 450 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

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 m^3

3.4 Meshing

In a meshing phase, initially the model is meshed using the automatic method under the global mesh control. The automatic method is limited to simple geometries and error free CAD model. The automatic mesh method has no control over the mesh flow and the specific mesh pattern, hence mesh quality criteria is applied to mesh model.

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.

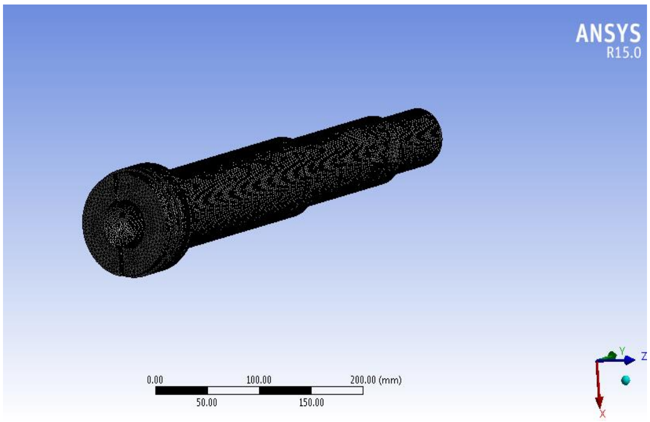

Fig -3: Mesh Model of VMC spindle

The model is meshed as the SOLID 187 element type as shown in Fig 3. 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.

3.5 Boundary conditions

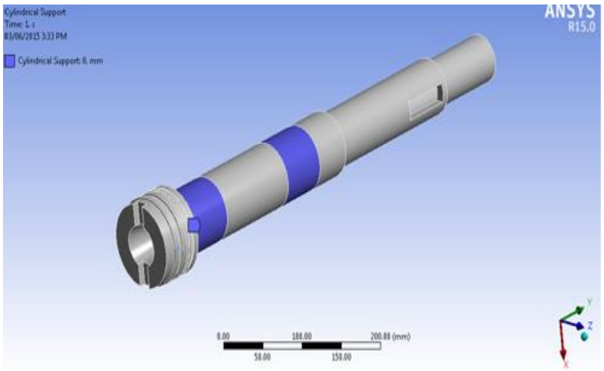

Fig -4: Boundary condition

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.

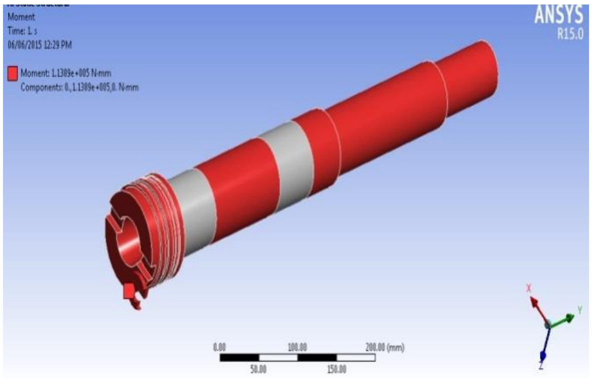

Fig -5: Torque on VMC spindle

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.
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.

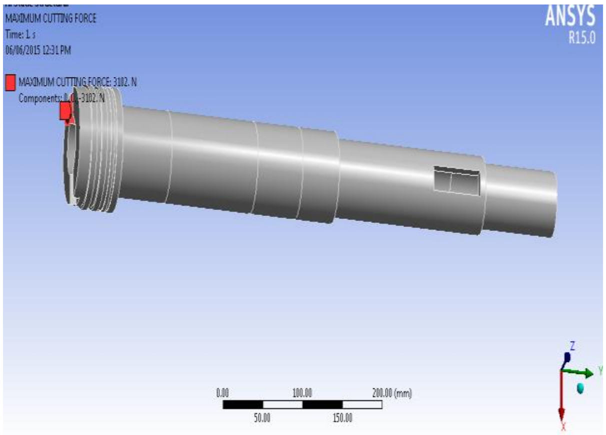

Fig -6: Load on VMC spindle

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.

4. RESULTS AND DISCUSSION

4.1 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 -1: Comparison of alternating stress

Case	VMC Spindle Shaft		Plane Shaft	
Equivalent alternating stress in (MPa)	Max	Min	Max	Min
	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).

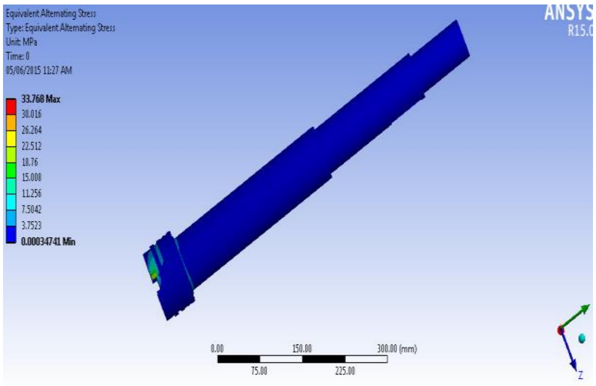

Fig -7: Equivalent alternating stress on VMC spindle

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 plane shaft. [Max. equivalent alternating stress for vertical machining center spindle shaft = 33.768MPa and max. Stress intensity for plane shaft =0.000347 MPa].

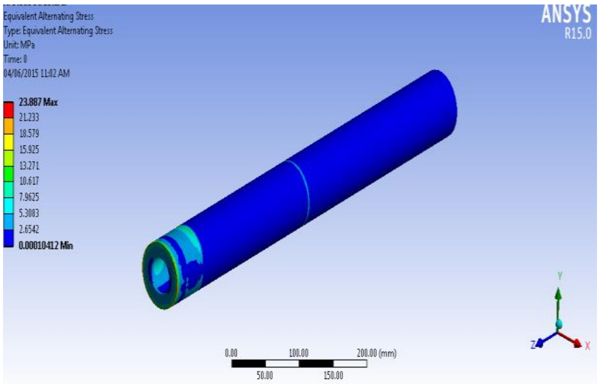

Fig – 8:Equivalent alternating stress on plane shaft

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.

4.2 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.

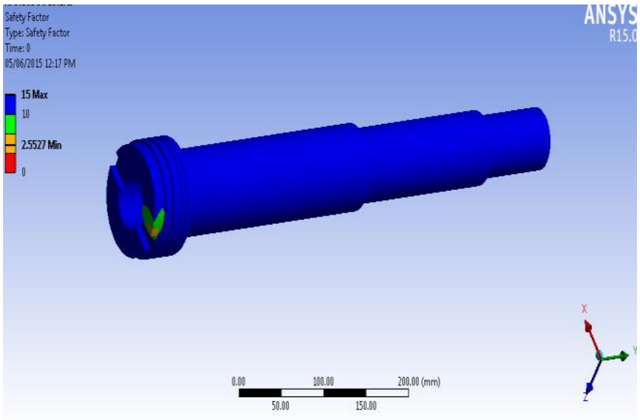

Fig –9:Factor of safety of VMC spindle

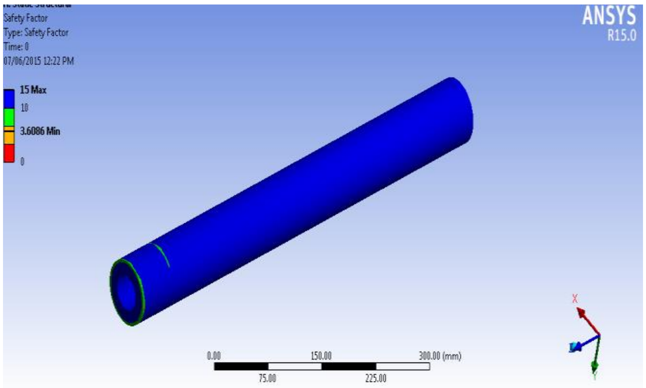

Fig – 10:Factor of safety of plane shaft

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. Maximum Fatigue 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.

4.3 Biaxiality Indication

The biaxiality indication gives an idea of the stress state over the model and how to interpret the results. A biaxiality of zero corresponds to uniaxial stress, a value of –1 corresponds to the pure shear state, and a value of 1 corresponds to a pure biaxial state. The fatigue material properties are based on uniaxial stresses but real world stress states are usually multiaxial. The biaxiality indication is ratio of the principal stress smaller in magnitude divided by the larger principal stress with the principal stress nearest zero ignored. The minimum biaxiality for the VMC spindle occurs at the node 2875 and the maximum biaxiality for the VMC spindle occurs at the node 241621.

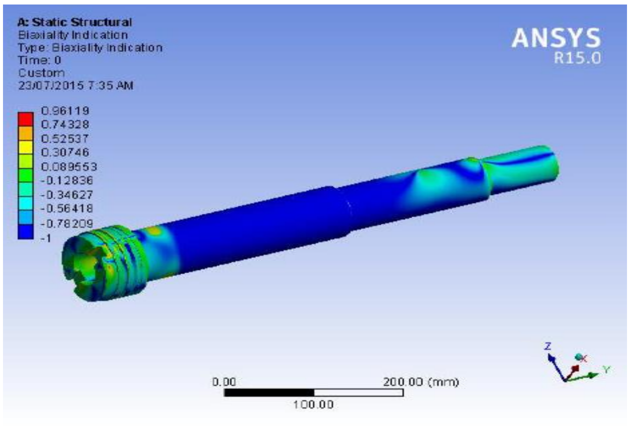

Fig – 11: Biaxiality indication for the VMC spindle

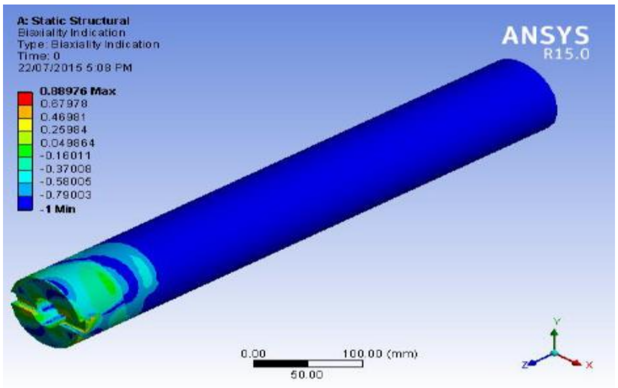

Fig – 12: Biaxiality indication for the Plane Shaft

The figure 12 shows the biaxiality indication for the plane shaft at maximum cutting force condition. The maximum biaxiality for the plane shaft occurs at the front end, results show that the biaxiality states present at the front end of the plane shaft.

4.4 Variation of equivalent alternating stress for different bearing spans

The variation of the equivalent alternating stress when the bearing span is changed from 158 to173 mm is plotted in figure 15. As the bearing span length increases the equivalent alternating stress on the VMC spindle also decreases from 38 MPa to 33.5 MPa.

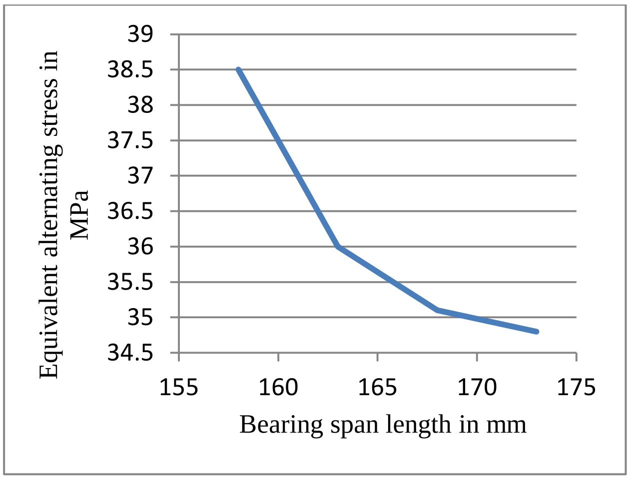

Chart -1: Variation of equivalent alternating stress for different bearing spans.

5. CONCLUSIONS

Maximum equivalent alternating stress for VMC 450 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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