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Dynamic Performance Analysis of Lathe Spindle Using ANSYS

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Abstract

The lathe spindle is a critical component of machining systems, playing a pivotal role in achieving precision and accuracy in manufacturing processes. This research paper presents a comprehensive investigation into the behavior and performance of lathe spindle components through finite element analysis (FEA) utilizing ANSYS software. The primary objective is to assess the structural integrity and stress distribution in the spindle system under varying operational conditions and design parameters. The study begins by developing a three-dimensional model of a typical lathe spindle, incorporating details of the spindle material and its supporting structure. The geometry and material properties of the spindle, as well as the support mechanism, are precisely defined. This model serves as the basis for a series of simulations and parametric analyses. The FEA simulations are conducted to explore the Von Mises stress distribution in the spindle system during different machining operations. Various loading conditions, such as turning, drilling, and milling, are applied to the spindle to mimic real-world scenarios. The results provide insights into stress concentrations, critical regions, and potential failure points within the spindle components. Furthermore, a parametric study is conducted to evaluate the influence of material properties and support design on spindle performance. Different materials, including various alloys and composite materials, are considered. The study investigates how alterations in material properties affect stress levels and overall structural behavior. Additionally, the design of the spindle support system is analyzed to assess its impact on stress distribution. The findings of this research paper are instrumental for enhancing the design and performance of lathe spindles in machining applications. By gaining a deeper understanding of stress distribution and structural behavior, manufacturers can make informed decisions regarding material selection and spindle support design. This research contributes to the optimization of lathe spindle systems, which directly translates into improved machining precision, reduced downtime, and enhanced productivity.

Keywords: FEA, ANSYS Software, Lathe Spindle

Introduction

For years, lathe machines have been essential to the industrial sector, allowing for the accurate shape and cutting of a broad variety of materials[1]. The lathe spindle is an essential component that is responsible for rotating the workpiece and may be found at the very centre of these machines. The performance of the spindle has a significant impact on the level of accuracy and speed achieved by the lathe's operations. Nevertheless, despite the important nature of their function, lathe spindles are not immune to malfunctions, which can result in a number of undesirable and expensive outcomes, such as production delays, increased maintenance costs, and a reduction in product quality. This study article dives into the diverse world of lathe spindle failures with the intention of illuminating their origins, ramifications, and, most importantly, techniques to prevent these failures. Fig 1 shows Conventional headstock schematic of hydraulic operated CNC lathe.

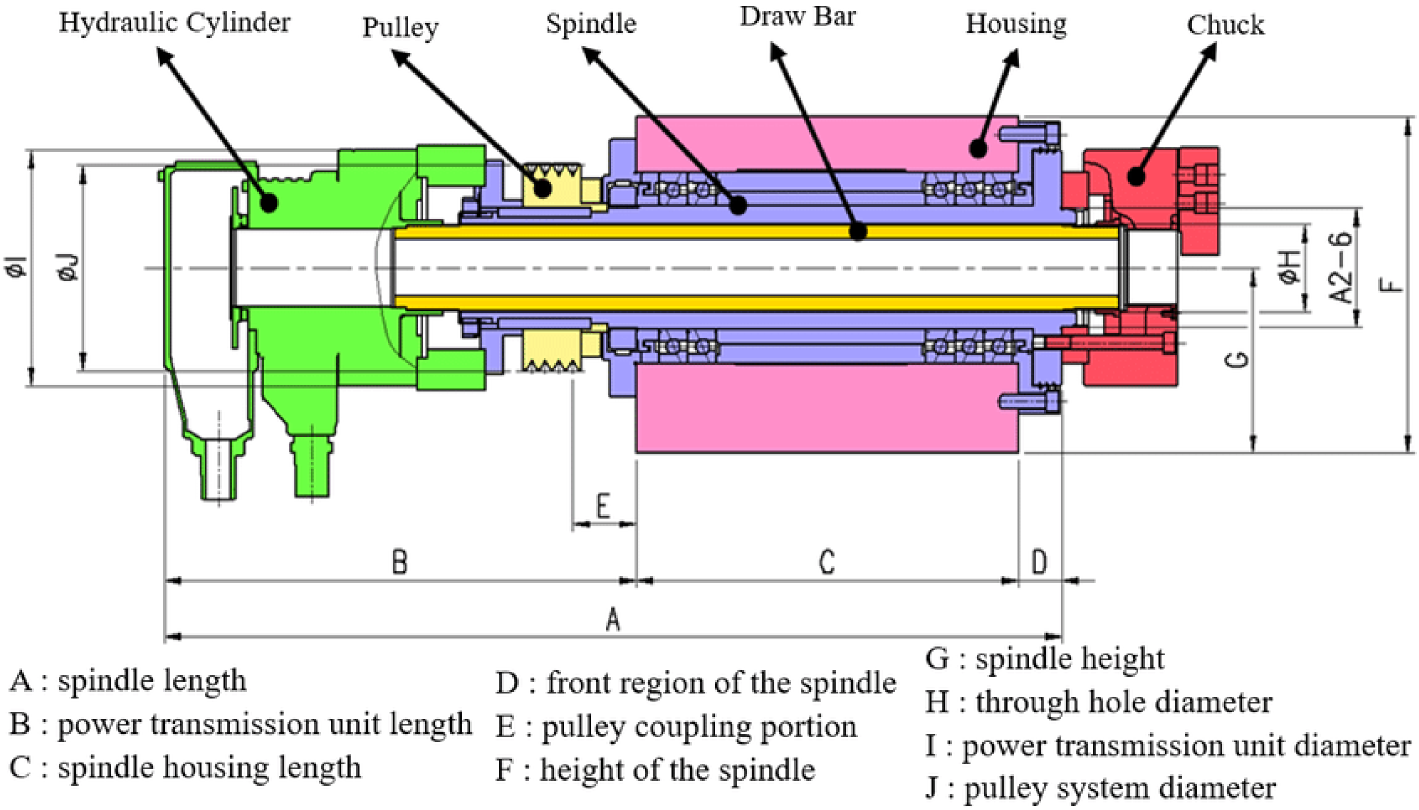


Figure 1: Conventional headstock schematic of hydraulic operated CNC lathe [1]

1. The Importance of Turning Spindles in a Lathe:

Turning machines, and precision lathes in particular, have developed into an essential component of contemporary industry. They are utilised in the manufacturing of a diverse selection of components, ranging from minute watch bits to enormous aerospace components, among other things. When performing machining processes, the lathe spindle, which is in charge of spinning the workpiece, plays an essential role in assuring precision and reproducibility. As a consequence of this, even the slightest interruption or failure in the functioning of the spindle can have significant repercussions for the level of quality, cost, and efficiency of the production processes.

2. The Worrying Prevalence of Lathe Spindle Breakdowns:

Lathe spindles are susceptible to failures that can be ascribed to a variety of circumstances, including mechanical wear, material fatigue, overheating, and inadequate maintenance practises. This is despite the fact that they play an extremely important function. These problems present themselves in a variety of ways, such as abnormally high vibration levels, errors in the dimensions of the workpiece, increased tool wear, and even catastrophic spindle destruction. These kinds of problems not only reduce the overall quality of the products that are produced, but they also result in expensive downtime and increased maintenance costs, which places a significant financial load on the manufacturing industry.

3. The Following are the Reasons Why Lathe Spindles Break:

The purpose of this study article is to explore the reasons behind the failure of lathe spindles in a thorough manner. This article investigates the numerous causes that contribute to the degradation of spindles. These factors include mechanical wear and tear brought on by high rotating speeds and frequent tool changes, fatigue brought on by cyclic loads, overheating brought on by protracted operations, and material flaws. In addition, the role that improper maintenance procedures, or a lack of maintenance procedures, play in spindle failures is scrutinised in great detail. The ultimate objective is to determine the major factors that contribute to spindle failures and to get an in-depth understanding of the processes that underlie these factors.

4. The Consequences of Spindle Breakdowns in the Lathe:

The breakdown of a lathe spindle can have far-reaching effects for the machine. These malfunctions not only throw a wrench into the production process, but they also have significant repercussions for both the economy and operations. Delays in production can lead to missed deadlines, which in turn can lead to dissatisfied customers. In addition, the necessity for emergency repairs or spindle replacements causes a rise in the expenditures associated with maintenance. The low quality of the machined components that can be traced back to problems with the spindle can lead to the recall of products and reputational harm for manufacturing companies. As a result, it is absolutely necessary to investigate the repercussions of these failures in order to emphasise how urgently we need to build efficient mitigation solutions.

5. Preventative Measures to Take in the Event of Lathe Spindle Breakdowns:

In light of the serious nature of lathe spindle failures, it is very necessary to study several solutions that might successfully alleviate these concerns. This research study will investigate a variety of potential solutions, such as upgraded spindle materials and design, improved maintenance practises, the inclusion of predictive maintenance procedures, and the utilisation of sophisticated monitoring and diagnostic technologies. This research intends to give manufacturers with useful insights into reducing spindle failures and preserving the efficiency and precision of lathe operations by examining these tactics and providing them with an overview of their effectiveness.

In conclusion, the examination of lathe spindle failures is an important endeavour because it addresses a recurrent problem in the industrial industry that has far-reaching repercussions. This study work aims to contribute to the increase of lathe spindle reliability and the overall efficiency of manufacturing processes by deciphering the reasons and effects of spindle failures and researching potential mitigation techniques.

Literature review

Numerous model-based dynamic analysis works have been carried out to explore the frequency response property of the spindlebearing-housing system. The findings of these studies have been published. The outstanding model that Jorgensen and Shin [2] devised to forecast the natural frequency of the high speed spindle-bearing was accomplished via the use of the static effect coefficient approach. The conclusion drawn from the experiment was that the adjunctive tool mass has a significant impact on the natural frequency of the first order.

The virtual simulation of the spindle-bearing-housing system was carried out by Cao and Altintas [3-5] using a finite element model that was based on the Timoshenko beam theory. The frequency response function (FRF) that was developed showed a high conformity with the curves that were observed, and the results of their study successfully anticipated the milling spindle dynamics. In addition, Erturk et al. [6] used the receptance coupling model to systematically evaluate the effect of the interface dynamic parameter of bearing-shaft, shaftholder, and holder-tool on the tool point FRF, and they found that the bearing-shaft dynamic parameter had the greatest influence.

Kato et al. [7] investigated the natural frequency as well as the mode shape of the spindle system that was made by carbon fibre reinforced plastic. However, in order to investigate the joint interface properties, only the linear spring was integrated into the model. Jiang and Zheng [8] utilised the Jones-Harris bearing model and coupled Hook-Jeeves search approach to analyse the spindle dynamic stiffness and critical speed via the transfer matrix method. This was done so that they could fill in the gap that had been left by previous researchers. It appears that the spindle dynamic stiffness and critical speed are not considerably impacted by the centrifugal force and gyroscopic moment of the bearing when the rotating speed is less than 20 thousand revolutions per minute; however, when the rotating speed is greater than 20 thousand revolutions per minute, both the dynamic stiffness and critical speed dramatically drop.

With the use of a TFLEX CAD 3D system, Yurkevich [9] created a three-dimensional model of the spindle head found in an MK3002 lathe. Additionally, a depiction of the temperature conditions that take place during spindle rotation was incorporated into this model. There are four alternative techniques of attachment that might be utilised for the housing of the spindle head. Each of these methods has their advantages and disadvantages. It has been found that there is one particular way of connecting that will yield the greatest outcomes.

Zhang et al. [10] created a five-degree-of-freedom dynamic model for an aerostatic bearing spindle to describe its translational and tilting motions and analyse the spindle vibration's effects on surface topography under different UPDT cutting processes. The spindle's translational and tilting responses were described by this model. It was shown that spindle processes occur at the axial, radial, and twin tilting natural frequencies. It was also found that when cutting moves from the outside to the core of the machined surface, the spindle's tilting movements eventually decrease and the axial translational motion dominates surface topography. Experiment results proved this.

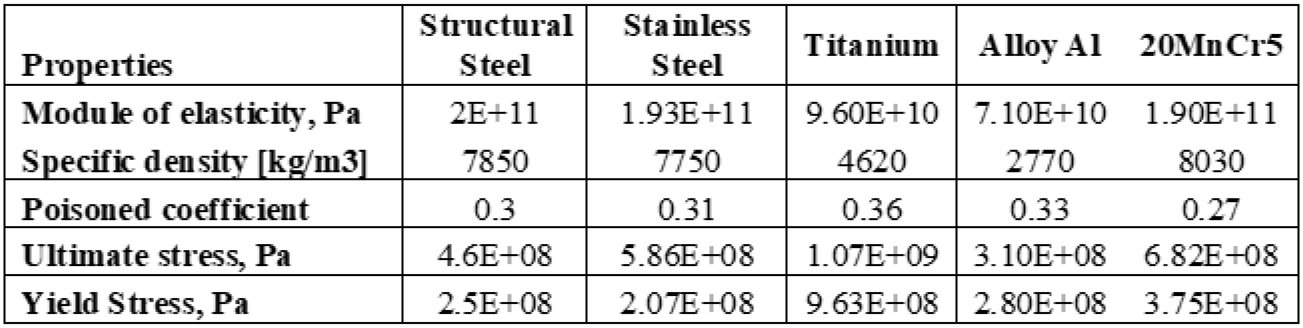
Jingxiang et al. 2017 examined machine tool spindle acceleration energy. Developing a computational model that saves money on the machine and system levels is helpful. Proper spindle and machine tool selection can reduce ESA, the y found. The team found that lowering acceleration time and developing lighter designs reduced ESA.

Juan et al. 2017 studied the vibrational qualities of an imbalanced motorised Spindle System response using finite elements. The steady-state imbalance response of the motorised spindle system experiences harmonic vibrations with the same frequency as the rotational speed when speed and damping are maintained constant. The vibration amplitude is proportional to the system's unbalanced mass. The finding provided crucial theoretical direction for motorised spindle system active balancing and vibration control research.

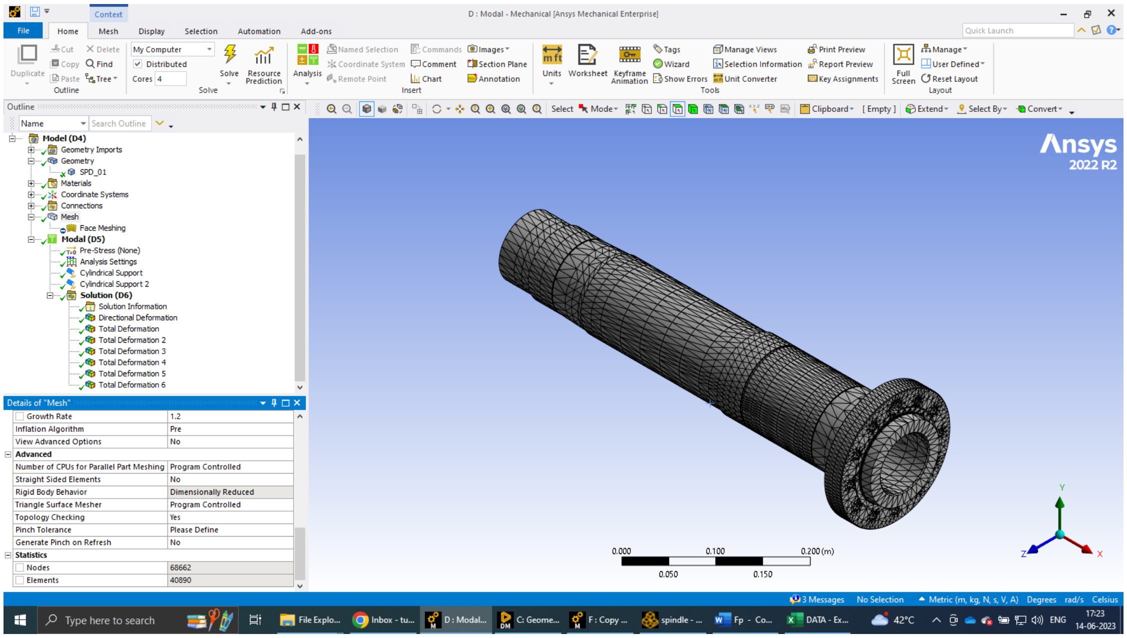
Methodology

Using the finite element method (FEM) tool known as ANSYS, the equation of motion for the lathe spindle was successfully solved. After that, this tool is utilised to compute stress and other parameters, and the findings that are obtained are compared with the FEA results of available literature. In order to conduct a study of stress and deformation, the finite element software known as ANSYS 2022R was employed. In order to accomplish this objective, the significant points were determined first, and then line segments were built connecting those locations to one another. A region has been created as a result of the lines being brought together. In order to model the lathe spindle in a range of configurations, both in terms of the diameter and the material configuration, this region was finally exposed to an extrusion process. This procedure was carried out in order to model the region. A three-dimensional structural solid element comprised of 20 nodes was utilised for the aim of simulating the lathe spindle. There were a total of 68662 nodes, with the spindle of the lathe having been broken down into 40890 individual pieces, the mesh model has shown in fig. 2. It is also feasible to imitate the boundary conditions of the lathe spindle by setting limits on the degrees of freedom of the nodes that are located on the right side of the tooth. The material properties have been provided in table 1 for the purpose of stress and deformation analysis of the lathe spindle, and the standards that have been adhered to in the creation of the lathe spindle are in line with Indian norms. This analysis was done so that the lathe spindle would function properly.

Table 1: Material properties



Properties	Structural Steel	Stainless Steel	Titanium	Alloy Al	20MnCr5
Module of elasticity, Pa	2E+11	1.93E+11	9.60E+10	7.10E+10	1.90E+11
Specific density [kg/m3]	7850	7750	4620	2770	8030
Poisoned coefficient	0.3	0.31	0.36	0.33	0.27
Ultimate stress, Pa	4.6E+08	5.86E+08	1.07E+09	3.10E+08	6.82E+08
Yield Stress, Pa	2.5E+08	2.07E+08	9.63E+08	2.80E+08	3.75E+08



Details of "Mesh"

Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No
Advanced	
Number of CPUs for Parallel Part Meshing	Program Controlled
Straight Sided Elements	No
Rigid Body Behavior	Dimensionally Reduced
Triangle Surface Mesher	Program Controlled
Topology Checking	Yes
Pinch Tolerance	Please Define
Generate Pinch on Refresh	No
Statistics	
Nodes	68662
Elements	40890

Figure 2: Mesh Model

Results and Discussion

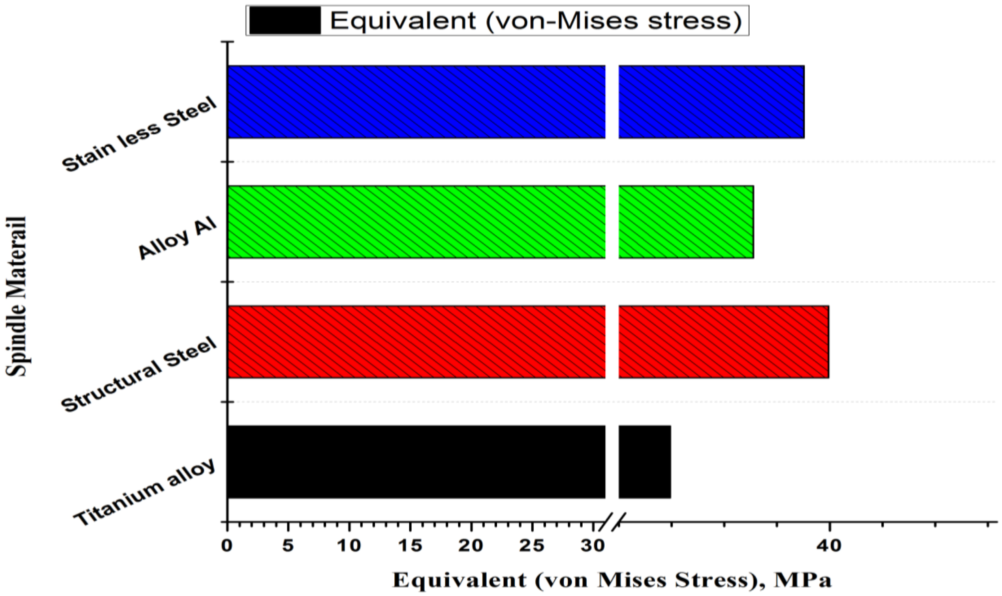
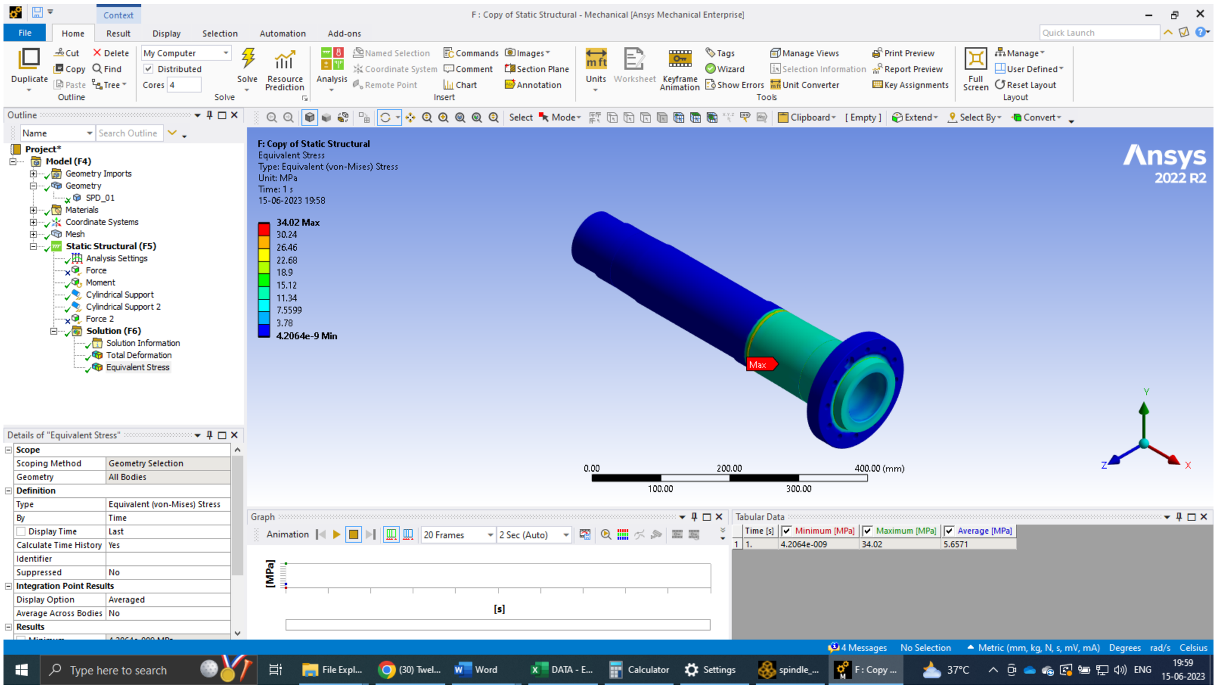


Figure 3: Effect of Spindle material on Equivalent (von-Mises Stress)

The effect that the material of the spindle has on the equivalent von-Mises stress is illustrated in Figure 3, which may be found here. It has been noticed that the spindle made of titanium alloy receives the smallest amount of equivalent von-Mises stress, whereas the spindle made of stainless steel experiences the most amount of equivalent von-Mises stress. Titanium, in comparison to other materials, possesses both a greater ultimate stress as well as a larger yield stress, which explains why this is the case. As a result, the use of a spindle made of titanium alloy is recommended in order to successfully carry out high and cyclic load operations. Because of this, it is possible to avoid the lathe breaking down, which in turn makes it possible to enhance output.

As a consequence of what has been said up to this point, it is feasible to arrive at the conclusion that spindles made of titanium alloy experience the least equivalent von-Mises stress, whereas spindles made of stainless steel experience the most equivalent von-Mises stress. This is because the highest equivalent von-Mises stress occurs when the spindle is made of stainless steel. When compared to the stress of the spindle made of stainless steel, the stress of the spindle made of titanium is 13.89% lower, which means that it is possible to make the conclusion that the stress of the titanium-produced spindle is lower.

Figure 4 illustrates the comparable von-Mises stress that is placed on the titanium alloy spindle during normal operation. It has been observed that the highest degree of distortion may be noticed near the very end of the spindle. When we were close to the spindle's centre, we saw the least amount of distortion that was even imaginable.



F: Copy of Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1 s
15-06-2023 19:58

34.02 Max
30.24
26.46
22.68
18.9
15.12
11.34
7.5599
3.78
4.2064e-9 Min

Details of "Equivalent Stress"

Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Equivalent (von-Mises) Stress
By	Time
☐ Display Time	Last
Calculate Time History	Yes
Identifier	
Suppressed	No
Integration Point Results	
Display Option	Averaged
Average Across Bodies	No
Results	

Tabular Data

	Time [s]	☑ Minimum [MPa]	☑ Maximum [MPa]	☑ Average [MPa]
1	1.	4.2064e-009	34.02	5.6571

4 Messages No Selection Metric (mm, kg, N, s, mV, mA) Degrees rad/s Celsius

Figure 4: Equivalent stress across Titanium alloy

Conclusion

In conclusion, the following is a summary of the conclusions from the research that was done on the influence of spindle material on equivalent von-Mises stress:

Titanium Alloy Outperforms Stainless Steel The investigation reveals that the spindle constructed of titanium alloy exhibits the least equivalent von-Mises stress when it is subjected to operating loads. This is a significant improvement over the performance of stainless steel. Titanium's ultimate stress and yield stress characteristics are significantly higher than those of other materials, notably stainless steel. This improved performance can be due to titanium's higher stress characteristics.

Using a Titanium Alloy Spindle Is Strongly Recommended for Applications Involving High and Cyclic Loads The findings of this study strongly encourage using a titanium alloy spindle for applications that include high and cyclic loads. Because of this decision, the corresponding von-Mises stress is reduced, which improves the spindle's longevity and lowers the danger of spindle failure during rigorous machining processes.

Gains in Performance and an Increase in Output: According to the findings of the research, producers may lessen the risk that their lathes will break down if they use a spindle made of titanium alloy. This, in turn, can lead to an increase in the amount of time that the machine is operational, a boost in production, and an improvement in the output quality.

Reduced Stress by a Substantial Amount It has been determined that the equivalent von-Mises stress of titanium alloy and stainless steel spindles differs by a considerable amount. It has been determined that the stress level in the titanium spindle is approximately 13.89% lower than the stress level in the stainless steel spindle. The large reduction in stress brought about by this modification is very necessary in order to guarantee the spindle's durability and dependability.

Localised Stress Concentration: Figure 4 demonstrates that during normal operation, the spindle experiences the greatest amount of distortion closer to the end of the spindle, whilst the spindle experiences the least amount of distortion closer to the centre of the spindle. This discovery offers helpful insights for spindle design and stress management, highlighting how important it is to address stress concentration locations in order to prevent failure at an earlier stage.

In a nutshell, the equivalent von-Mises stress that is endured during the turning operations of a lathe is significantly affected by the material that the spindle is made of. When it comes to lowering overall stress levels, improving spindle durability, and making the most of machining operations, titanium alloy is clearly the material of choice. When selecting spindle materials for specific applications, manufacturers are strongly recommended to take these results into consideration, with a particular emphasis placed on high and cyclic load activities. This will help manufacturers increase the overall efficiency of machining and reduce the likelihood of spindle-related problems.

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