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Design, Analysis and Testing of Spindle for high speed CNC Lathe Machine

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ABSTRACT: This report presents an expert CNC spindle design system strategy which is based on the efficient utilization of past design experience, the laws of machine design, dynamics and metal cutting mechanics. The configuration of the spindle is decided from the specifications of the workpiece material, desired cutting conditions, and most common tools used on the machine tool. The spindle drive mechanism, drive motor, bearing types, and spindle shaft dimensions are selected based on the target applications. The structural dynamics of the spindle are automatically optimized by distributing the bearings along the spindle shaft. Based on maximum cutting force incurred the analysis will be carried out. The main objective is to carry out the static analysis of spindle structure for maximum cutting force condition and predicting life of bearings. From static analysis, stress and deformation of the spindle can be found.

KEYWORDS: CNC, Spindle, Bearings, Maximum Cutting Forces, Static analysis.

I. INTRODUCTION

The spindle is the main mechanical component in machining centres. The static and dynamic stiffness of the spindle directly affect the machining productivity and finish quality of the workpieces. The structural properties of the spindle depend on the dimensions of the shaft, motor, tool holder, bearings, and the design configuration of the overall spindle assembly. The bearing arrangements are determined by the cutting operation type, and the required cutting force and life of bearings.

The main aim of machine tool design is to achieve long-term precision and high cutting productivity, which directly influence the operating costs of the machine. However, increases in productivity are very often limited by chatter occurring in the machine – tool – workpiece system. The type of cutting operation and the tool employed determine which part of the system will be excited and which will begin to vibrate with the highest amplitude.

The performance analysis of spindle system of machine tools based on finite element analysis software includes the following steps: creating finite element model, identifying constraints and imposing load, solving the model and analysing the output result. In finite element analysis, for different models, analysis types and analysis methods, the appropriate type of unit should be selected. It is necessary to take both the accuracy of the calculation and the cost together with the time of the calculation into account. The accuracy of finite element analysis result is closely related with the density of divided meshes. The more the mesh density is, the more the calculation accuracy is, but it also takes higher calculation cost. When the mesh density reaches certain extent, further increased mesh density will not lead to the improvement of the accuracy of analysis result but to doubled calculation cost. To make the mesh density achieve the best results, it is necessary to go through trial and error.[2]

A high speed spindle that will be used in a metal cutting machine tool must be designed to provide the required performance features. The major performance features include:

i. Desired Spindle Power.
ii. Maximum Spindle Load - Axial and Radial
iii. Maximum Spindle Speed Allowed
iv. Tooling Style, Size and Capacity for ATC
v. Belt Driven or Integral Motor-Spindle Design
vi. High running accuracy
vii. Great stiffness
viii. Low and even running temperature
ix. Minimum need of maintenance

.

Paper is organized as follows. Section II describes Design and Analysis of Spindle Assembly.Section III presents experimental results showing results of images . Finally, Section IV presents conclusion

II. DESIGN AND ANALYSIS OF SPINDLE ASSEMBLY

Cutting forces calculations:

Benefits of knowing and purpose of determining cutting forces-

The aspects of the cutting forces concerned:

- Magnitude of the cutting forces and their components.
- Directions and locations of action of those forces.
- Pattern of the forces: static and / or dynamic.

Knowing or determination of the cutting forces facilitate or are required for:

- Estimation of cutting power consumption, which also enables selection of the power source(s) during design of the machine tools.
- Structural design of the machine - fixture - tool system.
- Evaluation of role of the various machining parameters (process - V_c, f_o, t, tool - material andgeometry, environment - cutting fluid) on cutting forces.
- Study of behavior and machinability characterization of the work materials.
- Condition monitoring of the cutting tools and machine tools.

Cutting force (F_c) for turning operation is calculated by,

$$F_c = Ks.f.d$$

Where,

$K_s$is specific cutting resistance

$f$is feed rate (mm/rev)

d = Depth of cut (mm)

Results for Turning Operations:

For V_C=180 m/min $\sigma = 75\ kgf/mm^2$

Feed (mm/rev)	Radial Force (N)	Axial Force (N)	Torque (Nm)	Power (kW)
0.15	2207.25	1274.34	77.254	6.62

Shaft calculations:

Shaft is a common and important machine element. It is a rotating member, in general, has a circular cross-section and is used to transmit power. The shaft may be hollow or solid. The shaft is supported on bearings and it rotates a set of gears or pulleys for the purpose of power transmission. The shaft is generally acted upon by bending moment, torsion and axial force. Design of shaft primarily involves in determining stresses at critical point in the shaft that is arising due to aforementioned loading. Other two similar forms of a shaft are axle and spindle.

Fig.1 Spindle Shaft

Shaft material= 60C4

Here, d= diameter of shaft

D_o = outer diameter of shaft

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D_i = inner diameter of shaft
M_B= Moment at B
M_A= Moment at A
Pulley force acts at point P and the maximum cutting force acts at L

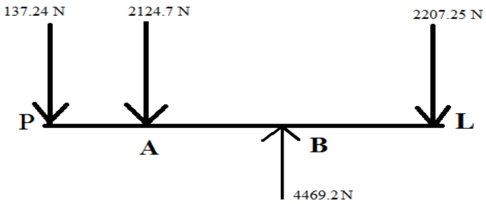

Fig.2 Free Body Diagram

Shaft diameter:-

$$d^3 = \frac{16}{\pi \times \zeta max} \sqrt{(K_b M_B)^2 + (K_t M_t)^2}$$

From above equation spindle diameter is 30mm

Bearing Calculations:
Bearing calculations were carried out as per the standard procedure using SKF Catalogue for spindle diameters starting from 30mm. The bearing of diameter 55mm satisfies the conditions of speed and strength. But for structural requirement we selected the bearing of diameter 60mm of BTM series, which is Super Precision Angular Contact Thrust Ball Bearing.
Bearing Designation- BTM 60 BTN9/ P4CDB

Deflection Calculation:
Maximum deflection of spindle was calculated using Macaulay's method.
Maximum deflection of spindle is 0.003 mm.

CAD Modelling
Creo Parametric 2.0 was used for 3D modeling of spindle assembly.

Fig.3 Spindle assembly

The figure above shows the complete assembly of the spindle. The modelling of every part of the assembly was done by keeping in mind all the design aspects and considerations.

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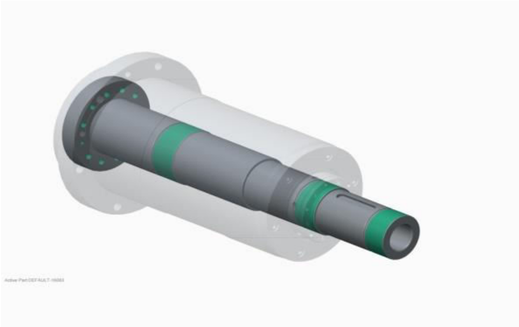

Fig.4 Spindle

The spindle or shaft which is the integral part of the assembly as seen above was modelled with a lot of attention to every detail.
The spindle was fully optimised in order to make it strong enough to withstand the forces acting on it.

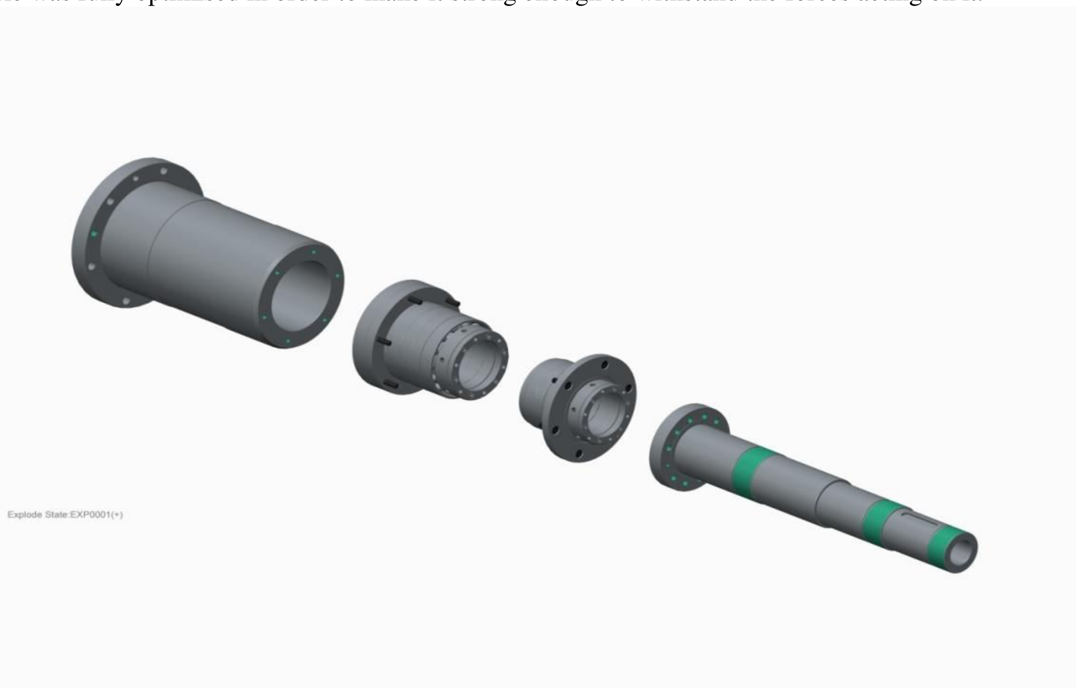

Fig.4Exploded view of spindle assembly

The above figure shows the exploded view of the assembly which consists of spindle, bearings, housing and other parts.

Analysis

The following results were obtained after carrying out the static analysis of the spindle using Ansys.[7]

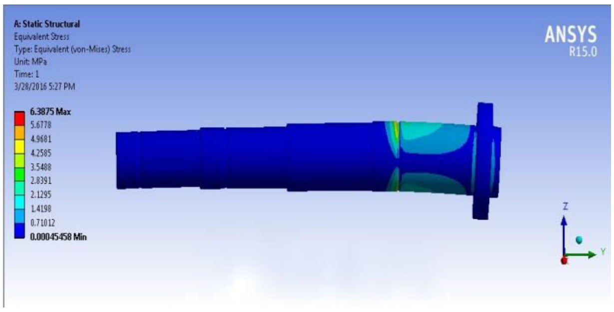

Fig.5Stress distribution

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The fig. depicts the stresses induced in the spindle after applying the forces at the appropriate points.

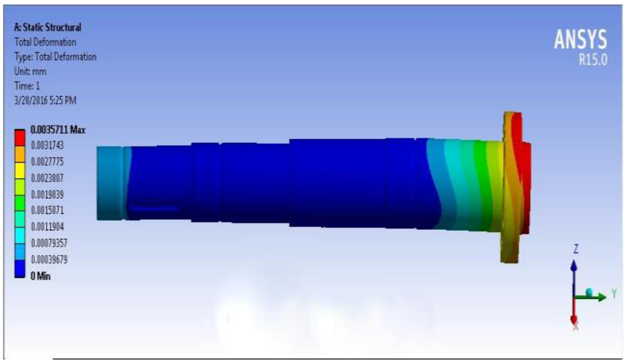

Fig.6 Total Deformation

The figure shows the maximum defoermation taking place after action of forces.

Result Table

Object Name	*Total Deformation*	*Equivalent Elastic Strain*	*Equivalent Stress*
State	Solved		
Scope			
Scoping Method	Geometry Selection		
Geometry	All Bodies		
Definition			
Type	Total Deformation	Equivalent Elastic Strain	Equivalent (von-Mises) Stress
By	Time		
Display Time	Last		
Calculate Time History	Yes		
Identifier			
Suppressed	No		
Results			
Minimum	0. mm	2.9101e-009 mm/mm	4.5458e-004 MPa
Maximum	3.5711e-003 mm	3.7768e-005 mm/mm	6.3875 MPa
Minimum Value Over Time			
Minimum	0. mm	2.9101e-009 mm/mm	4.5458e-004 MPa
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III. TESTING

Run-out (microns)	Noise level(dB)	Temperature(°C)	Speed (rpm)
1	87.4	44.4	6175
1	76.24	41.5	4500
1	65.4	38.6	3000
1	50.25	37.6	1500

The testing was successfully carried out on the spindle assembly considering the parameters mentioned in the table above. The spindle was mounted on the test rig and necessary clamping was provided as shown in photograph. The spindle was driven by a motor whose maximum speed was 2580 rpm and the ratio of motor pulley to the spindle pulley was 2.25. The designed speed of 6000 rpm was successfully reached. The run-out measured for the designed speed of 6000 rpm, on the inner surface of the spindle to check its circularity was 1 microns. Noise was measured for the same speed using noise level meter and it was 87.4 dB which is permissible and safe for the operator. After running the spindle at about 6175 rpm for about an hour, the temperature rise was measured using thermocouple. The rise in the temperature was 44.4°C which is safe for its operation.

a) Test Rig

b) Run-out Measurement

c) Noise Level Measurement

The above tests a, b and c were carried out on the spindle and the results were recorded. The results are mentioned in the above table.

IV. CONCLUSION

Project presents the Design of CNC lathe Spindle in which the design considerations were studied from various reference papers and the forces acting on the CNC spindle while various machining processes were calculated by referring to the theory of metal cutting. The torque and power required from the motor are calculated from the forces achieved.

This design data was used in the FEA of the spindle. The results obtained from multiple iterations of FEA were safe according to the design considerations and were used to manufacture the spindle.

The CNC Lathe Spindles used in the industry at present are having a low cycle time and spindle speed. The Spindle designed here has a high spindle speed which aims at reducing the cycle time efficiently and increases productivity.
High speed spindle allows the use of cemented carbide tools which cannot be used at low spindle speeds. Machining can be done at higher cutting speeds and feeds which would eventually reduce machining time and enhances the productivity.
The surface finish is also improved by using high speed spindle and cemented carbide tools as compared to low speed spindle machine

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