Use FEM to Investigate the Static and Dynamic Nature of the Lathe Spindle (Shaft) under Conventional Machining

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Abstract - The lathe spindle is regarded as an integral component that makes it possible to extract material during the machining process It has been absolute deformation, equivalent stresses and strains Used for determining the required content. The minimum values of total deformation and deformation are indicated by AISI 1045 carbon steel and equivalent strain in both situations. Similar stress patterns are found in all materials with a maximum stress role. It's also the same for different magnitudes. At the spindle face area and minimum, the value of full total deformation is observed. For all materials, in the spindle bearing part. The full equivalent stress of the spindle is caused in the spindle housing area and at the tail-end minimum. At the spindle housing area and minimum at the tail end, the highest equivalent strain is also observed Domain area. The rotational velocity has less impact on the production of spindle stresses and strains. Campbell with the aid of for choosing the best applicable material, critical velocity is also found in the diagram. The present work therefore tackles the static and the static, dynamic lathe spindle analysis for various materials.

The purpose of this paper is to research the static and dynamic behavior of the lathe spindle (shaft) under FEM to determine different stresses and strains under the same boundary conditions during turning operation. It is also important to note changes in deformation, stress and strain of von-Mises with changes in cutting force and RPM.

Key Words: FEM.; Static structural analysis; Equivalent stress; Lathe spindle; Total deformation; Cutting force;…

1. INTRODUCTION

This paper provides static and fatigue analysis by considering cutting forces and stresses in the belt and pulleys. The tool is fixed inthe tool post depending on the machining processes, and the working piece is kept on the chuck of a standard lathe structure. The motions parallel to the three spatial axes accomplish the relative motion. The axial motions along the screws, rack and pinion arrangements, linear guide paths and bearings, etc., will accomplish this. The computer consists of heavy steel materials and iron components. The machine's spindle is hollow [4]. Spindle specifications are that the spindle must rotate with a high degree of precision, that the spindle unit must have high dynamic stiffness and damping, that the spindle unit must have high static stiffness, that the wear resistance of the mating surface should be as high as possible.

For an electric motor, there are various ways of moving a spindle. Machine tool spindles are now defined as external or internal (built-in) driven on the basis of the electric motor-to spindle link and assembly process. Outside the spindle housing, externally driven spindles have their engine and the power is transmitted by belt, gear or chain systems. Internally driven spindles, on the other hand, have developed electric motors coupled with the spindle shaft within the structure. Depending on the building materials of their rotor and the alignment of the magnetic field in the motor and the rotation of the rotor, internal spindle motors may be either asynchronous or synchronous. Rotors are made of electrical steel in asynchronous engines and aluminum or copper conductive bars. The magnetic field created in the stator produces a flow of voltage and current through these laminations and causes the magnetic field to rotate the rotor. However, between the rotations of the magnetic field and the rotor, there is often a phase difference that makes asynchronous motors less precise and less effective. On the other hand, synchronous motors with their permanent magnet rotors have improved power and thermal characteristics to avoid slip effects and phase differences. In the last decade, asynchronous motors had major price advantages and ease of production. Synchronous motors, however, are becoming more competitive in price and are increasingly favored because of their major advantages in efficiency. To increase the performance and competitiveness of their machines, many machine tool builders are now switching to synchronous motors in their spindles.

1.2 BASIC SPINDLE STRUCTURE

The majority of machine tool spindles sold today are internal driven and do not require a mechanical transmission unit such as gears, belt, etc, unlike external driven spindles. Their efficiency and performance make them preferred over spindles driven externally. For cost and dimensional reasons, spindles with an inner bearing diameter greater than Ø150 mm are usually externally driven.

A lathe spindle essentially consists of the following major components,

1. Spindle housing
2. Spindle bearings
3. Spindle engine
4. Shaft of spindle

2. LITERATURE SURVEY

The object of this paper is to research the static and dynamic behavior of the lathe spindle (shaft) under turning operation using FEM to determine different stresses and strains under the same boundary conditions. It is also important to note changes in deformation, stress and strain of von-Mises with changes in cutting force and RPM.

Kang et al. [5] referred earlier to integrated computer-aided techniques for the design of spindle-bearing systems for machine tools. The effect of design parameters on the static and dynamic performance of spindle-bearing systems was investigated in this study in order to
implement the required design modifications. In the design of machine tool spindles, they also proposed a number of sample cases with a set of procedures.

Yu [6] in order to study the mechanical characteristics of the lathe spindle, considered finite element analysis. The ANSYS package was used to perform spindle analysis for the C7620 lathe. The findings revealed the phenomenon of resonance with the speed and rotation of the spindle.

Lin et al. [7] for the dynamic study of the spindle bearing method defined FEM as an effective approach. They reviewed significant studies on different dynamic models and the design of machine tool spindle bearing systems. Suggestions were made after careful review of the models.

Recently, Yang et al. [8] studied the static and dynamic characteristics of CK61125 CNC lathe bed using FEM. Theresults showed the values of maximum stress, strain and deformation. Results also focused on the resonance frequency obtained.

Also, Feng et al. [9] analyzed the static and dynamic characteristics of a spindle system in a camshaft grinding machine. The study proved that the design of the spindle system fully meets the production requirements with increased performance.

Osamu Maedaet.al [10]an expert spindle design system strategy was addressed, which is focused on the successful use of machine design rules, dynamics and metal cutting
mechanics. The spindle configuration is based on the specification of the material of the work piece, the appropriate cutting conditions and the tools commonly used on the machine tool.

Chi-Wei Lin et.al [11] the development of high-speed spindle technology is crucial for highspeed machining to be introduced (HSM). Motorized spindles are fitted with built-in motors for good power transmission compared to traditional spindles, but the built-in motors generate a significant amount of heat into the spindle system as well as additional mass to the spindle shaft, thereby affecting the spindle's dynamic behavior.

Dr. S. Shiva Kumar *et.al* [12]it presented the lathe spindle design and study in which alloy steel material was used for the spindle. The spindle was supported by two bearings with separate lengths. Bearings consist of balls with a certain amount of stiffness that serve as a cushioning

2.1 CONCLUSION OF LITRATURE REVIEW

It has been known from this literature review that cutting Forces produced during the operation of the turning can be experimentally calculated by using various geometry methods, Parameters of cutting and cutting, such as cutting speed, cutting depth, and Feed frequency. By taking these cutting forces into consideration, power needed It can be measured for service and thus as tension in the belt. Reactions attributable to support for bearings, cutting forces and stress inthe belt was put on the machine tool spindle for static output And study of fatigue.

2.2 OBJECTIVE OF WORK

Over the last two centuries, Lathe is the primitive system and oldest machine tool that has grown to be one of the most simple and flexible devices with large variants to be used in all manufacturing stores. The spindle is a rotational component of machines used in various spheres of industrial activity, especially in the process of metal cutting. The components are held together by a spindle shaft, identical to the housing, and placed on the spindle bearings.

3. MATERIAL AND METHOD

The torque spindle is regarded as an integral component that makes it possible to extract material during the machining process. The rigidity of the spindle plays an important role in the work piece's productivity and surface finishing. In pulleys and belts, the tool spindle contributes to unbalanced vibration and uneven stress. In the current analysis, a three-dimensional spindle model is being prepared. Four different materials are taken into account, such as AISI 1045 carbon steel, AISI 4140 alloy steel, AISI 304 stainless steel and grey cast iron. Based on FEM, under cutting forces and during rotation, the static and dynamic studies are carried out separately. Modal shapes are obtained from dynamic analysis. IN the ANSYS 15.0 workbench, computer simulation is performed and static structural analysis with varying cutting force and speed is performed. In the identification of the appropriate material, total deformation, equivalent stresses and strains were used. The minimum values of total deformation and equivalent stress are demonstrated by AISI 1045 carbon steel in all situations. In all materials, identical stress patterns are found, with the location of the maximum stress also being the same with varying magnitude.

The rotational velocity has less impact on the production of spindle stresses and strains. Essential velocity is also found for selecting the best applicable material with the aid of the Campbell diagram. The present work therefore explores the static and dynamic lathe spindle studies for various materials.

The properties of the materials which are used is listed in the below table

Table1. Mechanical properties

Material properties AISI 1045	Material properties AISI 1045	Material properties AISI 1045	Material properties AISI 1045	Material properties AISI 1045
Ultimate tensile strength	515 MPa	655 MPa	586 MPa	240 MPa
Yield strength	485 MPa	415 MPa	207 MPa	124MPa
Modulus of Elasticity	200 GPa	198 GPa	193GPa	110 GPa
Shear modulus	80 GPa	80 GPa	86 GPa	42.9 GPa
Poisson's ratio	0.29	0.27	0.30	0.28
Density	7.87 g/cm3	7.85 g/cm3	7.75 g/cm3	7.20 g/cm3
Hardnes, Brinell	170 HB	197 HB	123 HB	120-550 HB

3.1 Modeling and meshing of spindle

In this analysis, a lathe spindle shaft model is expected. The preliminary spindle specification involves angular contact ball bearings with a DBB arrangement mounted on the shaft. "In the ANSYS 15 workbench, the spindle shaft is developed using "build modeler. The shaft is made of a straight steel shaft with an inner diameter of 35 mm and an outer diameter of 65 mm, equivalent to a spindle. 508 mm is the total shaft length. A lathe spindle shaft model is anticipated in this study. Angular touch ball bearings with a DBB configuration mounted on the shaft are involved in the preliminary spindle specification." The spindle shaft is built in the ANSYS 15 workbench using "Modeller to build. The shaft is made of a straight steel shaft similar to a spindle with an inner diameter of 35 mm and an outer diameter of 65 mm. 508 mm is the length of the complete shaft. The shaft is secured and is set by ball bearings at two points. In Fig. 1, a given threedimensional model is shown. Meshing is the most critical component of all computer simulations. By splitting a large structure into tiny grid points, called nodes, meshing is achieved. Elements are connected to the nodes in the chain. Solid elements of the tetrahedral shape geometry permit uniform meshing, but the hexahedral shape provides more detailed results. The mesh geometry is as shown in Fig. 2. Both types of mesh are considered and, after studying the beneficial aspects, hexa mesh is selected. A close view of the mesh elements is also provided for a better knowledge of the grid pattern. Sufficient mesh sizes are obtained based on the performance. The element size is set at 2 mm. At 100, significance is preserved. The angle of span and centre of relevance are maintained as right. The model is made up of 828660 nodes and a total of 205803 elements. In Table 3, the properties of the materials used are described. Varying yield and tensile strength properties of the materials are available. There is a similar Shear Modulus continuum. They are of different elastic moduli as well. Two loads acting on the lathe spindle in the negative direction are on Fy. One load is applied on the spindle end. The other is cutting force during machining tasks. Torque is worked on one end of the spindle. At one end of the spindle, RPM is applied in a clockwise direction. Cylindrical supports are attached to the spindle to limit its radial and axial motion.

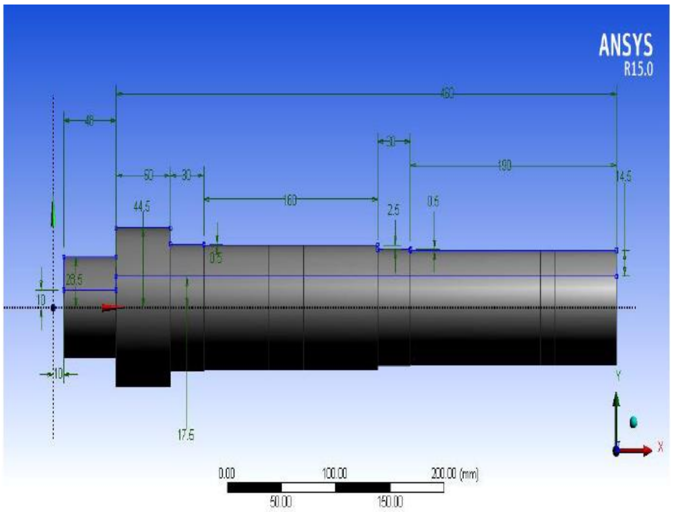

Fig.2 Model of lathe spindle.

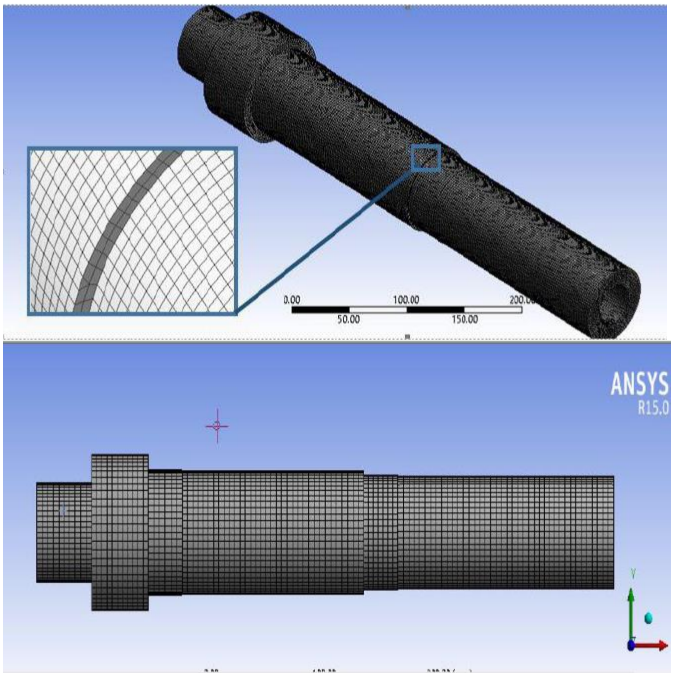

Fig. 3 Initial and final hexahedral mesh of lathe spindle.

4. MODELING AND SIMULATION

Static structure analysis is useful depending on the conditions applied to define and quantify the stress, strain and deformation caused in the lathe spindle. The sum of the three-dimensional displacements in the x, y, and z directions is the complete deformation. When resisting the applied load or force, equal stress or von-Mises stress is used to predict whether a given material will yield or fracture. It is used especially in the study of ductile materials, such as metals.

To specify the condition of strain in solids, equivalent strain is often used. The structural condition of the material developed as a consequence of the previous loading is to be portrayed. Cutting forces on the spindle are produced during machining, both in the axial and lateral directions. The elastic behaviour of both the shaft and bearings defines the resulting lateral deflection of the spindle due to loading. Deformation appears to increase as the cutting force rises. Deformation, stress and pressure are plotted and analyzed in this work.

Table 4 Maximum total deformation (mm) variation with cutting force.

Cutting force (N) AISI 1045	AISI1045 Carbon steel	AISI 4140 alloy steel	AISI 304 stainless steel	Grey cast iron
630	.0017381	.0018196	.0019678	.0033778
685	.0017501	.0018380	.0019896	.0034159
740	.0017622	.0018590	.0020114	.0034539
798	.0017839	.0018805	.0020346	.0034977

4.1 Total deformation with cutting force

Complete deformations under varying cutting forces of different materials are studied. On one end, various cutting forces are applied and the load is applied to the spindle end due to stress in the belt. Table 61 presents the overall deformation for all four components at various cutting forces. With the rise in cutting force, maximum overall deformation is increasing. A gross deformation of 0.0034977 mm in grey cast iron is observed for the cutting force of 798N, and a minimum deformation of 0.0017389 mm in AISI 1045 carbon steel. In both cases, AISI 304 steel has a deformation greater than AISI 4140 steel and less than grey cast iron. AISI 4140 steel also has AISI 1045 carbon steel and AISI 304 steel intermediate prices. Figures 9, 10, 11 and 12 display the distribution of total deformation around the spindle. For the highest cutting power, these contours are often drawn. It is observed that the greatest deformation for all materials occurs at the face region of the spindle and the minimum at the spindle bearing portion. AISI 4140 steel also has AISI 1045 carbon steel and AISI 304 steel intermediate prices. Figures 6.1, 6.2, 6.3 and 6.4 display the distribution of total deformation around the spindle. For the highest cutting power, these contours are often drawn. It is observed that the greatest deformation for all materials occurs at the face region of the spindle and the minimum at the spindle bearing portion.

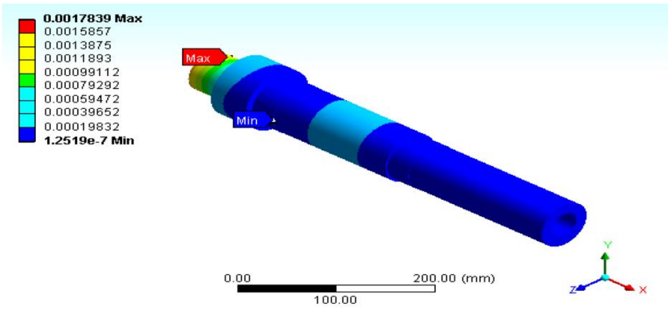

Fig. 4.Total deformation distribution for AISI 1045 steel

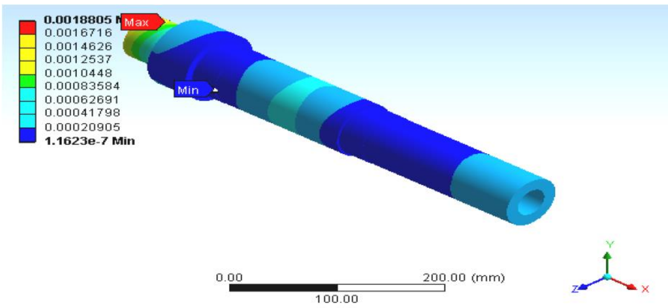

Fig. 5 Total deformation distribution for AISI 4140 alloy steel.

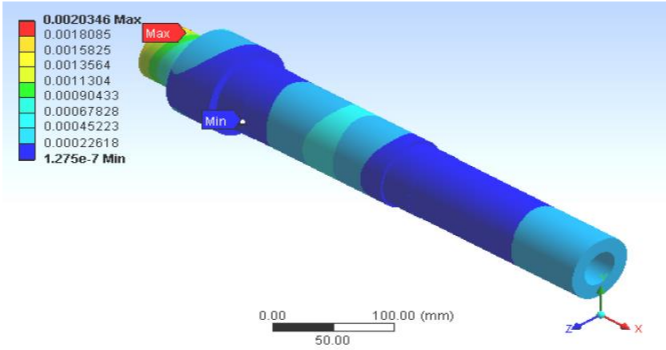

Fig. 6 Total deformation distribution for AISI 304 steel.

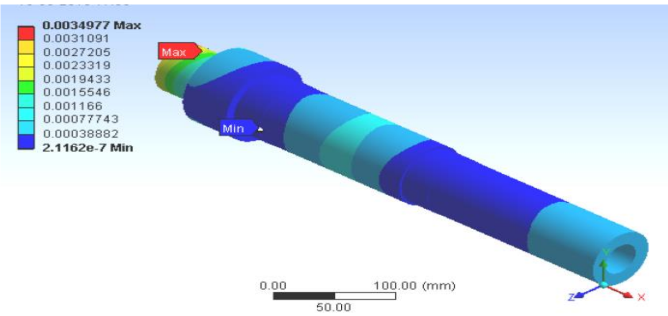

Fig. 7 Total deformation distribution for Grey cast iron.

4.2 Equivalent stress with cutting force

Table 6.2 provides similar alternating stresses for all four materials at various cutting forces. As the cutting force is raised in the spindle, the equivalent tension has also increased. The material is supposed to be secure if the stress value is below material yield power. Maximum equivalent stress observed on grey cast iron of 17,233 MPa and minimum stress observed on AISI 1045 carbon steel of 798 N cutting forces of 17,096 MPa. The low stress values of AISI 1045 carbon steel are among all the materials considered here. In all cases, with the place of maximal stress still being the same with varying severity, a common stress pattern is observed. The contours of the spindle equivalent stress distribution are shown in Figs. 13-16. In AISII, the maximum stress induced. As shown in Fig.13, 1045 carbon steel is 17.096 MPa. As shown in Fig.14, the maximum equivalent stress produced by AISI 4140 alloy steel is 17.155 MPa. As shown in Fig.15, the maximum equivalent stress produced by AISI 304 Stainless Steel is 17.22 MPa. In Grey cast iron, the maximum equivalent stress produced is 17,233 MPa as shown in Fig.16. Maximum equal stress is found at the part of the spindle rotor and minimum at the spindle body closest to the part of the bearing. AISI 1045 carbon steel, which may be attributed to its high yield and ultimate tensile capabilities, displays fewer deformation and stresses. The values also change less with the material shift.

Table 5 Equivalent stress (MPa) with rotational speed.

Cutting force (N) AISI1045	AISI1045 carbon steel	AISI4140 alloy steel	AISI 304 stainless steel	Grey cast iron
630	17.060	17.130	17.183	17.220
685	17.063	17.130	17.192	17.222
740	17.080	17.150	17.201	17.228
798	17.096	17.155	17.220	17.233

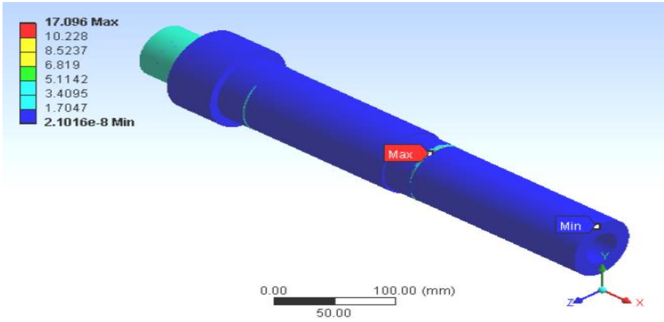

Fig. 8 Equivalent (von-Mises) stress in AISI 1045 carbon steel.

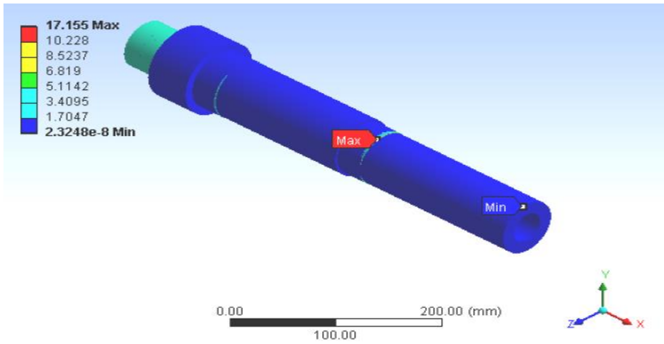

Fig. 9 Equivalent (von-Mises) stress in AISI 4140 alloy steel.

Table 6 Equivalent stress (MPa) with rotational speed.

Cutting force (N) AISI1045	AISI1045 carbon steel	AISI4140 alloy steel	AISI 304 stainless steel	Grey cast iron
1500	17.087	17.141	17.153	17.232
3000	17.122	17.186	17.207	17.266
4500	17.188	17.266	17.282	17.333
6000	17.296	17.395	17.404	17.441

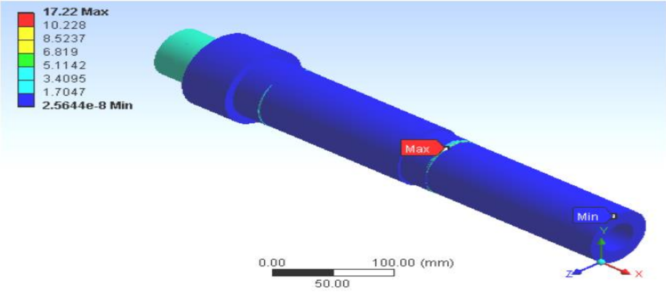

Fig. 10 Equivalent (von-Mises) stress in AISI 304 stainless steel.

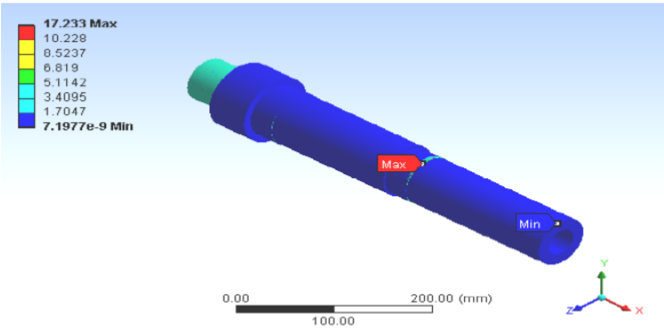

Fig. 11 Equivalent (von Mises) stress in Grey cast iron.

Table 7 Equivalent strain (mm/mm) with rotational speed.

Cutting force (N) AISI1045	AISI1045 carbon steel	AISI4140 alloy steel	AISI 304 stainless steel	Grey cast iron
1500	$8.3364e^{-5}$	$8.5315e^{-5}$	$8.8571e^{-5}$	$1.5672e^{-4}$
3000	$8.3562\ e^{-5}$	$8.5537e^{-5}$	$8.8753e^{-5}$	$1.5703e^{-4}$
4500	$8.3928e^{-5}$	$8.5937e^{-5}$	$8.9095e^{-5}$	$1.5764e^{-4}$
6000	$8.4520e^{-5}$	$8.6577e^{-5}$	$8.9654e^{-5}$	$1.5862e^{-4}$

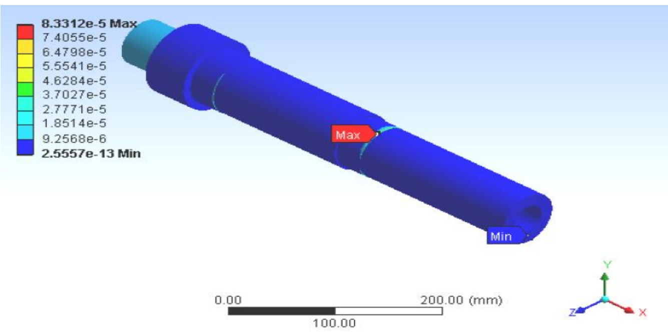

Fig. 12 Equivalent (von-Mises) strain in AISI 1045 carbon steel.

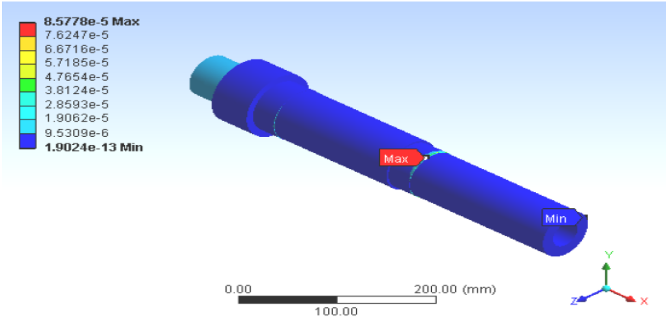

Fig. 13 Equivalent (von-Mises) strain in AISI 4140 alloy steel.

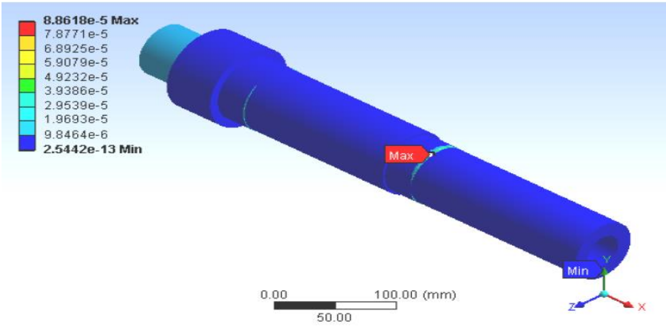

Fig. 14 Equivalent (von-Mises) strain in AISI 304 stainless steel.

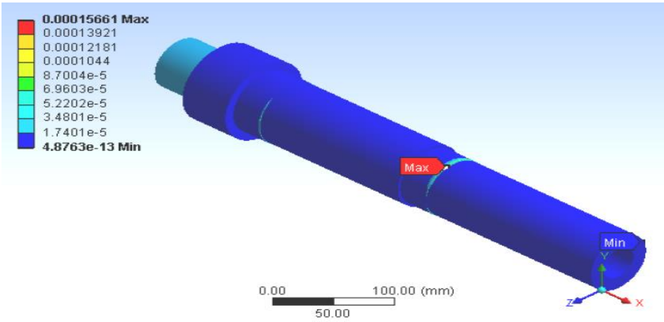

Fig. 15 Equivalent (von-Mises) strain in Grey cast iron.

Table 8 Equivalent strain (mm/mm) with rotational speed.

Cutting force (N) AISI1045	AISI1045 carbon steel	AISI4140 alloy steel	AISI 304 stainless steel	Grey cast iron
630	$8.310e^{-5}$	$8.522e^{-5}$	$8.851e^{-5}$	$1.5632e^{-4}$
685	$8.319e^{-5}$	$8.540e^{-5}$	$8.854e^{-5}$	$1.5641e^{-4}$
740	$8.322e^{-5}$	$8.565e^{-5}$	$8.9095e^{-5}$	$1.5652e^{-4}$
798	$8.331e^{-5}$	$8.577e^{-5}$	$8.861e^{-5}$	$1.5661e^{-4}$

4.5 Equivalent stress and strain with speed

The spindle typically rotates at a speed of 1500 to 6000 rpm. The spindle's stress production is also influenced by rotational speed. Table 5 shows the stress values for each of the four materials at various rotational speeds. There is very little difference in stress, and stresses are rising at a rapid rate. For Grey cast iron, maximum stress production occurs

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at 6000 rpm. For all speed situations, AISI 1045 showed less tension. The effect of speed on the production of stresses in the spindle can be verified. For the rise in speed from There is just a 1% rise in tension from 1500 to 6000 rpm. In addition, as the rotational speed increases, the equivalent strain increases as well. Table 6 shows the strain values for each of the four components at various rotational velocities. The values of strain in the lathe spindle display less variance with rpm, similar to stresses. For all speed situations, AISI 1045 showed less pressure. Grey cast iron shows the most strain growth at 6000 rpm.

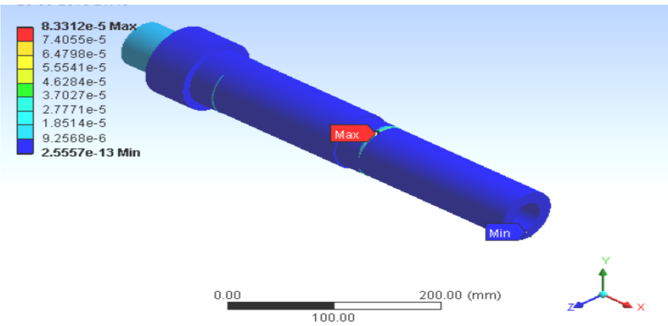

Fig. 16 Equivalent (von-Mises) strain in AISI 1045 carbon steel.

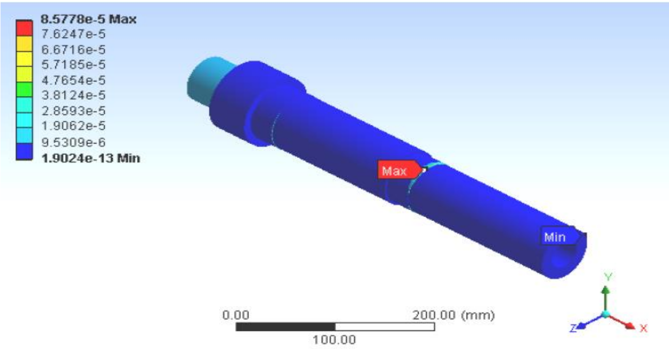

Fig. 17 .Equivalent (von-Mises) strain in AISI 4140 alloy steel.

4.6 Critical speeds and Campbell diagram

The dynamic behaviour of the spindle with various rotational speeds is studied to understand more. Since the working speed range of the spindle is between 0 and 6000 rpm, the critical speeds are supposed to be much higher than this range. In order to find the critical speeds, the study is carried out with several load measures for speeds between 0 to 100000 rpm. With the Campbell diagram, as shown in Fig.21, the natural frequency of the spindle can also be obtained at any working speed within the research speed range carried out. On the Campbell diagram, the essential speeds of the spindle are labelled. Within the working speed range of the spindle, it is found that (0-6000 rpm),the critical speeds stay above 1000 Hz.

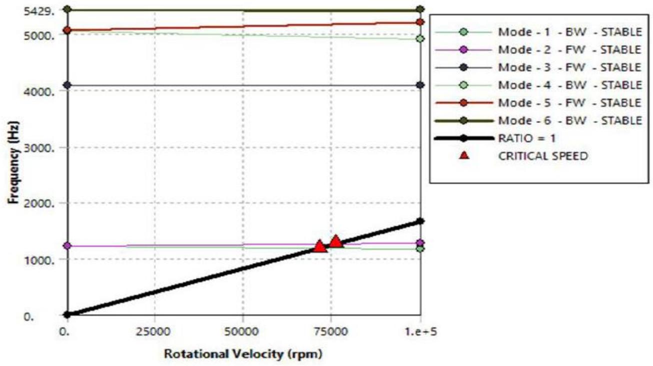

Fig. 18 Campbell diagram of the spindle.

5. CONCLUSIONS AND FUTURE SCOPE

In the present work, a lathe spindle is modelled, and AISI 1045 carbon steel, AISI 4140 alloy steel, AISI 304 stainless steel and grey cast iron are used as spindle materials. The computational model is built with the reference scale using the ANSYS 15.0 workbench and static structural analysis with a varied cutting force is carried out. Equivalent stresses, strains and deformation are examined with the cutting force ranging from 600 to 800 N.

1. Values are tabulated and contours are drawn for the case of the highest power. AISI 1045 carbon steel shows the minimum value of maximum gross deformation in the 630N example, which is 0.0017381 mm.

2. Thus, the overall deformation in grey cast iron is high at a force of 798N (0.0034977 mm), which is not desirable. The maximum equivalent strain of 1.5661e-4 is observed for grey cast iron and the minimum strain of 8.331e-5 is observed for AISI 1045 carbon steel.In grey cast iron, the maximum equivalent stress of 17.233 MPa is observed and the minimum stress of 17.096 MPa in AISI 1045 carbon steel is observed.

3. AISI 4140 alloy steel is lower in stress and deformation than AISI 304 stainless steel. Overall, AISI 1045 carbon steel has shown good efficiency when less stresses and deformations are found in all cases of cutting forces. Changs in the values of stresses and strains are less important with material transition.

4. It is necessary to modify deformation with material modification. The rotational speed also has an effect on the development of stresses and strains from the spindle. In the strain values in the lathe spindle with velocity, equal to stresses, less variation is observed. The vital speeds in the spindle speed range are found to remain above 1000 Hz using the Campbell diagram (0-6000 rpm).

Future Scope:

1. In future the more kind of shapes can be cut in the lathe spindle to see the changes inloaddeflection and stress-deflection curves.
2. Some more kind of simulation software's can be used or if time permits one can also seethe actual simulation of lathe spindle with same boundary conditions and thencomparison of simulation and experimental results can be performed.

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