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Expert System for Spindle Design

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Abstract:- In machine tools, spindle refers to that rotating axis of the machine. The machine tool spindle is considered the most important mechanical part of the metal removal process associated with machining operations. Flexible spindles give rise to unstable chatter vibrations. Modern spindles are made using the fundamental principles of metal-cutting dynamics and machine design. The expert spindle design system technique presented in this study is founded on the effective use of design expertise, machine design laws, and metal cutting dynamics. By determining the work material, the ideal cutting conditions, and the most frequently used tools on the machine tool, the spindle configuration is determined. The paper provides AI design guidelines that result in an automated and interactive spindle drive configuration design. With the arrangement of bearings, a spindle's structural dynamics are dispersed across the spindle shaft. The expert system's suggested design is illustrated by creating a spinning component for a CNC milling machine in an automatic manner. Most of them also opt to optimize some of the design parameters, such as shaft diameters, bearing span, and bearing preload, with an aim to minimize static deflection.

Keywords:- *Spindle, Shaft, Bearing Stiffness, Fuzzy Logic, Deflection, Deformation.*

I. INTRODUCTION

The spindle is one of the most crucial mechanical parts of a machining center. The spindle's structural characteristics have an immediate impact on workpiece productivity and finish quality. The shaft, tool holder, and bearing dimensions, along with the overall spinning assembly design arrangement, are what give the spindle its structural characteristics. Therefore, this study uses a suggested system of experts based on a digital knowledge base to examine the spindle parts choice and setup. Here, the chosen system is the aforementioned fuzzy logic expert system. The expert system-based computer program is made to solve complicated issues and make decisions just like an expert person would. One component of the expert system is AI. The first ES, which was also considered the first successful artificial intelligence technique, was introduced in 1970. A computer software designed to replicate the expertise and judgment of an expert human being in a given topic is called an expert system. It uses algorithms and rules to generate diagnoses, recommendations, and solutions depending on the input data as well as the domain-specific rules for which it was created. While the configuration and parts of the spindles are chosen based on the machine tool's torque, power, and speed requirements, the chatter vibration stability of the spindle must be taken into account when determining the precise bearing spacing. Iteratively, the ideal spindle design that satisfies chatter vibration-free cutting criteria was created.

II. METHODOLOGY

A. Expert System

A computer software that mimics the decision-making and actions of a human being or an entity with extensive expertise in a particular sector is called an expert system. A body of knowledge that incorporates the acquired experience and guidelines for applying the data base to every scenario that is explained to the program is typically included in such a system. MYCIN was one of the first useful expert systems created by Short Life. Patients who are infected with diseases can utilize the MYCIN system to help them make judgments about which therapy is best for them. Fuzzy logic uses fuzzy sets manage membership functions to deal with uncertainty. Uncertain facts in the spindle design process include things like high spindle speed, low cutting torque, etc. An expert system's knowledge base, inference engine, and user interface are its main constituents.

➢ *Forward Chaining*

Using the information that is now available, forward chaining uses the inference rules as best it can to increase the amount of information until it reaches the objective. When an inference engine employs forward chaining, it continuously looks for the rules that govern inference for one where the if clause has been determined to be true. It then adds this knowledge to its data and ends the then clause.

➢ *Backward Chaining*

To determine whether there is sufficient evidence to infer any of the goals, backward chaining begins with a list of objectives and work its way backward. Add that inference rule's if clause to the list of objectives if it isn't known to be true.

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III. IMPLEMENTATION

A. *Development of Expert System*

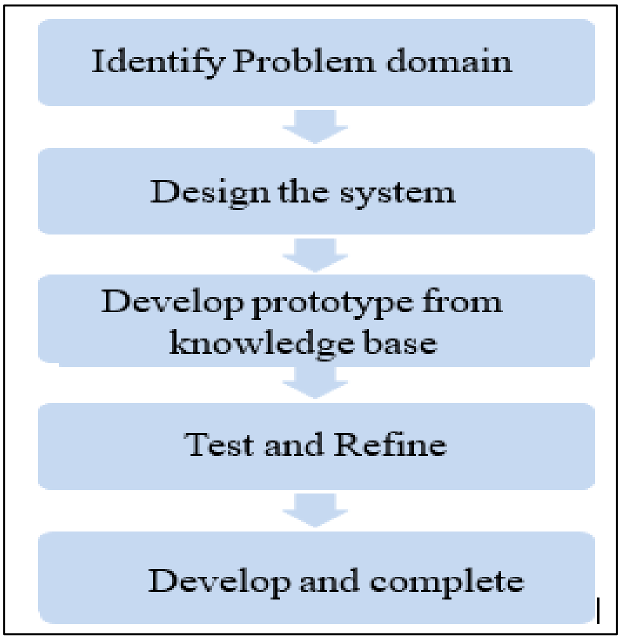

Fig 1: Development of Expert System

➢ *Fuzzy Logic*

It's a branch of logic which deals with approximations rather than precise or fixed thinking. Fuzzy logic is very helpful in handling the idea of partial truth, where the truth consider may range among entirely accurate and completely false. Contrary to classical logic, where variables in that system are true or false, fuzzy logic allows for values that fall between both extremes of entirely true and entirely false. For the spindle design, the designers typically employ logical words rather than precise numerical data. Using membership functions, fuzzy logic can handle range uncertainty. The spindle's design is constantly updated by technology, thus the uncertainty standards that better regulate it must also do the same.

➢ *Fuzzy Sets*

A fuzzy set may have degrees of membership, in contrast to a classical set where an element is either a part of the set or it is not. A membership function that determines the degree of membership by assigning a number between 0 and 1. But sometimes, things are more difficult to convey with clear boundaries.

➢ *Membership Functions*

These define how the map looks from a point of an input area to a membership value, and which ranges from 0 to 1. Fuzzy set theory gives the input-to-output mapping for this system. In order to provide a crisp result, its procedure often involves fuzzifying the input, applying fuzzy operators, aggregating the rules, and finally defuzzifying.

B. *Design Methodology*

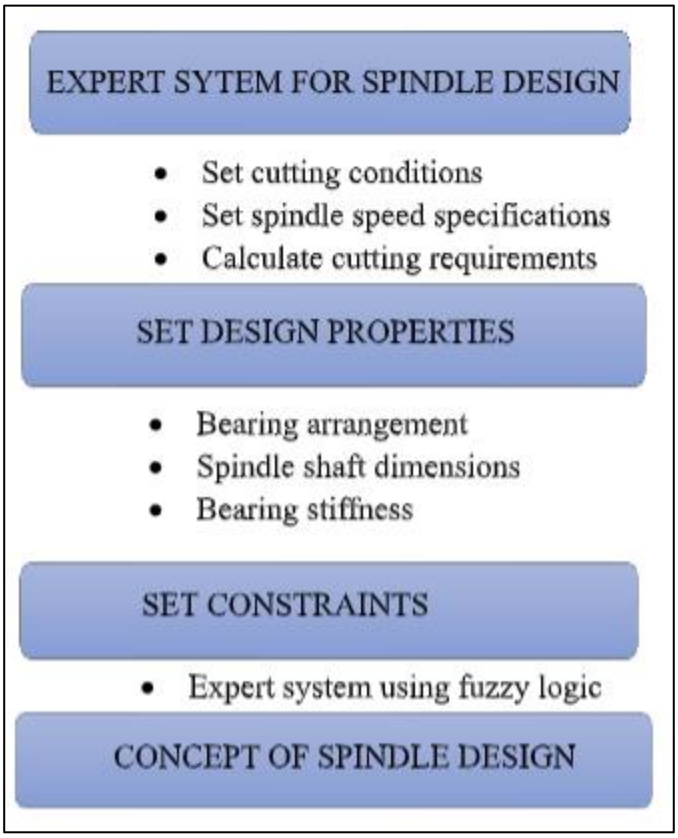

Fig 2: Flow Chart

C. *Basics of Spindle Design*

High speed cutting is preferred by the market for milling operations, particularly for machine tools. Bearing catalogs include some basic information regarding spindle design as well as an overview of current spindle design trends. Those working in HSM should exercise attention when choosing spindle designs. For high-speed spindles, low-density hybrid bearings are frequently chosen due to their high hardness, low thermal expansion property, and elevated modulus of elasticity.

➢ *Applications of the Expert System in Spindle Design*

The combination of fuzzy logic and an expert system functions as a selection system for the spindle design's component parts since fuzzy logic is a suitable uncertainty representation for the spindle design. Fig. 2 shows the spindle layout expert system. The laws of cutting mechanics are used to determine the input values required to achieve the spindle design cutting torque power. After being configured by an expert and fuzzified using membership functions, the fuzzy inference system receives an input value. The inference system that is employed is the Mamdani technique. Utilizing the max method on fuzzy set rules, aggregate fuzzy values. Users are permitted to use the external database that is interfaced with the system. When the inclination of fuzzy terms like "high," "middle," and "low" changes, the supervising engineer, who has the authority to manage this expert system, can alter the membership function and database.

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D. Design Principle for Milling Spindle

Machine tools are used in the production of machines, including machine tools. The most popular metal cutting machine is most likely the milling machine. One could argue that a machine's spindle, which is powered by a spindle motor, is its most important component. Because it is subjected to several bearings at high working speeds, the spindle also acts as the weakest component of the machine. The market demands, which include increased precision, increased productivity, and reduced cost, primarily determine the spindle specification. Some users need a spindle that is extremely accurate and rigid. Self-excited chatter vibrations, bearing lifespan, and malfunctioning operation all cause harm to the bearings. Chatter-free cutting operations have been enhanced by analytical analysis of chatter vibrations. The majority of industries employ machining centers under specific cutting circumstances, such as depth, width, and cutting speed. Determining the spindle's design characteristics to function best under a certain set of cutting parameters is the goal of the present research project.

E. Designing and Material Selection

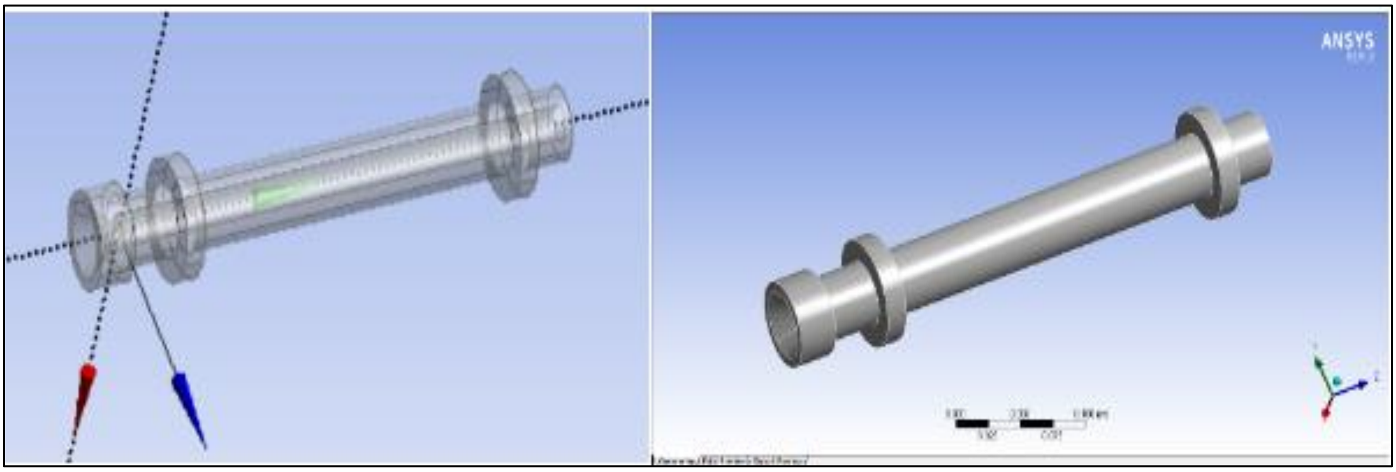

Fig 3: Spindle Drawing in ANSYS Software

Table 1: Material properties of C40 and C45

S.No	Material	Chemical Properties	Mechanical Properties	Physical Properties
1	C40	(C): 0.37% - 0.4% (Si): 0.1% - 0.4% (Mn): 0.5% - 0.8% (P): ≤ 0.045% (S): ≤ 0.045%	Yield Strength: Approximately 330 MPa Elongation: Around 16% (in 50 mm gauge length) Hardness: 170 - 210 HB	Modulus of Elasticity: About 210 GPa Thermal Conductivity: Around 48.6 W/mK at 23°C
2	C45	(C): 0.42% - 0.5% (Si): 0.1% - 0.4% (Mn): 0.5% - 0.8% (P): ≤ 0.045% (S): ≤ 0.045%	Yield Strength: 340 MPa Elongation: Approximately 16% in 50 mm gauge length Hardness: 170 - 210 HB	Modulus of Elasticity: About 210 GPa Thermal Conductivity: 49.8 W/mK at 23°C

F. Bearings

The spindle becomes firmer as the number of bearings increases, but the bearings' frictional resistance also regulates the maximum spindle speed. In particular, the majority of the load is supported by radial forces on the front bearings. Two front bearings are used by the high speed spindles, though this may change depending on the preload. Four front bearings is the most that can be found. The spindle shaft's bending vibration is prevented by the rear bearings. Designers must use finite element analysis to calculate and ascertain the spindle's dynamic qualities in order to decide the ultimate number of bearings. When the spindle shaft's back shakes wildly with the bearing, designers increase the number of the bearings up to three.

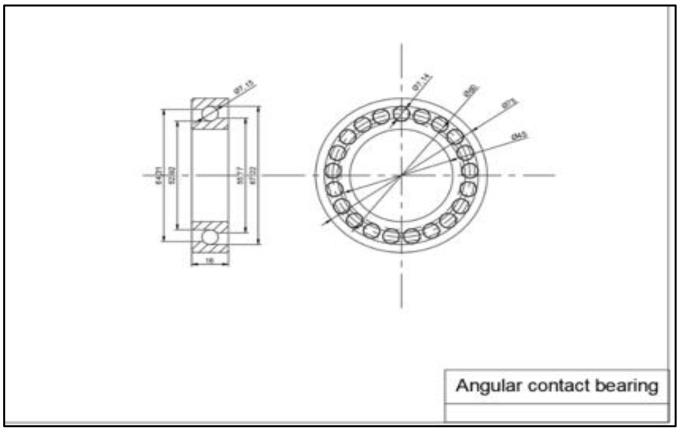

Fig 4: Angular Contact Bearings in AutoCAD

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G. Rigidity Calculations

Depending on the tool being used, a spindle provides drive to the tool or the work piece. While the strength of the housing is a crucial component, the overall stiffness of the spindle system is influenced by the stiffness of the spindle diameter. Since the housing is typically more rigid than other components of the spindle arrangement, its impact is not included here due to the total stiffness of the spindle system. The rigidity of the front bearing has a significant effect on the overall stiffness. At the position of applied load, the entire deflection of the bearings system caused by load {P` is provided by.

$$\delta = \delta_1 + \delta_2 = P\left[\frac{1}{S_A} * \left(\frac{a}{L} + \frac{L}{L}\right)^2 + \frac{1}{S_B} * \left(\frac{a}{L}\right)^2 + \frac{a^2}{3E} * \left(\frac{L}{I_L} + \frac{a}{I_a}\right)^2\right]$$

In the above equation it is assumed that the bearings, the diameter of spindle and overhang of spindle are fixed, it can be seen that the stiffness becomes a function of bearing span only. Here, δ- deflection, P- load, A- bearing stiffness at A, SB- bearing stiffness at B, a- length of overhang L- bearing span, E- Youngs modulus of the spindle material, IL- moment of inertia of shaft at bearing span, IA- moment of inertia of nose end of the spindle.

IV. RESULT

Table 2: Experimentation table for Face Milling-Training data by Kennametal C40 Material with Spindle Diameter 60mm and Rockwell Hardness as 120HRB

S. No	Cutti ng Speed(m/min)	Spindle speed (rpm)	Depth of cut (mm)	Feed per tooth(mm)	Feedrate	MRR (cm3 /min)	Tangential cutting Force(N)	Torq -ue (Nm)	Cutter Power (KW)	Motor Power (KW)
1	300	1591.5	1.5	0.15	1193.63	80.57	265.5	7.97	1.3	1.44
2	350	1856.8	1.5	0.15	1392.6	94	265.5	7.97	1.5	1.67
3	350	1856.5	1.5	0.1	928.4	62.7	177	5.3	1	1.11
4	400	2122.1	1.5	0.15	1591.58	107.4	265.5	7.97	1.8	2
5	400	2122.1	1.5	0.1	1061.05	71.6	177	5.31	1.2	1.33
6	450	2387.3	1.75	0.2	1790.48	120.9	265.5	7.97	2	2.22
7	450	2387.3	1.5	0.1	2387.3	188	413	12.39	3.1	3.44
8	500	2652.6	1.75	0.2	2652.6	208.8	413	12.39	3.4	3.78
9	500	2652.6	1.5	0.15	1989.45	134.3	265.5	7.97	2.2	2.44

Table 3: Experimentation Table for Face Milling-Training Data by Kennametal C45 Material with Spindle Diameter 60mm and Rockwell Hardness as 210HB.

S.no	Cutti ng Speed (m/min)	Spindle speed (rpm)	Depth of cut (mm)	Feedper tooth(mm)	Feed rate	MRR (cm3/min)	Tangential cutting Force(N)	Torq -ue (Nm)	Cutter Power (KW)	Motor Power (KW)
1	320	1724.2	1.25	0.1	862.1	48.5	147.5	4.43	0.8	0.89
2	320	1697.7	1.4	0.3	2546.55	160.43	495.6	14.87	2.6	2.89
3	450	2387.3	1.3	0.2	2387.3	139.7	306.8	9.2	2.3	2.56
4	450	2387.3	1.4	0.2	2387.3	150.4	330.4	9.91	2.5	2.78
5	450	2387.3	1.4	0.3	3580.95	225.6	495.6	14.87	3.7	4.11
6	500	2652.6	1.3	0.3	3978.9	232.8	232.8	13.81	3.8	4.22
7	500	2652.6	1.4	0.2	2652.6	167.11	330.4	9.91	2.8	3.11
8	550	2917.8	1.4	0.2	2917.8	183.8	330.4	9.91	3	3.33
9	600	3183.1	1.4	0.2	3183.1	200.54	330.4	9.91	3.3	3.67

➢ *Calculation for C40 Material:*

Assuming cutting speed (V_c) as 350 m/min

- $V_c = \frac{\pi * D * N}{1000}$, $N = \frac{1000 * V}{\pi * D}$ where N = spindle speed
- $N = \frac{1000 * 350}{\pi * 60}$ = 1856.8 RPM, $T = \frac{P * 9.549}{N}$, T= F*r, Hence: T= 7.97 Nm
- Now, to calculate motor power: $T = \frac{P * 9.549}{N}$, $7.97 = \frac{P * 9.549}{1856.8}$ = 1.5 KW
- Deflection: $\delta = \delta_1 + \delta_2 = P\left[\frac{1}{S_A} * \left(\frac{a}{L} + \frac{L}{L}\right)^2 + \frac{1}{S_B} * \left(\frac{a}{L}\right)^2 + \frac{a^2}{3E} * \left(\frac{L}{I_L} + \frac{a}{I_a}\right)^2\right]$

Assuming values as per the drawing dimensions: $S_A = S_B$=115.5N/µm, a=65mm, L=295mm, E=190GPa, d=45mm. Substituting in the equation we get $\delta = 3.45$µ.

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➢ *Calculation for C45 Material:*
Assuming cutting speed (V_c) as 450 m/min

- $V_c = \frac{\pi * D * N}{1000}$, $N = \frac{1000 * V}{\pi * D}$ where N = spindle speed
- $N = \frac{1000*450}{\pi*60}$ = 2387.3 RPM, $T = \frac{P*9.549}{N}$, T= F*r, Hence: T= 9.2 Nm
- Now, to calculate motor power: $T = \frac{P*9.549}{N}$, $7.97 = \frac{P*9.549}{1856.8}$ = 2.56 KW
- Deflection: $\delta = \delta_1 + \delta_2 = P\left[\frac{1}{S_A} * \left(\frac{a}{L} + \frac{L}{L}\right)^2 + \frac{1}{S_B} * \left(\frac{a}{L}\right)^2 + \frac{a^2}{3E} * \left(\frac{L}{I_L} + \frac{a}{I_a}\right)^2\right]$

Assuming values as per the drawing dimensions: $S_A = S_B = 115.5$N/µm, a=65mm, L=295mm, E=190GPa, d=45mm. Substituting in the equation we get $\delta = 3.98\mu$

A. Results of Inference Engine using Fuzzy Rules C40, C45

Fuzzy inference systems (FIS) might be used to model the behaviour of a C40 steel material under automobile applications, dealing with uncertainties and variations of material properties in control processes. Using software like FIS Pro and create a fuzzy logic model that simulates the performance of the C40 and C45 steel under conditions such as cutting force, motor power.

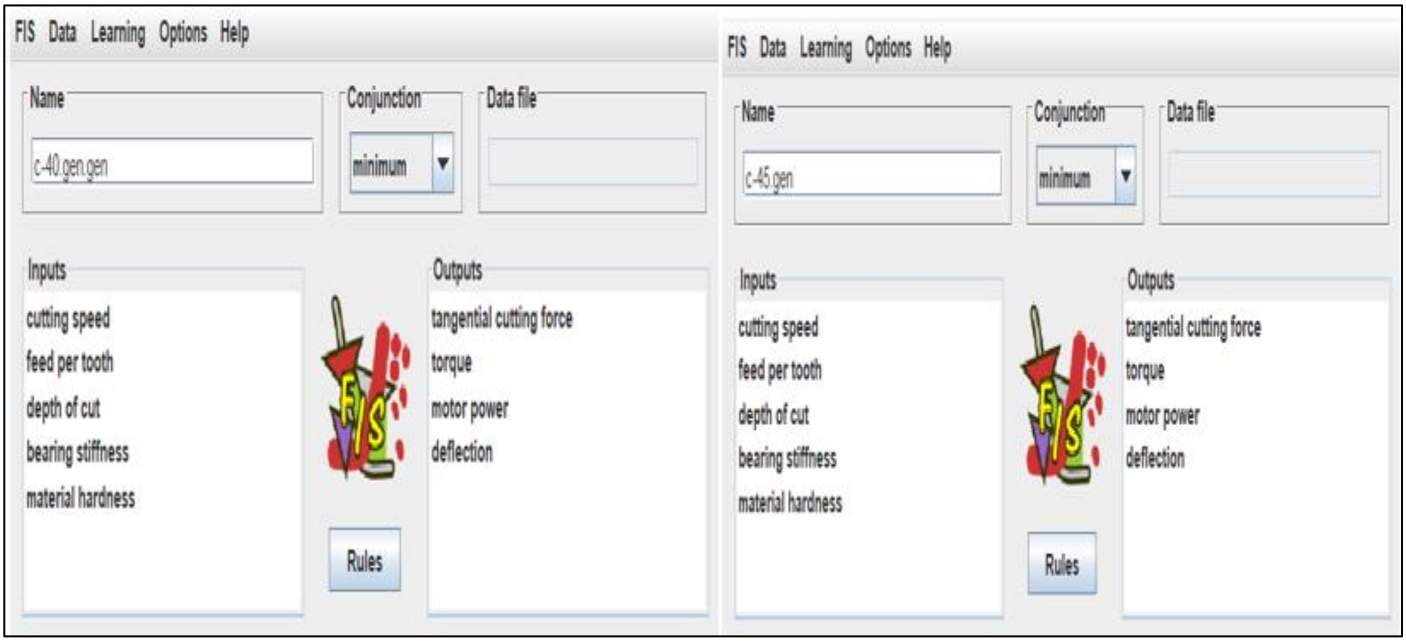

Fig 5: Inputs and Outputs Given in FIS Pro Application for C40 and C45 Material

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Rules Display

Rule	Active	IF cuttin...	AND fe...	AND de...	AND be...	AND ma...	THEN t...	torque	motor p...	deflecti...
1	✓	very low	low	low	medium	low	low	low	very low	low
2	✓	very low	low	low	medium	high	low	low	very low	low
3	✓	very low	low	high	medium	low	medium	medium	medium	medium
4	✓	very low	low	high	medium	high	medium	medium	medium	medium
5	✓	very low	medium	low	medium	low	medium	medium	high	medium
6	✓	very low	medium	low	medium	high	high	medium	high	medium
7	✓	very low	medium	high	medium	low	high	high	high	high
8	✓	very low	medium	high	medium	high	high	high	very high	high
9	✓	very low	high	low	medium	low	medium	medium	medium	medium
10	✓	very low	high	low	medium	high	medium	medium	high	medium
11	✓	very low	high	high	medium	low	medium	medium	high	medium
12	✓	very low	high	high	medium	high	high	high	high	high
13	✓	low	low	low	medium	low	low	low	very low	low
14	✓	low	low	low	medium	high	medium	low	very low	low
15	✓	low	low	high	medium	low	low	medium	medium	medium
16	✓	low	low	high	medium	high	medium	medium	high	medium
17	✓	low	medium	low	medium	low	low	low	very low	low
18	✓	low	medium	low	medium	high	medium	low	medium	low
19	✓	low	medium	high	medium	low	low	medium	high	medium
20	✓	low	medium	high	medium	high	high	high	very high	high
21	✓	low	high	low	medium	low	medium	medium	medium	medium
22	✓	low	high	low	medium	high	medium	medium	high	medium
23	✓	low	high	high	medium	low	high	high	very high	high
24	✓	low	high	high	medium	high	high	high	medium	high
25	✓	medium	low	low	medium	low	low	low	medium	low
26	✓	medium	low	low	medium	high	medium	low	medium	low
27	✓	medium	low	high	medium	low	medium	low	medium	low
28	✓	medium	low	high	medium	high	high	medium	high	medium
29	✓	medium	medium	low	medium	low	low	low	medium	low
30	✓	medium	medium	low	medium	high	medium	medium	medium	medium

Rules Display

Rule	Active	IF cuttin...	AND fe...	AND de...	AND be...	AND ma...	THEN t...	torque	motor p...	deflecti...
1	✓	very low	low	low	normal	low	low	low	low	low
2	✓	very low	low	low	normal	high	low	low	low	low
3	✓	very low	low	high	normal	low	low	low	low	low
4	✓	very low	low	high	normal	high	medium	medium	medium	medium
5	✓	very low	medium	low	normal	low	low	low	low	low
6	✓	very low	medium	low	normal	high	medium	medium	medium	medium
7	✓	very low	medium	high	normal	low	medium	medium	medium	medium
8	✓	very low	medium	high	normal	high	medium	medium	medium	medium
9	✓	very low	high	low	normal	low	low	low	low	low
10	✓	very low	high	low	normal	high	medium	medium	medium	medium
11	✓	very low	high	high	normal	low	medium	medium	medium	medium
12	✓	very low	high	high	normal	high	high	high	high	high
13	✓	low	low	low	normal	low	low	low	low	low
14	✓	low	low	low	normal	high	low	low	low	low
15	✓	low	low	high	normal	low	low	low	low	low
16	✓	low	low	high	normal	high	medium	medium	medium	medium
17	✓	low	medium	low	normal	low	low	low	low	low
18	✓	low	medium	low	normal	high	medium	medium	medium	medium
19	✓	low	medium	high	normal	low	medium	medium	medium	medium
20	✓	low	medium	high	normal	high	high	high	high	high
21	✓	low	high	low	normal	low	medium	medium	medium	medium
22	✓	low	high	low	normal	high	high	high	high	high
23	✓	low	high	high	normal	low	medium	medium	medium	medium
24	✓	low	high	high	normal	high	high	high	high	high
25	✓	medium	low	low	normal	low	low	low	low	low
26	✓	medium	low	low	normal	high	low	low	low	low
27	✓	medium	low	high	normal	low	low	low	low	low
28	✓	medium	low	high	normal	high	medium	medium	medium	medium
29	✓	medium	medium	low	normal	low	low	low	low	low
30	✓	medium	medium	low	normal	high	medium	medium	medium	medium

Fig 6: Rules Given in the Engine for C40 and C45 Material Respectively

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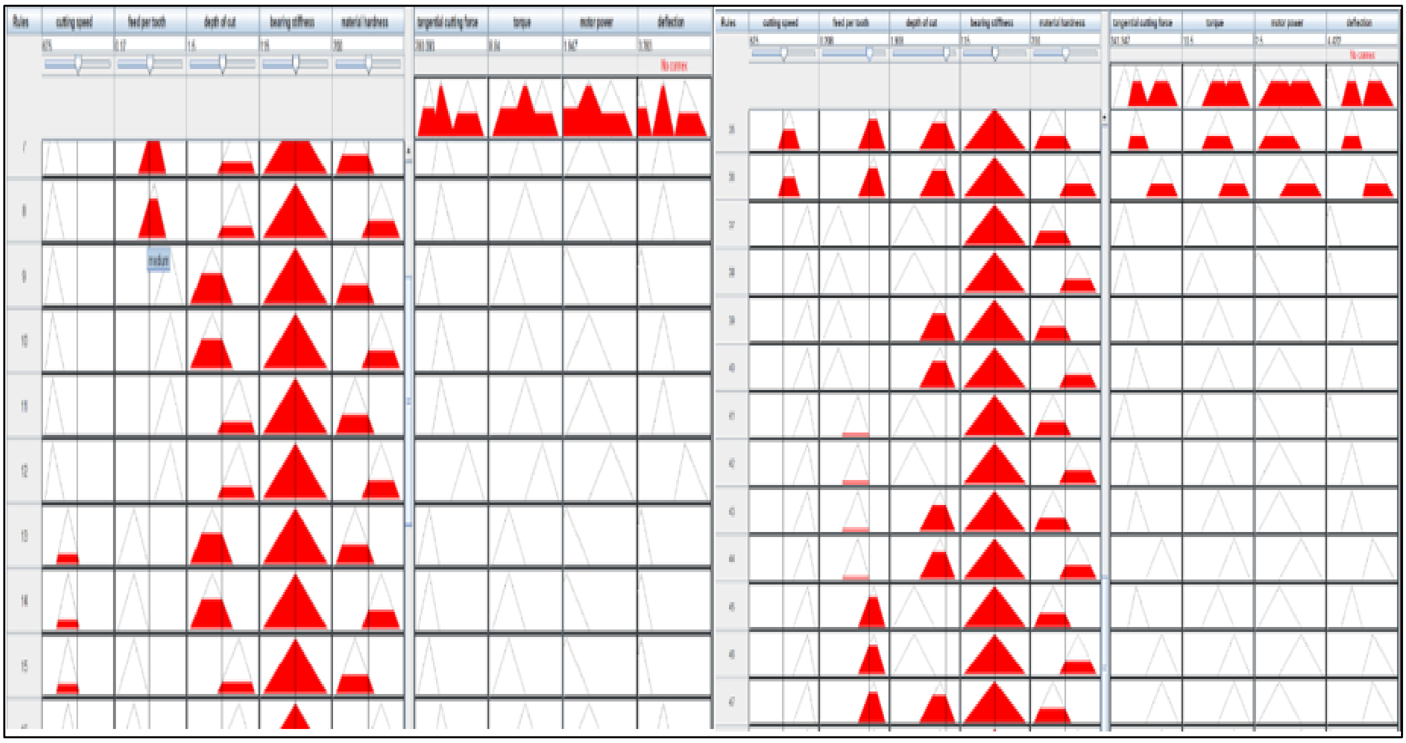

Fig 7: Fuzzy Inferences of C40 Material using the Above Table. Inference Engine Created by Using Fuzzy Logic to the Expert System

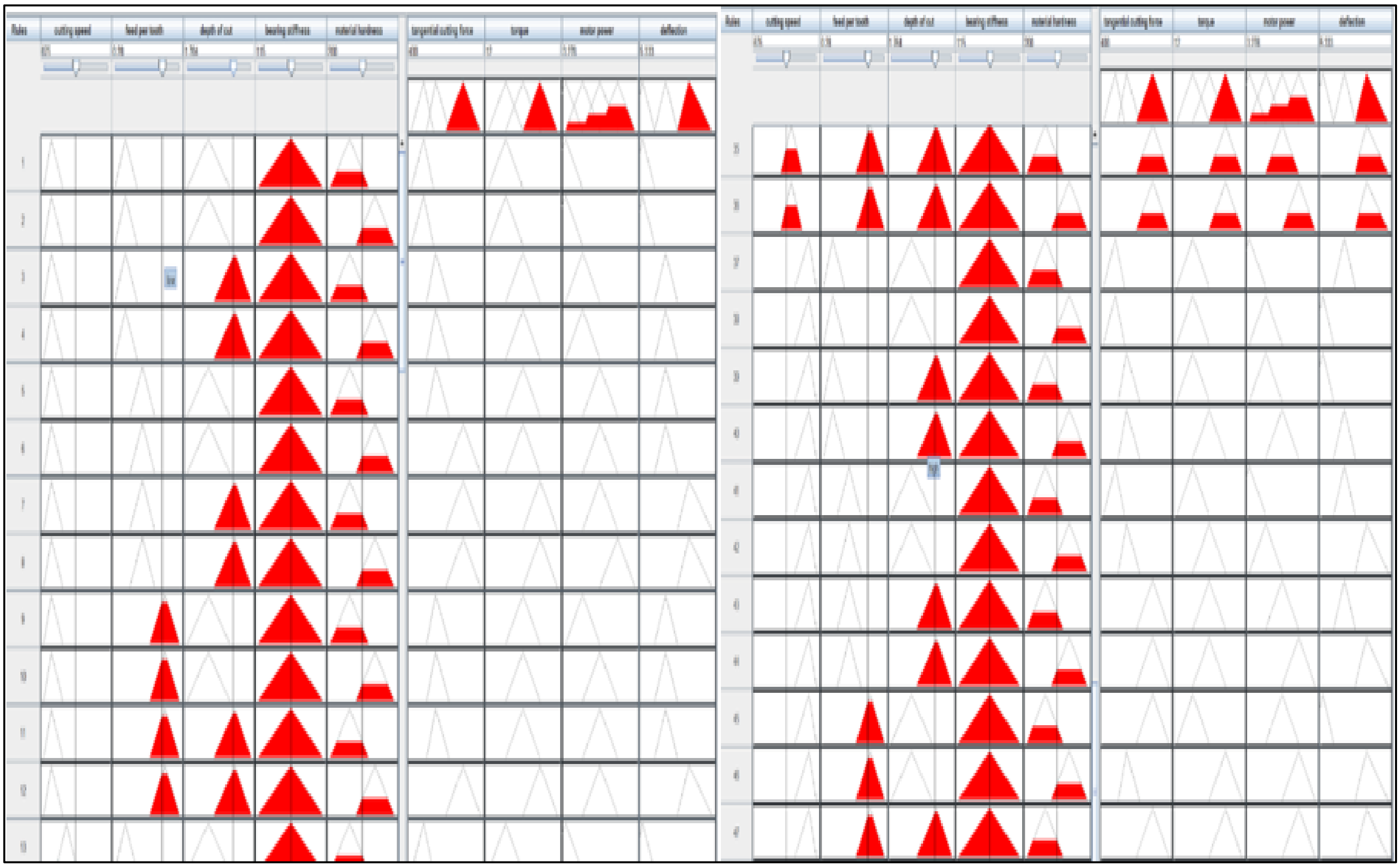

Fig 8: Fuzzy Inferences of C45 Material using the Above Table. Inference Engine Created by using Fuzzy Logic to the Expert System

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B. Analysis

There were also the static structural analysis, in ANSYS, through the aforementioned cutting force and the direction of force, which are demonstrated by Fig 9.

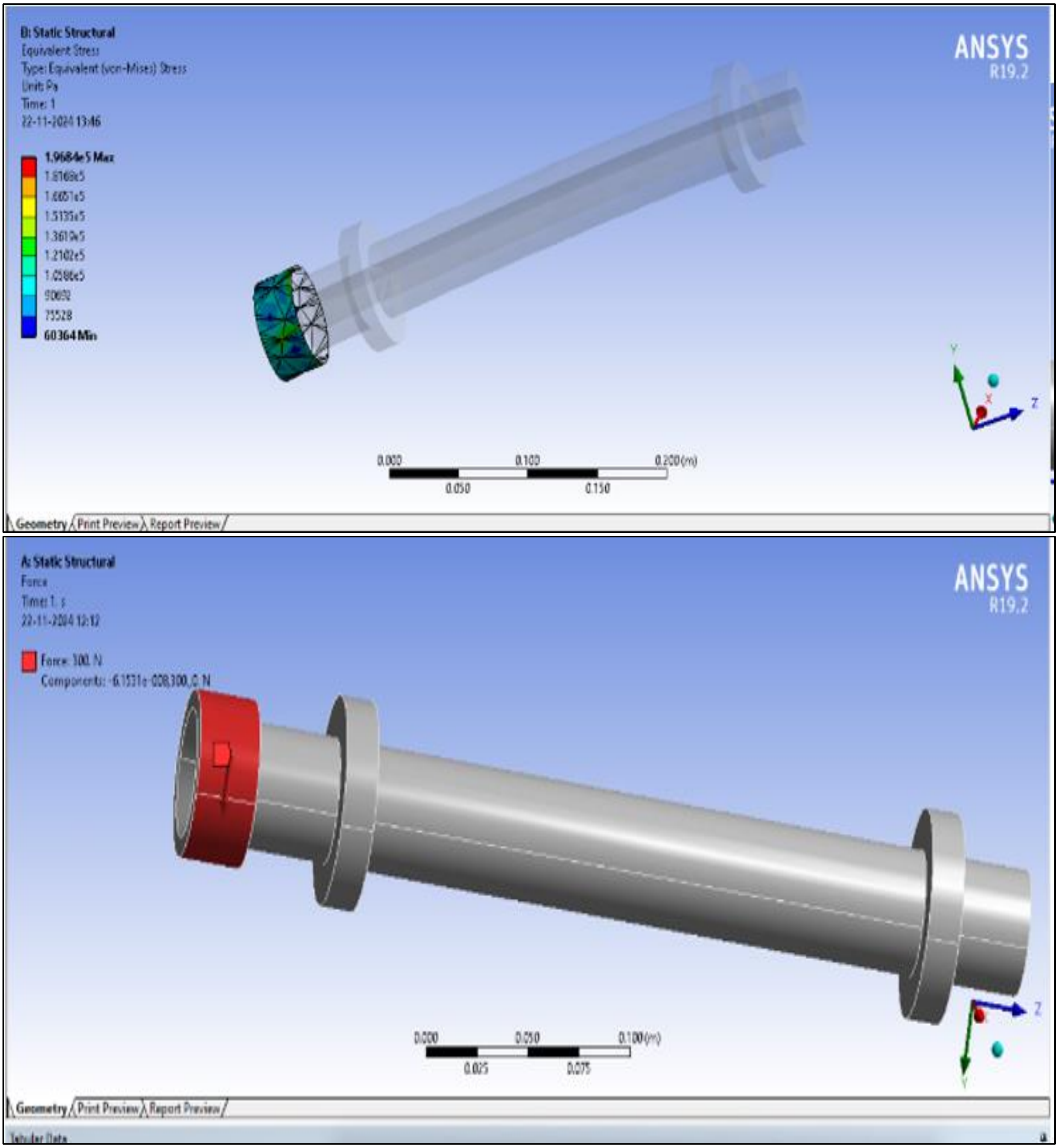

Fig 9: Force Acting Downwards on the Unfixed End of the Spindle

The static structural analysis of the spindle was successfully conducted in ANSYS, evaluating stress distribution under the applied loads and boundary conditions as shown in Fig 10.

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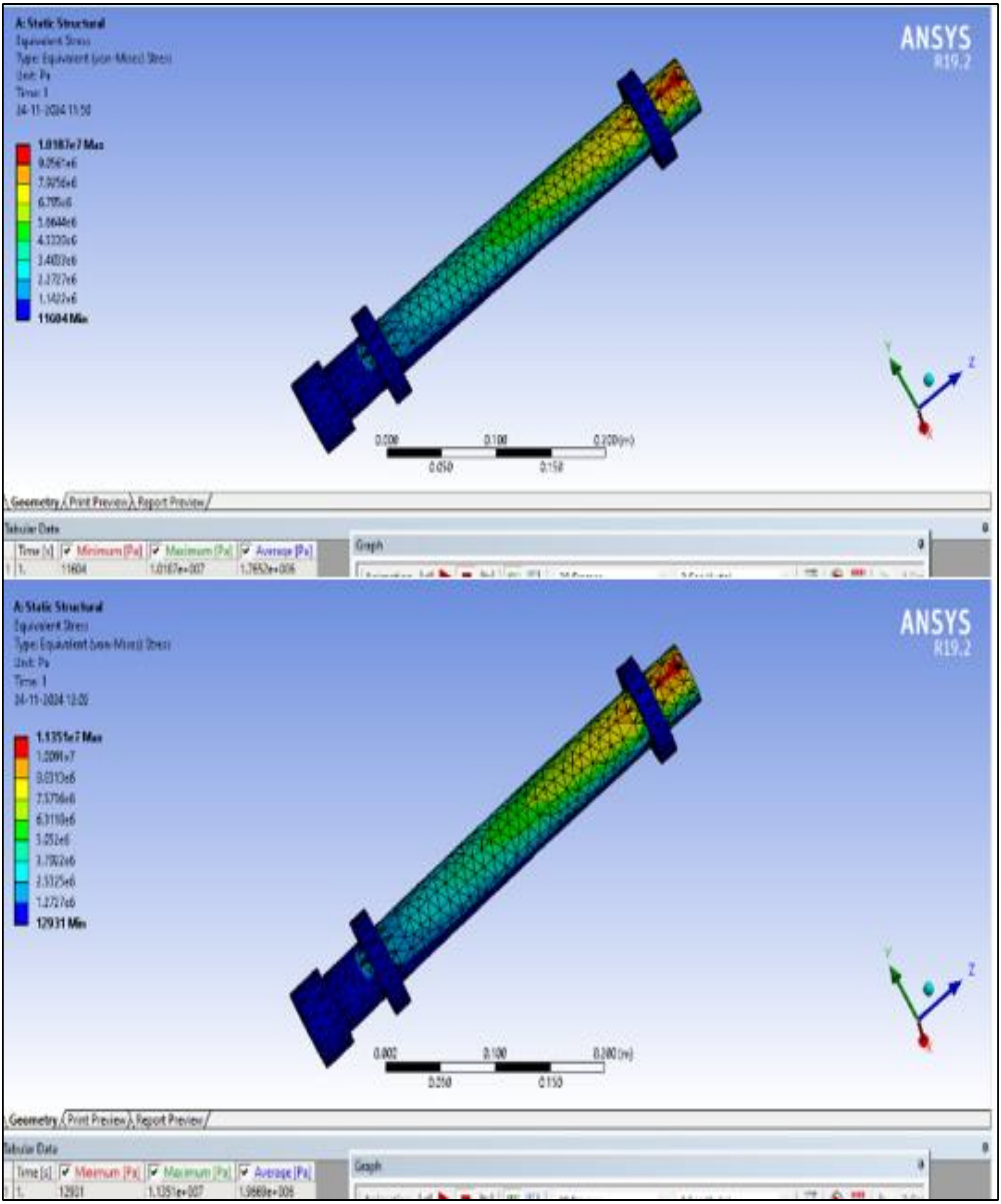

Fig 10: Maximum and Minimum Stresses Acting on the Spindle

The static structural analysis was performed in ANSYS to validate the spindle under applied loads and boundary conditions like those shown in Fig 11, analysing stress distribution, deformation, and integrity of the structure.

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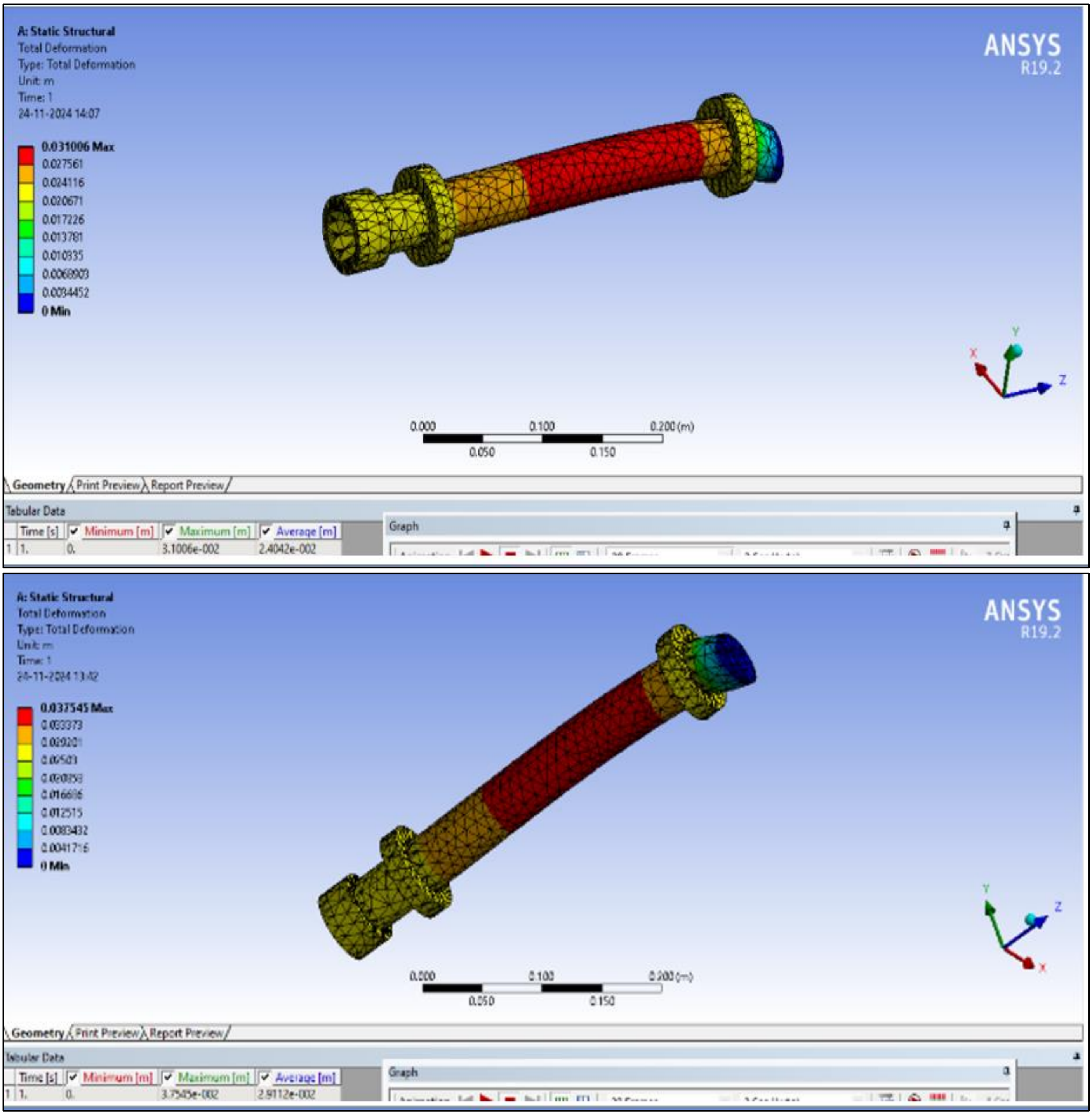

Fig 11: Displacement and Deformation Analysis of the Spindle

Table 4: Stress, Deflection and Deformation Analysis using Cutting Force in ANSYS Software (C40).

S.no	Tangential Cutting Force(N)	Deflection (μ)	Max stress (Pa)	Min Stress (Pa)	Deformation (m)
1	265.5	3.45	1.3097e7	14920	0.037569
2	177	2.3	8.7314e6	9946.7	0.037551
3	265.5	3.45	1.3097e7	14920	0.037569
4	177	2.3	8.7314e6	9946.7	0.037569
5	177	2.3	8.7314e6	9946.7	0.037545
6	265.5	3.45	1.3097e7	14920	0.037545
7	413	5.36	2.0373e7	23209	0.03952
8	265.5	3.45	1.3097e7	14920	0.037545
9	472	6.13	2.32864e7	26524	0.041321
10	413	5.36	2.0373e7	23209	0.03952

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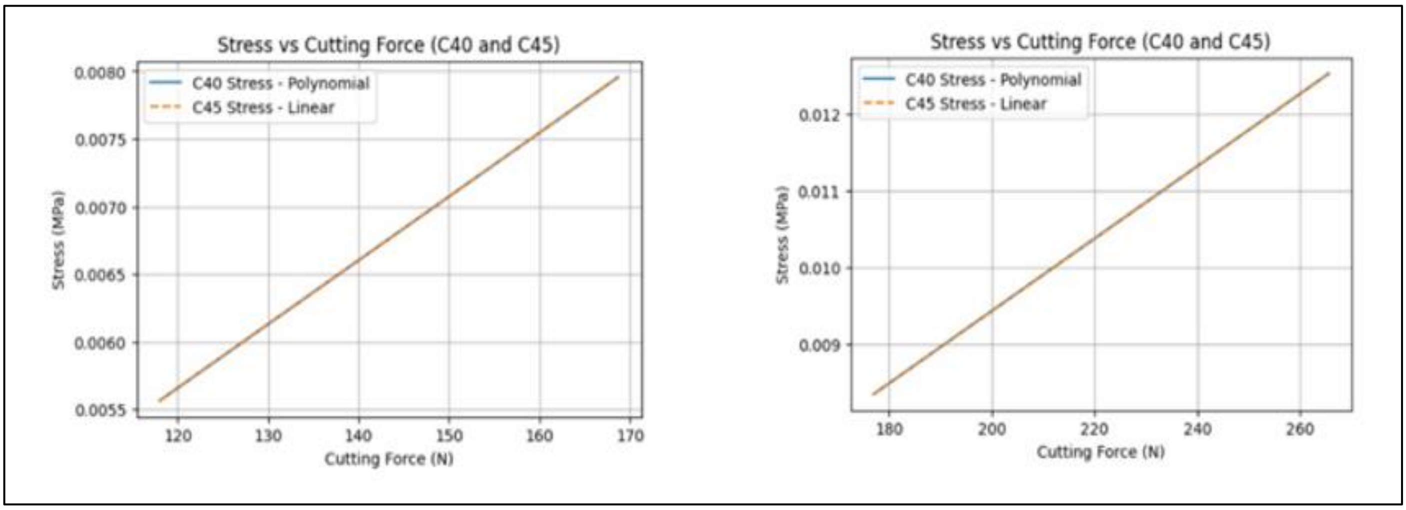
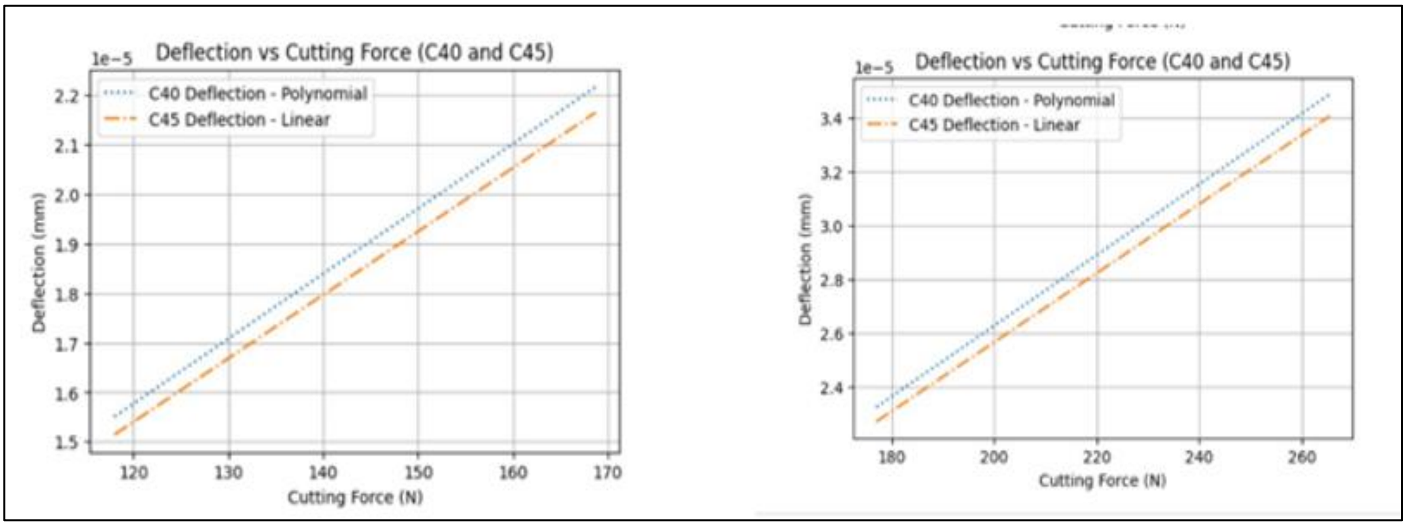
Table 5: Stress, Deflection and Deformation Analysis using Cutting Force in ANSYS Software (C45)

S.no	Tangential Cutting Force(N)	Deflection (μ)	Max stress (Pa)	Min Stress (Pa)	Deformation (m)
1	147.5	1.91	7.2762e6	8288.9	0.035331
2	495.6	6.44	2.4448e7	27851	0.036689
3	306.8	3.98	1.5134e7	17241	0.035796
4	330.4	4.29	1.6299e7	18567	0.036689
5	495.6	6.44	2.4448e7	27851	0.042001
6	232.8	3.02	1.1484e7	13082	0.040976
7	330.4	4.29	1.6299e7	18567	0.036689
8	330.4	4.29	1.6299e7	18567	0.036689
9	330.4	4.29	1.6299e7	18567	0.036689
10	201.73	4.29	1.6299e7	18567	0.035791

The tables 4, 5 shown above are used to find the relation between cutting forces and deflection, stress calculated using ANSYS software and displacement that is used to analyse deformation of the spindle. The relation is thus shown in graphs 1 and graph 2.



Graph 1: Shows the Stress Behaviour of Both Materials as Cutting Force Increases



Graph 2: Shows the Deflection Behaviour Both Materials as Cutting Force Increases

➢ *The Following are the Details of the Represented Graph*

- x-axis: Cutting Force (N).
- y-axis: Stress (MPa) or Deflection (mm), depending on the graph.
- C40: Represented using a cubic polynomial curve.
- C45: Represented using a linear curve.
- C40 curves use solid (-) and dotted (:) styles.
- C45 curves use dashed (--) and dash-dot (-.) styles.

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This representation provides a clear comparison of how C40 and C45 materials respond to varying cutting forces in terms of stress and deflection.

V. CONCLUSION

- Expert System: A computer program that mimics the decisions and actions of a person or an organization with extensive expertise in a certain sector is known as an expert system. A knowledge base with accumulated expertise and a set of guidelines for using that knowledge base to each specific scenario that is given to the program is usually included in such a system.

➢ *Cutting Parameters:*

- Cutting Speed: The higher the cutting speed, the greater the tool's exponential decrease due to raised temperatures associated with increased wear.
- Feed Rate: Higher feed rates do lead to lower tool life. However, the effect is weaker than cutting speed
- Depth of Cut: Larger depths of cut increase cutting forces, leading to faster tool wear.
- Fuzzy Logic: Fuzzy logic is a form of logic that concerns the reasoning that is fuzzy, than being stiff and precise. Where logic requires that the variables be true or false and not between true and false, fuzzy logic allows values between completely true and false.

The outcomes of Kennametal data and experimental data is analysed and compared for the development of expert system. These experiments help understand the property of the material and calculations of face milling. Fuzzy logic has been used by using the Kennametal data to develop the expert system which gives the advice whether machine cutting dynamics are in optimal conditions for the machine to work.

REFERENCES

[1]. Creighton, thermal analysis on a micro-milling spindle to get the temperature and resultant thermal expansion (Creighton et al., 2010), Volume: 07, Issue: 03 | Mar 2010.

[2]. Kajal Chourasia et.al, static and dynamic analysis of offset bearing using ANSYS. Volume: 05, Issue: 12 | Dec 2020.

[3]. Sachidanand Reur et.al, analyzed featured the characteristics of motorised and non-motorised milling spindles. University of Montenegro, Issue: 2020

[4]. Jared Padayachee et.al, Advanced robotic systems are an Industry 4.0 enabler in smart factories, Volume 6, Issue: 2021.

[5]. Tzu-Chi Chan, Finite Element Analysis and Structure Optimization of a Gantry-Type High-Precision Machine Tool, Journal of Cornell University, Issue: 20| Jan 2023.

[6]. Arman Mohammadi, Efficient degradation of parathion as a pollutant and diazinon, International Journal of Scientific Research in Engineering and Management (IJSREM), Volume: 07, Issue: 01 | September - 2023.

[7]. Quang Tu Vu, A study on an Oil- air mixed lubrication monitoring system for the spindle unit of a CNC Milling machine, (2021) 71-75

[8]. Himanshu Bhatt, made Developments in Machine Tool Spindle Technology. Esteve Josa, Chassis Design Target Setting for a High-Performance Car Using a Virtual Prototype, Applied Sciences Journal, Issue: 7 January 2021.

[9]. S.W. Hong, observed the Effects of Bearing locations on the characteristics of a spindle system supported by Tapered roller bearings. Journal of University Teknikal Malaysia Melaka, Issue:2020

[10]. Piyush Singhal, Design and verification of natural frequency using ANSYS software. International Journal of Advance Research and Innovation, Volume: 09, Issue: 2022.

[11]. P. Naik, analysis and testing of spindle for high speed CNC Lathe machine. International Journal of Enhanced Research in Science Technology & Engineering, Vol.3Issue7, July-2016.

[12]. V. Tong, multi objective optimization of Machine tool spindle – bearing system., Issue: 2020.

[13]. S. Chattopadhyaya, Modeling and validation of spindle shaft followed by goal driven optimization. Journal of Physics: Conference series, Issue: 2012

[14]. V. Gagnol, Stability based spindle design optimization. International Journal of Scientific & Engineering Research Volume: 8, Issue: 12, December 2007.

[15]. D.H. Kim Static and Dynamic analysis and optimization. International Journal of Engineering Research and Technology, Volume: 14, Issue: November 10 (2013).

[16]. Satish Kumar, Design and analysis of machine tool spindle, International Journal of Engineering Research and Technology, Volume: 14, Issue: November10 (2017)

[17]. M. Sen, Selection of mill cutter and cutting parameters through expert system. International Journal of Advance Research in Science and Engineering, Volume: 9, Issue: 9, September 2007.

[18]. Beizhi Li, Dynamic analysis of high speed grinding spindle. International Journal of Design Conference, Issue: 2008

[19]. H. Klemme, International Journal of Research in Aeronautical and Mechanical Engineering, volume: 2, Issue: August 2020.

[20]. F. J. Alonso, Optimal machine tool spindle drive gearbox design. International Journal of Mechanical and Production Engineering Research and Development, Vol. 9, Issue: 4, Aug 2008.