Journal of Material Science and Mechanical Engineering (JMSME)
Print ISSN: 2393-9095; Online ISSN: 2393-9109; Volume 2, Number 2; January-March, 2015 pp. 153-157

http://www.krishisanskriti.org/jmsme.html

A Review on Design and Analysis of Machine Tool Spindle

Shivaraj S. Vadgeri[1] and S.R. Patil[2]

[1]PG Student, Mechanical Design Engineering AISSMS College of Engineering, Pune-01
Savitribai Phule Pune University, Pune Maharashtra, India
[2]Mechanical Engineering Department AISSMS College of Engineering, Pune-01
Savitribai Phule Pune University, Pune Maharashtra, India
E-mail: [1]shivrich73r@gmail.com, [2]srpatil@aissmscoe.com

Abstract—*This paper describes a review on Design and Analysis of machine tool spindle.Machine tool spindle is the most important mechanical component in removing metal during machining operations. Spindle is a rotating axis of the machine and machine tool spindle includes front and rear bearings to support. The stiffness of the spindle directly affectson machining productivity and finish quality of the work pieces. Machine tool spindles lead to unstable chatter vibrations, cutting forces and uneven tensions in the belt and pulleys. This paper also includes the literature on static and fatigue analysis of spindle by considering different forces acting on the machine tool spindle during the turning operation. Generally during the lathe turning operation, forces acting on the spindle are cutting forces, tension in the belt and reactions due to bearing support to spindle.Cutting Forces generated during turning operation can be determined by experimentally using dynamometer for different tool geometry and cutting parameters.From static analysis stress and deformation of the spindle will be obtained. The purpose of this paper is to determine the life of the spindle and factor of safety by fatigue analysis.*

Keywords: *Spindle, Spindle Design, Bearings, Cutting Forces, Static and Fatigue analysis.*

1. INTRODUCTION

Machine tool spindle is the most important mechanical component in removing metal during machining operations. The structural dynamics of spindle are evaluated at the tool tip since it directly affects the material removing rate [13]. Spindle is a rotating axis of the machine, which frequently used has a shaft at its heart. The shaft itself is called spindle. Machine tool spindles lead to unstable chatter vibrations, cutting forces and uneven tensions in the belt and pulleys [12]. This paper presents static and fatigue analysis by considering cutting forces and tensions in the belt and pulleys.

Depending on the machining processes, the tool is fixed in the tool post and the work piece is held on the chuck of a typical lathe structure. The relative motion is achieved by the movements parallel to the three spatial axes. This can be achieved by the axial movements are along the screws, rack and pinion arrangements, linear guide ways and bearings etc. The machine is made up of heavy steel material and iron parts.The spindle of the machine is hollow[13].

Requirements of spindle are spindle should rotate with high degree of accuracy, spindle unit must have high dynamic stiffness and damping, spindle unit must have high static stiffness, wear resistance of mating surface should be as high as possible, spindle bearing should be selected in such a way that the initial accuracy of the unit should be maintained during the service life of the machine tool. For design optimization of spindle cutting forces are plays very important role.

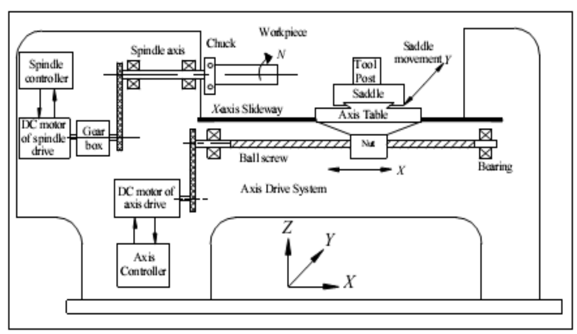

Fig. 1: Block diagram of lathe machine [13].

The main components of the lathe machine are illustrated in Fig. 1. The lathe spindle drive generates a rotary motion to the work piece. The X-axis drive system is used to develop a longitudinal motion of the table over the slide-ways. DC motor connected to a gearbox, which transfers the motion to the spindle shaft using a pulley and belt mechanism.

2. FORCES ACTING ON A MACHINE TOOL SPINDLE

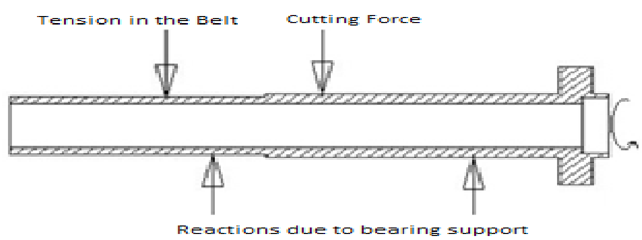

Fig. 2: Loading condition of spindle[12].

Above Fig. shows the forces acting on the lathe spindle during the turning operation, these forces are cutting force, tension in the belt, torque and reactions due to front and rear bearing support. Out of the forces cutting forces are plays very important role, which may vary as the tool cutting tool geometry and cutting parameters vary. Some of the important parameters are depth of cut, cutting speed, and tool geometry such as rake angle, approach angle, entering angle, type of insert and nose radius of insert etc. Tension in the belt is mainly depends on power of the driving mechanism. And this power depends on cutting forces. The purpose of this paper is to provide a vision for determine the life of the spindle and factor of safety for these force conditions.

3. LITERATURE SURVEY

Literature survey plays an imported part in formulating any work. There are many papers available for the analysis of spindle of which few are selected based on the relevance of the statement of this paper. Based on these research papers, a different methodology will be chosen which is suitable for analysis of spindle. The referred papers are explained in brief as below.

Osamu Maeda*et.al*[1] discussed an Expert spindle design system strategy which is based on the efficient utilization of the laws of machine design, dynamics and metal cutting mechanics. The configuration of the spindle is based on the specification of the work piece material, necessary cutting conditions and commonly used tools on the machine tool. The spindle drive mechanism, driving motor, bearing type and spindle shaft dimensions were selected based on the required applications. They iteratively find out the Frequency Response Functions (FRF) of the spindle at the tool tip using the Finite Element Method (FEM).This work predicted the cutting operation at the required speed and depth of cut for different flutes of cutters. The arrangement of bearings was optimized using Sequential Quadratic Programming (SQP). Fig. 3 shows the design variables for bearing locations.

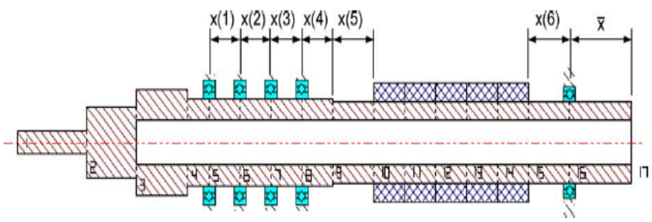

Fig. 3: Design variables for bearing locations[1].

Chi-Wei Lin *et.al*[2]discussed that Development of high speed spindle technology is critical to the implementation of High speed machining (HSM). As Compared to the conventional spindles, motorized spindles are equipped with a built-in motors for good power transmission but the built in motors produces large amount of heat into the spindle system as well as extra mass to the spindle shaft, thus it affect to the dynamic behavior of the spindle. The author presents an integrated model with experimental validation and sensitivity analysis for studying various thermo mechanical dynamic spindle behaviors at high speeds and the fallowing effects are observed that is the bearing preload effects on bearing stiffness, and overall spindle dynamics, high speed rotational effects. The results of this paper shows that a motorized spindle softens at high speed because of the centrifugal effect on the spindle shaft.

Dr. S. Shivakumar *et.al*[3] discussed the Design and analysis of lathe spindle in which alloy steel material was used for the spindle. Two bearings were supported by spindle with different spans. Bearings consist of balls with the certain amount of stiffness, which acts as cushioning effect to the spindle so they considered the spring in the Ansys for the analysis and also carried out static analysis and dynamic analysis of a spindle supported by the front and rear bearing. Bearing stiffness value was calculated by an iteration procedure and using numerical relations life of bearings was calculated.

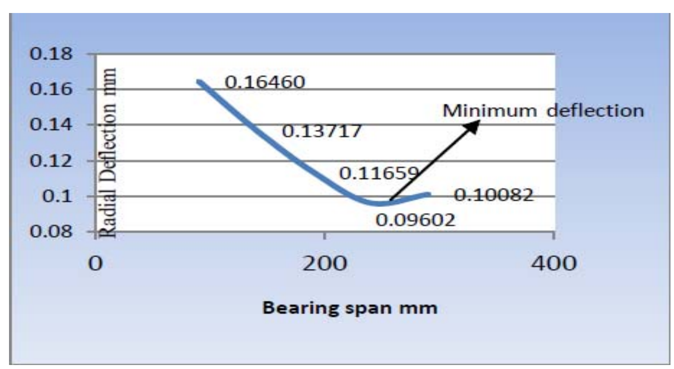

Fig. 4: Graph of bearing span v/s radial deflection[3].

It can be decided from above graph that the optimum bearing span having length 240 mm has got minimum deflection.

Tobias Maier *et.al*[4] discussed modeling of the thermo mechanical process effects on machine tool structures, in machine tools thermally induced deviations are key issues specially when considering the actual trends of high performance and dry cutting. The interactions between the cutting process and the machine tool structure are significant boundary conditions for the numerical prediction of the thermo mechanical machine behavior. This paper presents an approach for the atomistic modeling of process effects, it includes process of heat, cutting forces and increased load on feed and main drives. Author provided an empiric data for the relation between cutting forces and active drive power.

A.Ertuk *et.al*[5] discussed the Effect analysis of bearing and interface dynamics on tool point FRF for chatter stability in machine tools by using new analytical model for spindle tool assemblies. It is observed that the bearing dynamics is controlled by rigid body modes of the assembly, where as the first mode is affected by spindle holder interface dynamics and second mode that is elastic mode is affected by holder tool interface dynamics. Individual bearing and interface translational stiffness and damping values control the natural frequency and the peak of their relevant modes respectively. From this paper it is concluded that rotational contact parameters do not affect the resulting FRF considerably. In this paper, the analytical method was presented for modeling spindle–holder–tool assemblies and predicted the tool point FRF. By using this model, the effects of bearing and interface dynamics on the tool point FRF were studied.

Tugrul Ozel, Taylan Altan[6]presented paper titled Process simulation using finite element method prediction of cutting forces, tool stresses and temperatures in high speed flat end milling. End milling of die mold steels is a highly demanding operation because of stresses and temperatures generated on the cutting tool due to high hardness of work piece. Modeling and simulation of cutting processes have ability for selecting optimum conditions and improving cutting tool designs, especially in an application such as high-speed milling. The main objective of this study was to develop a methodology for simulating and predicting chip flow, cutting process in flat end milling, operation cutting forces, temperatures and tool stresses using finite element analysis (FEA). It was used in the application for machining of P-20 mold steel with 30 HRC hardness by using the commercially available software DEFORM-2D.

Mr. Sahil, Mr. Jiten Saini[7]has written a paper on Static, fatigue and modal analysis of connecting rod under different loading conditions. Connecting rod is an important link between crankshaft and piston, and its primary function is to convert reciprocating motion into rotary motion of crankshaft. Connecting rod is subjected to many stresses than any other Engine components. In this paper static and modal analysis was performed on the connecting rod and the S-N approach by modified Goodman criterion for predicting fatigue life of the connecting rods is presented. The model was created using Solid modeling software-Solidworks2013. Further author conducted finite element analysis using Ansys14 Workbench to determine the von-mises stresses and strains, fatigue life and modal frequencies under different loading conditions.

R. A. Gujar, S. V. Bhaskar [8]presented paper on Shaft design under fatigue loading by using modified Goodman method. In this paper, shaft was used in an inertia dynamometer rotated at 1000 rpm. Considering the different parameters like torque acting on a shaft, forces it helps to calculate the stresses induced. With the help of FEA stress analysis carried out and the results which were obtained from FEA compared with the theoretical values. Consider the stress concentration factor to find the fatigue life.

Wojciech Stachurski, Stanis law Mideraet.al [9] discussed the effect of processing conditions on the value of the cutting force (*Fc*), during straight turning operation. The process is based on equations in the form of power polynomials which were obtained from the results of experimental tests. The tests were conducted while turning C45 carbon steel metal with and without the use of cutting fluid. Here cutting forces were determined by using three-component piezoelectric dynamometer. Fig. 5 shows the influence of cutting parameters on cutting force.

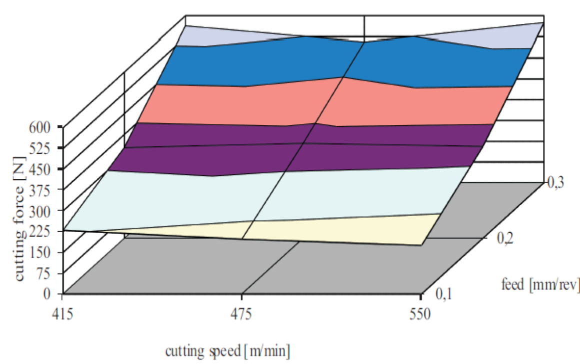

Fig. 5: Influence of cutting parameters (f, Vc) on the cutting force[9].

Haci Saglam, Suleyman Yaldiz*et.al* [10] presented paper on the effect of tool geometry and cutting speed on main cutting force and tool tip temperature. In this paper, the effects of rake angle and entering angle in the tool geometry and cutting speed on cutting force components and the temperature generated on the tool tip in turning operation were investigated. The data used for the investigation were derived from experiments conducted on a CNC lathe. During the tests, the depth of cut and feed rate were kept constant. They found that rake angle was effective on all the cutting force components, while cutting speed was effective on the tool tip temperature. They got average deviation between experimental measured and calculated force results were found as 0.26%.

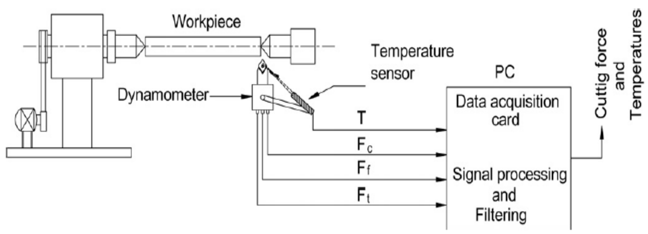

Fig. 6: Experimental setup to determine cutting forces and tool tip temperature[10].

Haci Saglam, Faruk Unsacar*et.al* [11] presented a paper titled investigation of the effect of rake angle and approaching angle on main cutting force and tool tip temperature. This author also done the same work as [10] and same experiment setup was used, this paper differs in selection of parameters during turning operation. They considered effect of rake angle and approaching angle on cutting forces and tool tip temperature. They got average deviation between experimental measured and calculated force results were found as 0.37%. Here author has an empirical approach to calculate cutting main force. The cutting forces were assumed to be linearly proportional to the uncut chip area A_c. The relationship between main cutting force F_c and uncut chip area A_c and specific cutting stress k_s is expressed by Kienzleas

$$F_c = A_c k_s$$

Where, $F_c$is the main cutting force in N, A_c is the chip crosssection in $mm^2$and $k_s$is the specific cutting force in N/mm^2.

4. DISCUSSION

From this literature review it has been found that cutting forces generated during the turning operation can be determined experimentally by using different tool geometry and cutting parameters such as cutting speed, depth of cut and feed rate. By considering these cutting forces, power required for operation can be calculated and so as tension in the belt. Reactions due to bearing support, cutting forces and tension in the belt applied on the machine tool spindle to perform static and fatigue analysis.

5. CONCLUSION

The topic of this study focus on the reviews of static and fatigue analysis of machine tool spindle during the turning process. By the results obtained from this review it is found that:

- The configuration of the spindle is based on the specification of the work piece material, required cutting conditions and commonly used tools on the machine tool.
- A motorized spindle will soften at high speed because of the centrifugal effect on the machine tool spindle shaft.
- It was found out that the optimum bearing span to support the spindle is having length 240 mm and has got minimum deflection.
- During the cutting force measurement, it was found that rake angle was effective on all the cutting force components, while cutting speed was effective on the tool tip temperature.
- It was observed that all cutting forces were increased when the feed rates were increased. Optimum machining condition was obtained at rake angle = 0^0, approaching angle = 75^0.
- Cutting forces during turning operation can be measured experimentally and analytically by using empirical relations, at this cutting force condition analysis of machine tool spindle can be done.

REFERENCES

[1] Osamu Maeda, Yuzhong Cao, Yusuf Altintas "Expert Spindle Design system ",*International Journal of Machine Tool and Manufacturer 45* ,2005, pp. 537-548.

[2] Chi-Wei Lin, Jay F Tu, Jou Kamman "An integrated thermo mechanical dynamic model to characterize motorized machine tool spindles during very high speed rotation", *International Journal of Machine Tool and Manufacturer 43*, 2003, pp.1035-1050.

[3] Dr. S. Shivakumar, Dr.Anupama N Kallol, Vishwanath Khadakbhavi, "analysis of lathe spindle using ansys", *International Journal of Scientific & Engineering Research*, Vol 4, September-2013, ISSN 2229-5518.

[4] Tobias Maier, Michael F. Zaeh, "Modelling of the Thermo mechanical Process Effects on Machine Tool Structures", *3rd CIRP Conference on Process Machine Interactions, Procedia CIRP 4*, 2012, pp. 73-78.

[5] A.Erturk, H.N Ozguven, "Effect Analysis of bearing and interface dynamics on tool point FRF for chatter stability in machine tools using a new analytical model for spindle tool assemblies"*International Journal of Machine Tool and Manufacturer 47*, 2007, pp. 23-32.

[6] Tugrul Ozel, Taylan Altan, "Process simulation using finite element method prediction of cutting forces, tool stresses and temperatures in high speed flat end milling", *International Journal of Machine Tools & Manufacture*, 2000, pp.713–738.

[7] Mr. Sahil, Mr. Jiten Saini, "Static, Fatigue and Modal Analysis of Connecting Rod under Different Loading Conditions",*IJESRT*,2013, ISSN. 2277-9655.

[8] R. A. Gujar, S. V. Bhaskar "Shaft Design under Fatigue Loading By Using Modified Goodman Method", *IJERA*, Vol.3, Jul-Aug 2013, pp. 1061-1066.

[9] Wojciech Stachurski, Stanis law Midera, "Determination of Mathematical Formulae for the Cutting Force *FC* during the Turning of C45 Steel", *Mechanics and Mechanical Engineering* , Vol. 16, No. 2 ,2012, pp.73–79.

[10] Haci Saglam, Suleyman Yaldiz, “The effect of tool geometry and cutting speed on main cutting force and tool tip temperature”, *Materials and Design 28*, 2007, pp.101–111.
[11] Haci Saglam, Faruk Unsacar, Suleyman Yaldiz, “Investigation of the effect of rake angle and approaching angle on main cutting force and tool tip temperature”, *International Journal of Machine Tools & Manufacture 46* ,2006, pp.132–141.
[12] Santosh Arali,V.V.Kulkarni, “Analysis of CNC lathe spindle for maximum force condition and bearing life”, *International journal of Innovative research in advance Engineering*,Vol.1, 2014, ISSN:2349-2163.
[13] Osama Maeda, “Expert Spindle Design system”, *the faculty of graduate studies Mechanical Engineering, Kobe University, Japan*, August 2003.