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STATIC AND DYNAMIC ANALYSIS OF SPINDLE OF A CNC MACHINING CENTRE

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ABSTRACT

In any machining centre the spindle forms a vital component as it supports, holds and rotates the cutting tool. As such, the modeling and analysis of this part of the machining center is crucial for successfully designing and subsequently manufacturing them. The dimensional accuracy and surface finish of the work piece in machining operation are of particular interest and the manner in which the machine tool spindle influences these parameters is of great concern to the user. In the present work, an attempt has been made to study the static and dynamic behavior of spindle of a CNC horizontal machining centre using finite element analysis. The geometric model of spindle is created in UNIGRAPHICS software as per the drawing. This model is imported to HYPERMESH through IGES format and FEA model with converged mesh is developed. To this FEA model various loading conditions like static and dynamic analysis and operating conditions are applied using ANSYS to obtain the deflections and stresses. The deflection curves and mode shapes for various types of gear and cutting forces in its different speed ranges are presented. The outcome of this work can be used for CNC machining centers.

KEYWORDS: Finite Element Analysis, Spindle, Static Analysis, Dynamic Analysis

INTRODUCTION

Machine tool must meet the ever increasing demand of modern industry for faster speeds, greater accuracy, smoother finish and production rate at minimum cost. Such considerations are influenced by machine tools spindles with its support bearings. The machine tool builder, spindle maker and bearing manufacturer are all of the great importance in achieving these goals. The machine tool spindle is expertly designed to meet above requirements [1]. Quality, accuracy of machine and rate of production depends largely on the bearing that supports the spindle. It is important to know the operating history of spindle which includes: Operating speed, Type of lubrication, Estimating the work loads, Torque, Spindle material. The spindle is one of the most essential parts of the machine tools. It receives the cutting tool or work piece and rotates. Spindle is usually made of case hardened Ni-Cr steel. The configurations of spindle depend on how it holds the cutting tools, the fit of drive element and type of its bearings. Spindles are usually made hollow to contain draw bar and decrease the spindle weight. The spindle noses of general purpose machines are standardized. Machine tools must be able to produce consistently work pieces of desired accuracy within close limits. It is not therefore sufficient for a spindle to be able to rotate at varying speeds but also to do so without vibration or irregular running that will cause in accuracies in the work pieces. Also, to maintain the accuracy under the influence of cutting forces and the moving weight of the machine tool elements, the structure, particularly spindle must possess high static and dynamic stiffness .For this condition the spindle should be rigid enough to withstand the various forces acting on it [2].

Spindle Structure

The structure of the spindle is shown in Figure 1. In order to meet the requirements of high-speed processing, the standardized tool interface HSK (Hohlschaftkegel) is placed at the spindles front end. The spindle is supported by two sets of angular contact ball bearings which are XCB series super precision spindle bearings produced by the FAG in Germany. For the sake of reducing the axial run out of the spindle and improving the axial stiffness of the spindle, the two sets of angular contact ball bearings are installed in the back to back [3].

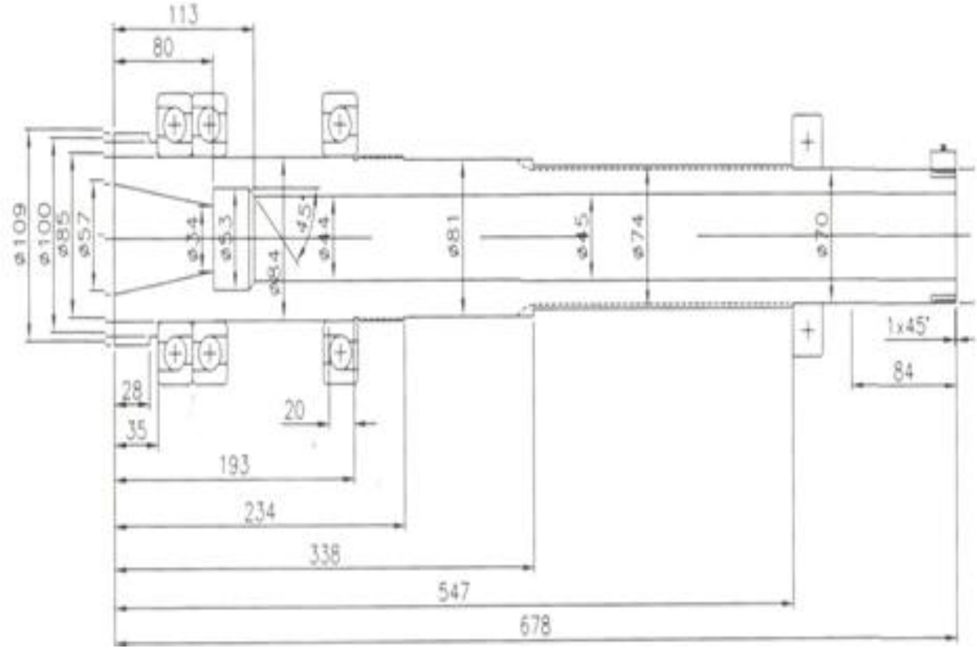

Figure 1: Spindle Structure [3]

LITERATURE REVIEW

Al-Shareef et al. [4] developed a quasi-static method of analyzing machine tool spindles. Their analysis takes the amplitude of the dynamic forces and applies them to a static model of the spindle-bearing system. For the static analysis the deflection contribution of the spindleshaft. Wang and Chang [5] simulated a spindle-bearing system with a finite-element model; then compared it to the experimental results. Radial and tilting springs and dashpots were considered in angular contact spindle ball bearings. The FEM model showed that additional tilting characteristics have a significant effect on higher-order vibration modes. and the deflection contribution of the spindle support bearings are superimposed to obtain the total deflection of the system. Zhao Haitao et.al.[6] in their paper proposed a method for computing the coefficient of convection heat transfer of the spindle surface by referencing the theory on computing the coefficient of convection heat transfer of a flat plate when air flows along it. Yuzhong Cao and Altintas [7] in their paper presented a general, integrated model of the spindle bearing and machine tool system, consisting of a rotating shaft, tool holder, angular contact ball bearings, housing, and the machine tool mounting. Chi-Wei Lin. et al. [8] in their paper presented an integrated model with experimental validation and sensitivity analysis for studying various thermo-mechanical-dynamic spindle behaviors at high speeds.

FINITE ELEMENT MODEL OF SPINDLE

In fact, the spindle can be modeled as a shaft, supported at each end by a set of bearings. This representation has been used in Figure 2. Below shows a diagram of the simplified representation of the spindle system considered here in. The Equivalent dynamic model of a spindle is established by ANSYS and UNIGRAPHICS commercial software.

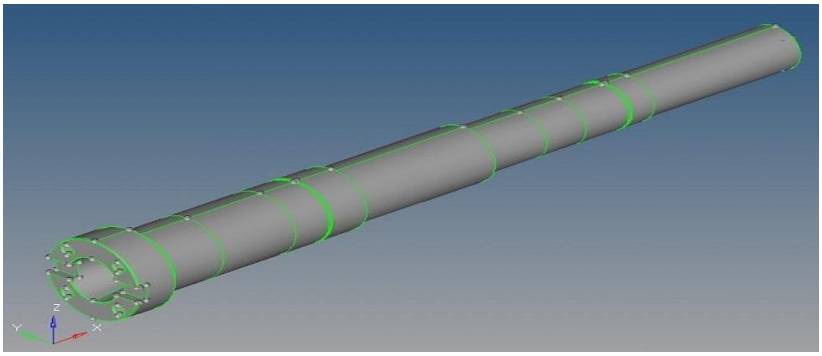

Figure 2: F. E. Model Used in Static Analysis

COMBIN14 element which can be applied to simulate springs and dampers is provided in UNIGRAPHICS and ANSYS commercial software. The Solid 187 element which is a tetrahedral element with ten nodes is used to simulate spindle part. The finite element model is shown in Figure 3 below. The material of the spindle is EN24.

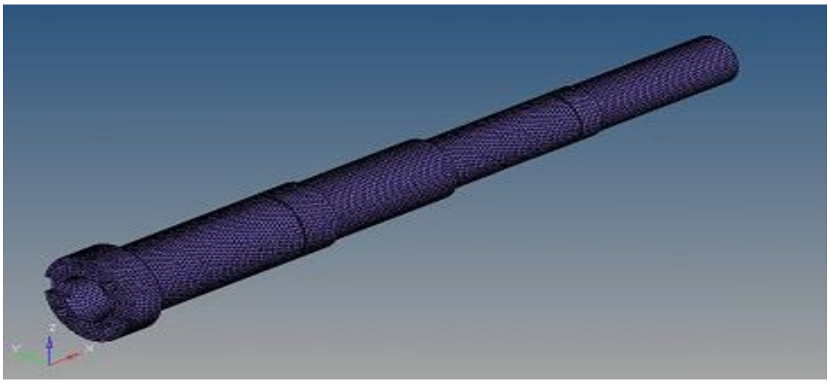

Figure 3: The F. E. Model Applied in Hypermesh

RESULTS & DISCUSSIONS

Static Analysis

In static analysis we find the deflection of spindle at spindle nose and bearing that support the spindle for various loads applied on the spindle is shown in figure 4 & figure 5 below. For the static analysis, first the assembled stiffness matrix is to be formed. Then the vector of forces acting at the nodal points is to formed in which the forces and moments are assembled at their appropriate locations. In the engineering, there are few cases of machine failure owing to the fatigue fracture of the spindle, but there are many cases of machine failure as a result of spindle's large deformation self-excited vibration under the action of the cutting force. Therefore, the static design of the milling spindle unit is mainly related with the static stiffness of the spindle which is referred to spindle stiffness. The spindle stiffness is closely related with the load capacity and vibration resistance, which is an important performance index of the motorized spindle.

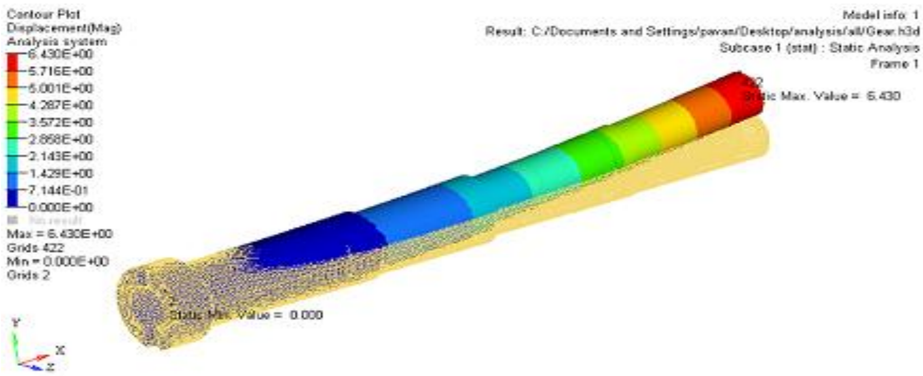

Figure 4: Static Analysis of Spindle with 200mm Cutter in Low Range

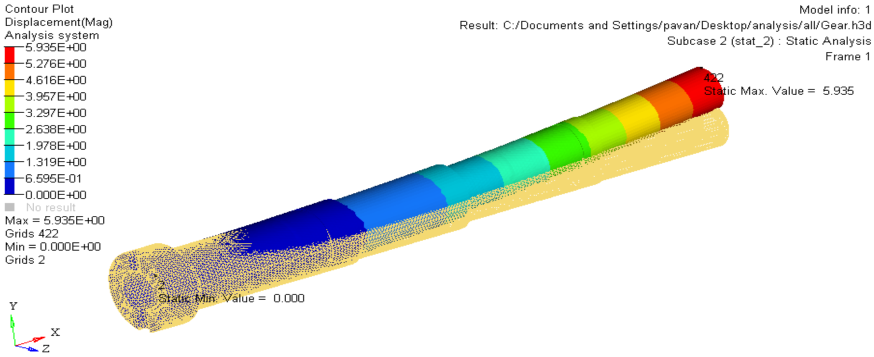

Figure 5: Static Analysis of Spindle with 160mm Cutter in Low Range

STIFFNESS OF THE SPINDLE

The spindle stiffness includes the axial and bending stiffness. In normal operating condition, the bending stiffness is more important than axial stiffness. The bending stiffness (*K*) of the spindle unit is defined as follows: if the front part of the spindle generates unit radial displacement δ, the force required to be imposed on the direction of the displacement is Fr

$$K = Fr/\delta \ (N/\mu m)$$

The static stiffness of spindle can be calculated, whose result is max stiffness is 49.8kgf/microns and minimum of 18.6 kgf/microns are compared. According to ISO standards a minimum stiffness of 10 kgf/microns is required.

DYNAMIC ANALYSIS

Finite element dynamic calculations require generation of individual element stiffness. The spindle of cnc horizontal machining centre has been analyzed and found the first three natural frequency by using FEM package ANALYSIS and UNIGRAPHICS. The mode shapes & corresponding to natural frequency of spindle with various types of cutter are shown in figure 6 & 7 below. Harmonic analysis of spindle for various frequencies is shown in figure 7 & 8. The natural frequencies of system are calculated from the given equation.

$$F = NM/60 \quad Hz$$

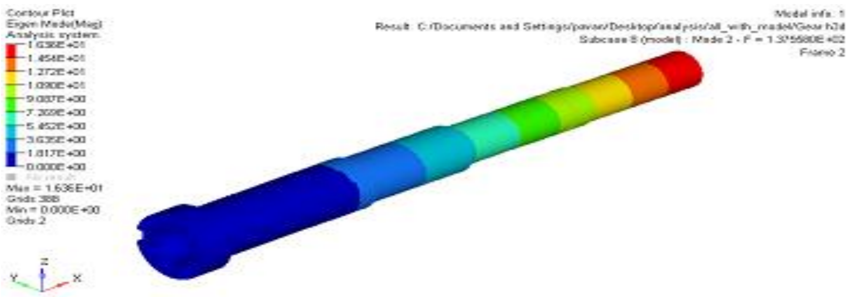

Figure 6: First Modal Shape of Spindle with 200mm Cutter

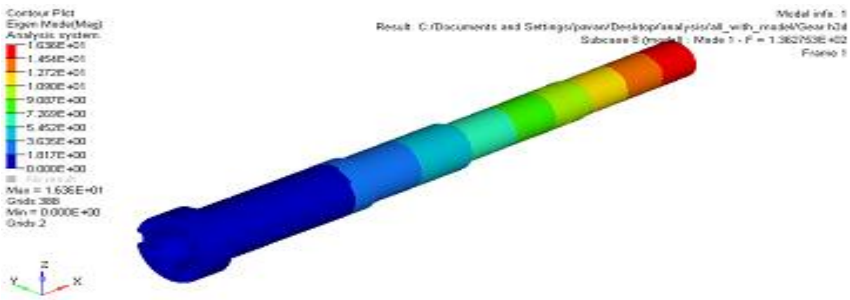

Figure 6: First Modal Shape of Spindle with 160mm Cutter

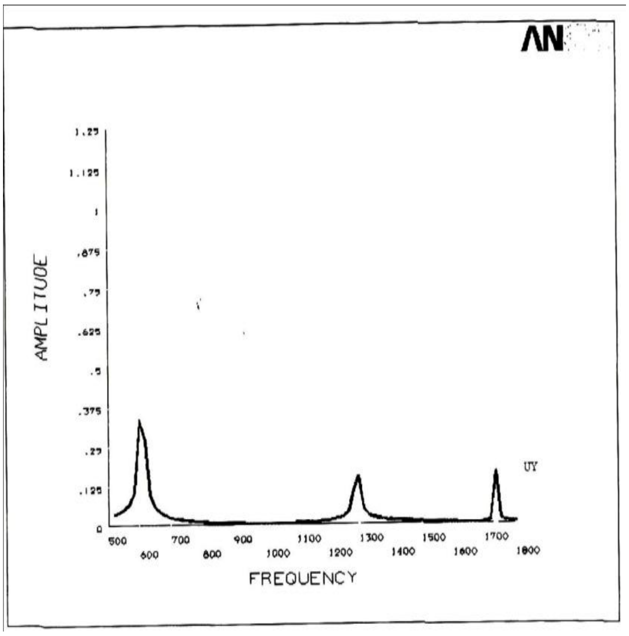

Figure 7: Harmonic Analysis of Spindle with 200mm Cutter

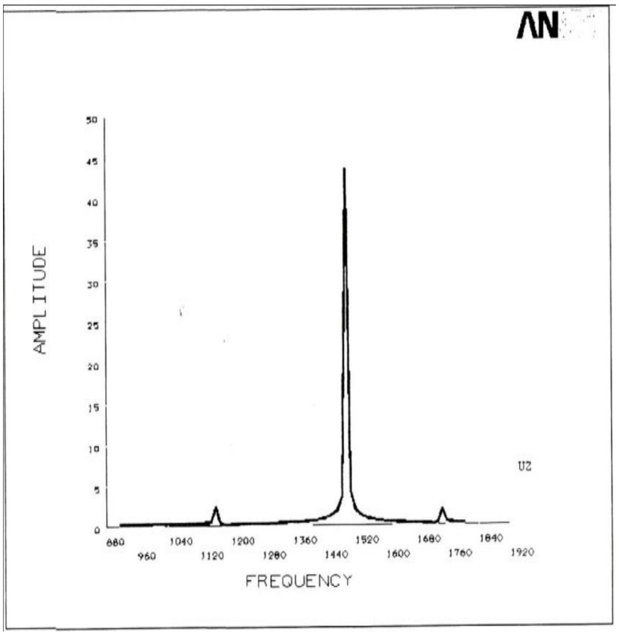

Figure 8: Harmonic Analysis of Spindle with 125mm Cutter

CONCLUSIONS

In the present work FEA analysis has been carried out at the static and dynamic conditions of spindle for different cutting and gear forces in its different speed ranges. A spindle is designed based on stiffness criteria. Sufficient design margins are required to adopt in the stiffness of spindle design. Structural analysis is carried out using Finite Element Method (FEM) to evaluate stiffness. As the proposed design is stiffness based design displacement is calculated for each configuration against the load. The max deflection of 64.3 microns is computed at cutting point which is 40mm away from spindle nose when 63 gear teeth acts likes a driver for 125 diameter cutter. The dynamic response of spindle is studied from which the natural frequencies and corresponding mode shapes are compared. The natural frequencies obtained from the analysis 604Hz, 1158Hz, 1290Hz. are found to be far away from the system natural frequencies. Hence the system is safe from dynamic point of view also.

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