

Static Analysis of VMC Spindle for Maximum Cutting Force

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Abstract— Spindle of VMC450 machine is an important component of a vertical machining center. The spindle shaft rotates at different speeds and holds a carbide tool cutter, which machines a work piece attached to the machine tool table. The stiffness of spindle directly affects the VMC machining productivity and finish excellence 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 proficiency, which leads into unavoidable dynamic effects that occur in the machine tools spindle during production process such as regenerative chatter. The objective of this dissertation is to optimize the parameters inducing the stiffness of the high Speed VMC spindle. In this dissertation work, the significant parameters of the spindle bearing spam, diameter, over hanging length, torque are considered while modeling the spindle. The Modeling as well as the analysis of the spindle is done by using ANSYS ® software.

Key words: Analysis of VMC Spindle, VMC Spindle

I. INTRODUCTION

Spindle is the main mechanical component in VMC. The spindle shaft rotates at different speeds and holds a cutter, which machines a job attached to the machine tool table. The Static and Dynamic stiffness of spindle directly affect the machining productivity and finish quality 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 competence, which leads into inescapable dynamic effects that occur in the machine tools spindle during production process such as regenerative chatter. Stiffness of Spindle is greatly affected by factor such as type of surface finish, Geometry of spindle, Bearing Arrangement. Therefore, the analysis of the Spindle for stiffness is the basic objective of this dissertation.

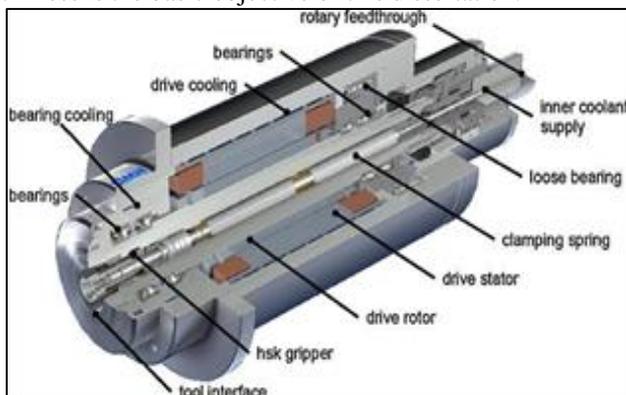


Fig. 1: Sectional view of a motor spindle

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 VMC machine tool consists of base and column arrangement which serves as a balancing support for the entire machine. The machine is built of cast iron & steel parts. The base of the machine is rigid and usually is of cast iron. For the analysis of structure the lowest deflection region near loading point is considered

II. LITERATURE REVIEW

Many researchers had conducted analysis on the VMC Spindle of various type of machine. V.V.Kulkarni et al[1] completed Analysis on CNC lathe spindle for maximum Cutting force condition and bearing life using FEM. This work deals with static, fatigue analysis of lathe 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 total deformation of the lathe spindle was very less. Equivalent alternating stress, factor of safety and life of the lathe spindle is found by fatigue analysis and results are closely matches with the analytical values.

Deping Liu et al [2] presented a method to investigate 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, which is determined by the correlated dynamics of machine tool mechanical structure and cutting process. This paper taking the milling spindle of CX8075 produced by Anyang Xincheng Machine Tool Co. Ltd. as an example, a FEA model of the high-speed motorized spindle is derived and presented [2]. The model takes into account bearing support contact interface, which was established by spring-damper element COMBIN 14. Furthermore, the modal analysis, static analysis, thermal analysis and harmonic analysis were done by means of ANSYS commercial software. The results show that the extreme rotating speed of the motorized spindle was far smaller than the natural resonance section speed, and the

static stiffness of the milling spindle can meet the requirements of design.

Anandkumar Telang [3] presented static stiffness analysis on high frequency milling spindle. The objective of this work was to optimize the parameters influencing the stiffness of the high frequency milling spindle running at 12000 rpm with power rating of 10 KW[3]. Theoretical analysis has been carried out to evaluate the spindle stiffness and to minimize deflection at the nose by varying Bearing arrangement, overhang of spindle nose from the front bearing and Spindle diameter between the bearings. Finite element analysis result had shown that the diameter of the spindle between the bearings has more influence on the rigidity.

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

Dr. S. Shivakumar investigated Analysis of lathe spindle using ANSYS. This work deals with design and analysis of 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 definite stiffness, which acts as a cushioning effect for the spindle and hence can be considered as a spring in the software for analysis [5]. Finite element result had shown that Optimal bearing span of 240 mm is considered for fixing distance between front and rear bearings [5]. The vibration analysis showed that no resonance occurs expected results are verified with models.

III. THEORETICAL ANALYSIS OF VMC SPINDLE

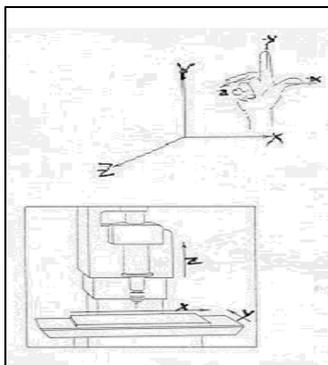


Fig. 2: Cutting force Component Milling Operation
Static stiffness is one of the important performances parameter of VMC machine tool. Stiffness of the spindle is defined as its capability to resist deflection under the action of cutting force [4]. As shown in Fig. 1 when a force exerted on the spindle nose is F_z [4], the displacement at the spindle-nose is ' δ '

Hence stiffness of VMC spindle is given by following equation

$$K = F_z/\delta \quad (1)$$

Where

F_z = force in Z direction

δ = deflection of spindle

A. Cutting force in VMC spindle

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

Maximum cutting force in VMC is given by following equation,

$$P_z = \frac{6120 \times N \times 9.81}{V} \quad (2)$$

Where,

N=Power of the motor

V=Cutting speed

B. VMC Spindle Rigidity

The static rigidity is the force required to obtain a deflection of the spindle due to its own bending under the force in addition to the deflection caused due to bearing elasticity[4].

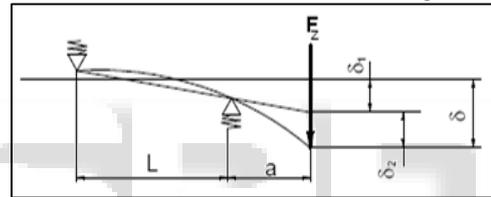


Fig. 3: Deflection of VMC spindle

$$\delta = F_z \left[\frac{1}{S_A} \left(\frac{a+L}{L} \right)^2 + \frac{1}{S_B} \left(\frac{a}{L} \right)^2 + \frac{a^2}{3E} \left(\frac{L}{I_L} + \frac{a}{I_a} \right) \right] \quad (3)$$

Where,

δ_1 = Deflection due to radial yielding of the bearings in mm

δ_2 = Deflection due to elastic bending of the spindle in mm

a = Length of overhang in mm

L = Bearing span in mm (varying)

E = Young's modulus of Spindle material in N/mm²

F_z = Cutting force in N

S_A = Stiffness of the front bearing in N/mm

S_B = Stiffness of the rear bearing in N/mm

I_L = Mass moment of inertia of the shaft at the bearing span in mm⁴

C. Optimum Bearing Span Length

$$L_o = \left[6EI_L \left(\frac{1}{S_A} + \frac{1}{S_B} \right) + \left(\frac{6EI_a}{aS_A} \right) Q \right]^{\frac{1}{3}} \quad (4)$$

Where,

L_o = Static optimum Bearing Span Length in mm

E = Young's modulus

a = Length of overhang

S_A = Stiffness of front bearing

S_B = Stiffness of rear bearing

I_a = Moment of inertia of the shaft at the overhang

I_L = Moment of inertia of the shaft at the bearing span

Q = Trial value for iterative determination of $L_o = 4xa$

IV. ANALYSIS OF VMC SPINDLE BY FEA

A. Modeling of Spindle

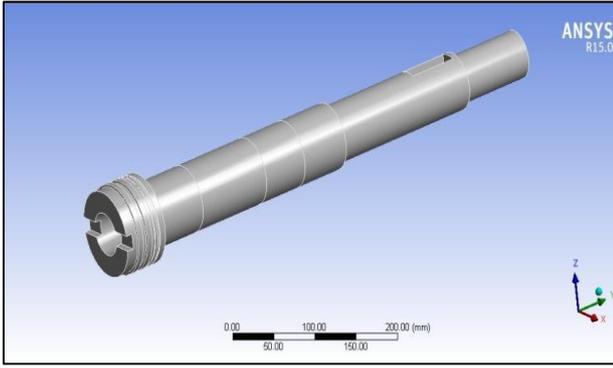


Fig. 4: 3-D model of VMC Spindle

A 3-D model of spindle is created by using ANSYS ® Software as shown in Fig. 4. 3-D model that has been generated from 2-D drawing. The fillets and chamfers of the VMC spindle are removed in the models used for the analysis in order to reduce the complexity of the models and the runtime.

B. Material of Spindle

The raw material for the spindle is 20MnCr5. The 20MnCr5 has good wearing resistance compared to another material. The property of the material is presented in Table1.

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

Table 1: Material properties

C. Meshing

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

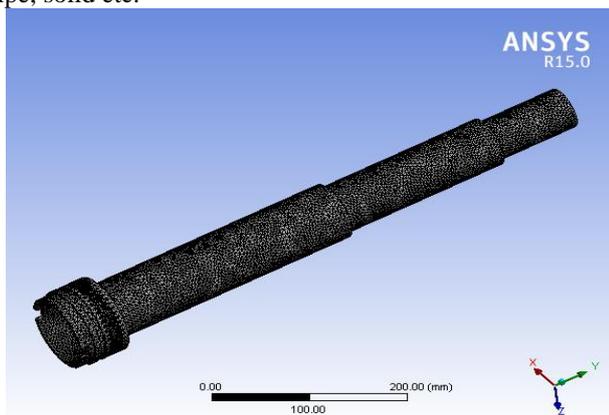


Fig. 5: Mesh Model of VMC spindle

The model is meshed as the SOLID 187 element type as shown in Fig. 4 The size of each element is set to 4 mm. the Patch Conforming mesh method is used in s ANSYS ® software to mesh the VMC spindle. The SOLID187 is defined by eight nodes having 3 DOF at each nodes .The element have plasticity, stress stiffening, creep

and strain capabilities. The SOLID 187 have mixed formulation capability for simulating deformations of nearly incompressible as to plastic materials.

D. Boundary conditions

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

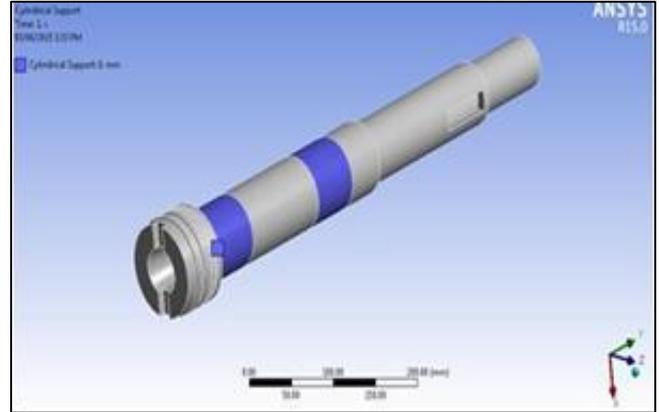


Fig. 6: Boundary condition

E. Loading

Maximum cutting load for the spindle are applied on the Fz negative direction shown in Fig. 6. The maximum force on the VMC 450 spindle is 3102.0085 N.

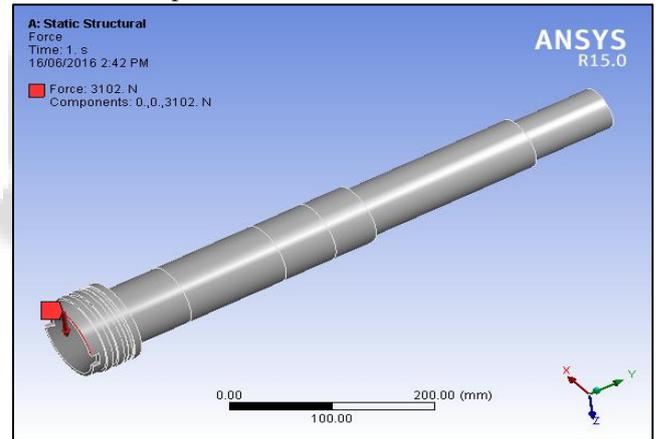


Fig. 7: Load on VMC spindle

V. RESULTS AND DISCUSSION

The deflection of the spindle nose is function of bearing span length, diameter of the spindle and overhang length of spindle. The deflection of the spindle affects the machining accuracy.

Bearing Span in mm	Theoretical		Ansys	
	Deflection at spindle nose µm	Stiffness N/µm	Deflection at spindle nose µm	Stiffness N/µm
172	13.46	230.32	10.35	299.71
173	13.43	230.93	10.38	298.84
178	13.26	233.89	10.39	298.55
183	13.10	236.69	10.41	297.98

Table 2: Comparison of Theoretical & FEA values for deflection and stiffness at the spindle nose when the span length varies from 172 mm to 183 mm for the spindle diameter of 70mm and overhang length 55mm.

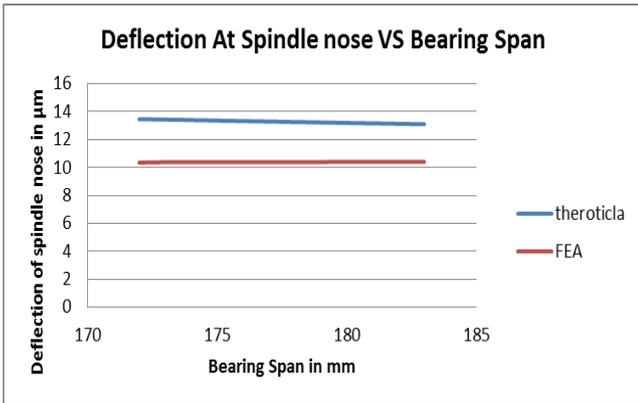


Fig. 8: Deflection at the spindle nose for different Bearing Span.

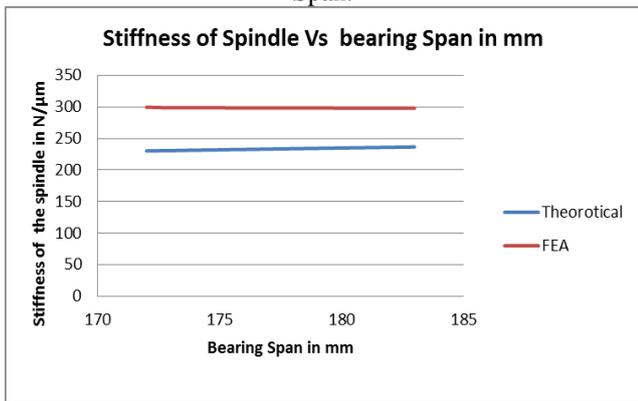


Fig. 9: Stiffness at the spindle nose for different Bearing Span.

	Theoretical		ANSYS	
	Deflection at spindle nose μm	Stiffness $\text{N}/\mu\text{m}$	Deflection at spindle nose μm	Stiffness $\text{N}/\mu\text{m}$
60	14.65	211.75	11.70	265.12
62	14.30	216.86	11.11	279.20
65	13.90	223.16	10.61	292.36
68	13.59	228.16	10.41	297.98
70	13.43	230.93	10.38	298.84

Table 3: Comparison of Theoretical & FEA values for deflection and stiffness at the spindle nose when the diameter of spindle varies from 60 mm to 70 mm for the bearing span of 173mm and overhang length 55mm.

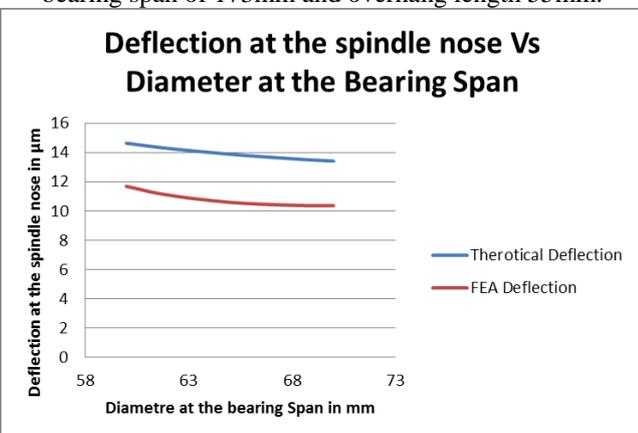


Fig. 10: Deflection at the spindle nose for different Spindle Diameter.

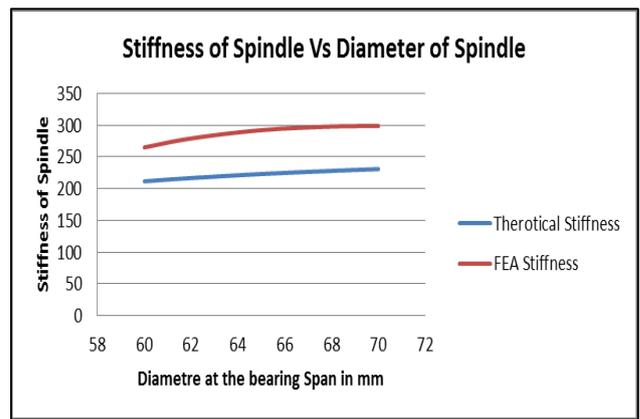


Fig. 11: Stiffness at the spindle nose for different Spindle diameter.

Overhang length in mm	Theoretical		Ansys	
	Deflection at spindle nose μm	Stiffness $\text{N}/\mu\text{m}$	Deflection at spindle nose μm	Stiffness $\text{N}/\mu\text{m}$
55	13.43	230.93	10.38	298.84
58	13.99	221.64	10.98	282.51
60	14.38	215.69	10.99	282.28
65	15.38	201.62	12.14	255.51
70	16.44	288.64	12.83	241.77

Table 4: Comparison of Theoretical & FEA values for deflection and stiffness at the spindle nose when the overhang length of spindle varies from 55 mm to 70 mm for the bearing span of 173mm and diameter 70mm

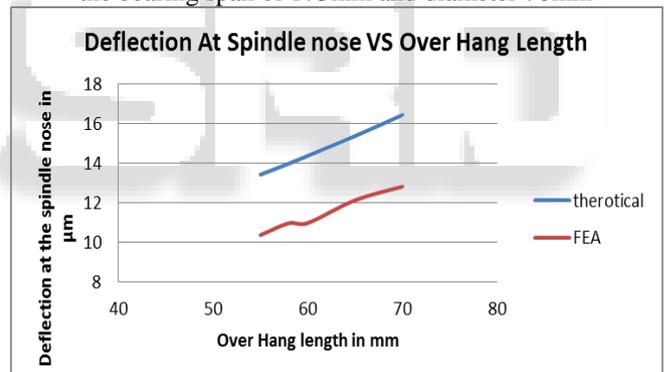


Fig. 11: Deflection at the spindle nose for different Overhang length.

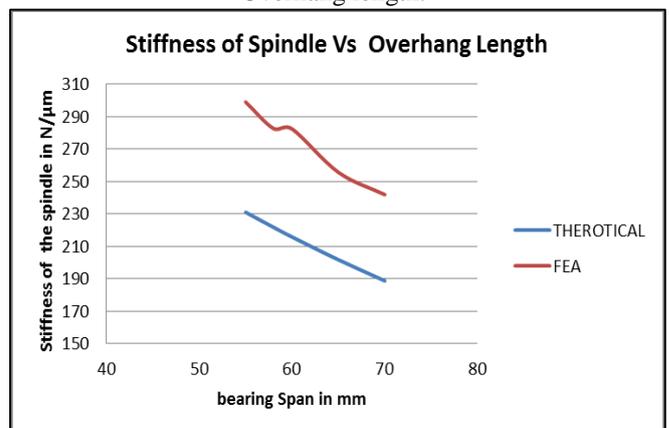


Fig. 12: Stiffness at the spindle nose for different Overhang length.

VI. CONCLUSION

The diameter of the VMC spindle between the bearings has more influence on the rigidity as is evident from the results. This diameter could be varied to the extent of a maximum of 70 mm from the practical considerations of the bearing speeds. At this diameter the stiffness of the VMC spindle has a value of around 230.93N/ μm and the deflection of the spindle nose based on FEA analysis is around 10.38 μm .

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