UJEAS

UNIZIK JOURNAL OF ENGINEERING AND APPLIED SCIENCES

UNIZIK Journal of Engineering and Applied Sciences 3(4), September (2024), 1102-1116
Journal homepage: https://journals.unizik.edu.ng/index.php/ujeas
PRINT ISSN: 2992-4383 || ONLINE ISSN: 2992-4391

Chatter in CNC milling machine of 4340 alloy steel under varying lubricating conditions

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Abstract
In this study of chatter in a CNC milling machine of 4340 alloy steel under varying lubricating conditions, the study conducted an experimental study of machining vibration on 4340 Alloy Steel with various cutting fluids. The fluids employed were soluble oil, mineral oil and sunflower oil. The Physiochemical Properties of soluble oil, Sun-Flower Seed Oil and Mineral Oil were determined. The study employed Box-Behnken Design for the machining vibration study, with three factors and three levels of parameters, including cutting speed, feed rate, and depth of cut. The vibration meter VB-8206SD machine was used to measure the machining vibration during the experimentation under the three-lubrication process. The interaction study shows that the cutting speed, when increased with the increase of feed rate and the depth of cut, reduces the vibration. Also, the increase in depth of cut from 0.5 mm to 1.5 mm leads to an increase in the machining vibration; the highest vibration of 62 (mm/sec) was observed. The optimal machining vibration parameters for this study are a cutting speed of 2000 rpm, feed rate of 134 mm/rev, and depth of cut 0.5 having machining vibration of 40.18 mm/sec, 33.72 mm/sec, and 28.72 mm/sec, respectively. The results show that mineral oil reduces chartered vibration by 13% compared to soluble oil-cutting environments. Furthermore, sunflower reduces the vibration by 8% compared to mineral oil and 20% with soluble oil. Therefore, the study concluded that manufacturers can employ sunflower oil as a viable cutting fluid for a sustainable machining process.

Keywords Chatter Vibration, End Milling, Cutting Fluid, Vegetable Oil, Sunflower Oil.

1. Introduction

Milling is machining flat, curved, or irregular surfaces by feeding the workpiece against a rotating cutter containing several cutting edges (Ozoegwu et al., 2024). The milling machine consists of a motor-driven spindle that mounts and revolves the milling cutter and a reciprocating adjustable worktable that mounts and feeds the workpiece. Milling is a fundamental machining operation among several CNC industrial machining processes (Okonkwo et al., 2015). End milling and face Milling are the most common metal removal operations encountered. It is broadly used in various manufacturing industries, including the aerospace and automotive sectors, where quality is a vital factor in the production of slots, pockets, precision moulds and dies. Milling is one of the most common processes in manufacturing and is very commonly employed in numerical control machines for material removal operations (Hemantsinh et al., 2017). Machine tool chatter is one of the major constraints that limit the turning process's productivity; hence, chatter monitoring is essential considering the economy of machining operations and competitiveness in the market (Okonkwo et al., 2018). Chatter is broadly classified into two categories: Primary chatter and secondary chatter. Primary chatter is sub-classified as frictional, thermo-mechanical, and mode-coupling (Ezugwu et al., 2016). This chatter is also referred to as regenerative chatter or self-excited chatter. Chatter is the most obscure and delicate of all problems facing the machinist.

Stability analysis on regenerative chatter for the orthogonal cutting process was done by Tlusty (2002), who obtained a stability lobe diagram (SLD) based on stability analysis, which showed the boundary between stable and unstable cuts. Using SLD, the operator may select chatter-free operations for the turning and milling machines for established quality control parameters. More detailed discussions regarding SLD can be seen in many papers. Chatter vibration has various negative effects, such as poor surface quality and unacceptable accuracy, tool wear and tool damage, excessive noise, low material removal rate (MRR), and low productivity rate. Metal cutting processes can entail three different types of mechanical vibrations that arise due to the lack of dynamic stiffness of one or several elements of the system composed by the machine tool, the tool holder, the cutting tool and the workpiece material (Okokpujie & Tartibu, 2023a). These three types of vibrations are known as free vibrations, forced vibrations and self-excited vibrations. Free vibrations occur when the mechanical system is displaced from its equilibrium and can vibrate freely. In a metal removal operation, free vibrations appear, for example, due to an incorrect tool path definition that leads to a collision between the cutting tool and the workpiece. Forced vibrations appear due to external harmonic excitations. The principal source of forced vibrations in milling processes is when the cutting edge enters and exits the workpiece. Engineers have developed several widely known methods to mitigate and reduce their occurrence. This vibration brings the system to instability and is the most undesirable and the least controllable. For this reason, chatter has been a popular topic for academic and industrial research (Quintana & Ciurana, 2011).

The tendency of the various structures (work-piece material, cutting tool, spindle, tool holding subassembly, etc.) to vibrate at their natural frequencies while interacting during machining and the possibility of synchronisation of the vibrations lead to chatter vibration. This phenomenon is known to be regenerative and associated with many negative effects. Chatter vibration defines the cutting parameter's maximum values, thereby operating as the limiting factor to production setups. The primary function of the MQL in metal machining operations is to serve as a coolant and lubricant, thereby reducing friction and tool wear. It is generally agreed that applying MQL can improve the tool life and result in a good surface finish by reducing thermal distortion and flushing away the machined chip (Okokpujie & Okonkwo, 2015). Cutting fluids, usually in the form of a liquid, are to the formation zone to improve the cutting condition. The application of cutting fluids is another alternative to obtain higher material removal rates. Cutting fluids have been used widely in all machining processes; however, using different cutting fluids (lubricants) for the minimum cutting lubrication condition will reduce friction and tool wear, reducing the frequency vibration and improving the cutting condition.

Therefore, this study aims to compare the results of the chartered vibration analysis from three cutting fluids: soluble oil, mineral oil, and sunflower oil. Also, the effects of the machining parameters were studied in these various cutting environments. The following objectives are enlisted to design the experimental setup using the Box-Behnken Design for three factors at three levels to achieve it. Determine the Physiochemical Properties of Sun-Flower Seed Oil and Mineral Oil, which will be used as lubricants. Compare the results of the machining vibration frequency of soluble, mineral, and sunflower oils.

2.0 Material and methods

2.1 Determination of the Physiochemical Properties of Soluble Oil, Sun-Flower Seed Oil and Mineral Oil.

The different methods used to determine the physiochemical properties like density, kinematic viscosity, moisture content, acid value of oil, cloud and pour point of oil were applied to determine the physiochemical properties of soluble, mineral, and sunflower seed oil.

2.1.1 pH value determination

The pH of a solution measures the hydrogen ions concentration in mol / dm^3 contained in the solution. It determines the acidity or alkalinity of a solution. This study determined the pH reading using the Oakion ion-700 pH meter. The sample was poured into a 250 ml beaker, and the pH meter probe was inserted. Thereafter, the pH value was determined when the reading remained stable and indicated ready on the pH meter.

2.1.2 Density

The density was determined at room temperature and 40 ^oC. The empty density bottle (pycnometer) was weighed and recorded as W_1. Afterwards, the density bottle was filled with water, and the weight was recorded as W_2. Furthermore, the bottle was emptied and properly cleaned, the sample was poured into the bottle, and the weight was recorded as W_3.The density of the sample was then determined using equation (1):

$$RD = \frac{W_0}{W_W} = \frac{W_3}{W_2} - \frac{W_1}{W_1} = \frac{W_3}{W_2} \tag{1}$$

2.1.3 Kinematic viscosity

Transesterification reaction reduces the viscosity in both edible and non-edible oils. Viscosity was determined according to the ASTM D445 procedure. A programmable rheometer was used to carry out this analysis. The rheometer comprises a spindle, a stainless cup and a rotor. The sample was preheated to 60^oC and was poured into the stainless cup of the DV-III –ultra–programmable rheometer (Brookfield: model III U). The rotor and spindle were immersed into the cup, and the rheometer was set to a speed of 250 rpm. The dynamic viscosity was immediately recorded when the temperature dropped to 40^oC, room temperature, and 15^0C; the kinematic viscosity was determined using the equation (2), where μ is dynamic viscosity.

$$V = \frac{\mu}{Density\ of\ the\ sample} \tag{2}$$

2.1.4 Moisture Content

The sample's moisture content was determined by weighing an empty pan with the lid, after which some oil was poured into the pan. The weight was noted before heating at 105^0C for 1 hour, and the final weight after heating was also noted. The formula in equation (3) was used to calculate the moisture content of all the oils.

$$\text{Moisture Content} = \frac{\text{Initial weight of sample} - \text{final weight of sample}}{\text{Initial weight of sample}} \tag{3}$$

2.1.5 Acid Value of Oil

The acid value measurement was carried out according to the ASTM-D664 method. A solvent (125cm^3) consisting of 50% toluene and isopropyl alcohol, respectively, was properly prepared in a beaker and mixed in a beaker. 2g of the oil sample and 2 drops of phenolphthalein indicator were added to the mixture. The solution was titrated with 0.1M KOH (Potassium Hydroxide) until the colour changed to pink and the titer value was noted. The acid value was calculated using the equation (4) (Nishat et al., 2024).

$$\text{Acid value} = \frac{56.1 * \text{M}}{\text{Sample weight}} \tag{4}$$

56.1= Molecular weight of KOH; M = Molarity of KOH

2.1.6 Cloud and Pour Point

A measuring cylinder and thermometer determined the sample's cloud and pour points produced under optimum conditions. The measuring cylinder was filled with the sample to determine the cloud point, after which it was preheated to obtain a clear colour. The measuring cylinder was then sealed with a stopper, and the thermometer was dipped into the measuring cylinder (Usman et al., 2024). The cylinder was placed in a fridge (ice bath) while the cloudiness was observed at 2mins. Afterward, the temperature at which the cloud was observed in the measuring cylinder was recorded as the cloud point. Following the same manner of determining the cloud point, the pour point was observed as the temperature at which the sample could not move or pour out from the measuring cylinder, which is the freezing point.

2.2 Workpiece Materials Properties and Experimental Setup

The workpiece used for the study is an AISI 4340 alloy steel plate because it is important in manufacturing industries to produce mechanical components with dimensions of 100 mm (length), 40 mm width and 10mm thickness. Detailed information on the chemical composition and the physical properties of the 4340 alloy steel is provided in Table 1 and Table 2, and details of the experimental outlay for the turning tests are shown in Table 3.

Table 1: Chemical composition of 4340 Alloy steel

Carbon	0.38-0.43%
Chromium	0.7-0.9
Iron	Balance
Manganese	0.6-0.8
Molybdenum	0.2-0.3
Nickel	1.65-2
Phosphorus	0.035 max
Silicon	0.15-0.3
Sulphur	0.04max

Table 2: Physical properties of 4340 Alloy steel

Properties	Units
Density	7850kg/m^2
Melting point	1427^{0}C
Tensile strength	745 MPa
Yield strength	470 MPa
Bulk modulus	140 MPa
Shear modulus	80 GPa
Elastic modulus	190-210GPa

Table 3: Details of the Experimental Outlay

Parameter Factors	**Levels**			**Lubrication Condition**
	1	**2**	**3**	
Cutting speed	1000	1500	2000	Soluble Oil
Feed rate	100	150	200	Mineral Oil
Depth of cut	0.5	1	1.5	Sunflower Oil

2.3 Experimental Setup and Procedure

Figure 1 shows the experimental setup of WM40-WARO CNC milling machine with Spindle speed 4000rpm, Feed rate 50-400mm/min, Axis -3axis, Power-3hp, frequency 50hz for the machining of 4340 Alloy steel. The VB-8206SD Vibration Meter was used to measure machine vibration using the three lubricants. The following steps were employed.

i. Each workpiece of the referenced materials was clamped in the machine table. The machine vibration was determined experimentally by placing the vibrometer on the surface between the workpiece and the cutting tool.
ii. The reference points were taken for the three-axis milling machine before the machining process occurred.
iii. An HSS Cutting Tool of 16 mm diameter was employed as the machining tool.
iv. At each machining process, the cutting speed, feed rate, and depth of cut were automatically set to determine the effects of the machining parameters on the machine vibration. The experimental setup is depicted in Figure 1.

After each machining media, i.e. lubricant, the machine is cleaned, and the other lubricants are used for comparative analysis. Seventeen experimental runs were carried out for the soluble oil, and the vibration analysis was recorded. The same was done for mineral oil and sunflower oil.

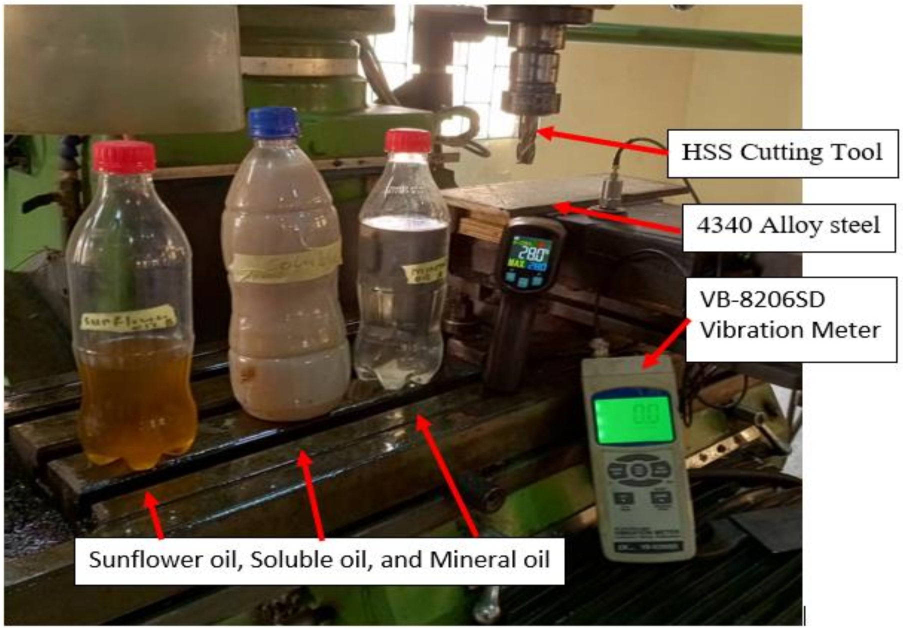

Figure 1: Experimental setup

The experiment design for the current research is based on the Box-Behnken. Box-Behnken parameter design is a type of response surface methodology design similar to traditional DOE methods in that multiple input parameters can be considered for a given response. The Bx-Behnken method allows researchers to predict the ideal combination of independent variables (or input variables) to give the best result on a dependent variable. It can also be used to find which input variable has the greatest effect.

3.0 Results and Discussions

3.1 Results of the Physiochemical Properties of the Developed Cutting Fluid

The physiochemical analysis of the cutting fluid employed in this study shows the viability of implementing cutting fluids such as mineral oil and sunflower oil in the machining process. Table 4 shows the physiochemical properties of mineral oil and sunflower oil. However, sunflower oil is locally developed without additives compared to the mineral oil extracted from plants.

Table 4: Comparative Study of the Physiochemical Properties of Soluble Oil, Mineral Oil and Sunflower Oil

S/N	Physiochemical properties	Soluble oil	Mineral oil	Sunflower oil
1	Moisture content	66%	6.1%	11.8%
2	Kinematic viscosity	0.249cp	0.039cp	0.088cp
3	Acid value	6.17g/ml	2.244g/ml	2.104g/ml
4	Density	$1.016g/cm^3$	0.846g/cm	$^3 0.890g/cm^3$
5	Pour point	-20^0C	-18^0C	-14^0C
6	Cloud point	-8^0C	-10^0C	-8^0C
7	pH value	6.35	7.03	6.40

The kinematic viscosity was measured at an environmental temperature of 40^oC, with the soluble oil 0.249cp, mineral oil 0.039cp and 0.088cp for sunflower oil. This shows that the soluble oil has a higher flow resistance than the mineral oil and sunflower, and the sunflower oil's kinematic viscosity is slightly higher in the flow resistance than the mineral oil and soluble oil so it will serve as a good lubricant for friction and vibration reduction. The moisture content of the soluble oil is 66%, while the mineral oil has 6.1%, and sunflower oil is 11.8% with a density value of $1.016g/cm_3$, $0.846\ g/cm^3$ and $0.890\ g/cm_3$. An acid value of 6.17g/ml for soluble oil, 2.244g/ml for mineral oil and 2.104g/ml for sunflower oil. A pour point of -20^0C was obtained for soluble oil, -18^0C was obtained for mineral oil, and -14^0C was achieved for sunflower oil. This finding aligns with the study of Sahasrabudhe et al. (2017). Also, it can be seen that the pH values of the three oils are within the range of 6.35 and 7.03, which is quite good. The cloud point values within the range of -10^{0}C to -8^{0}C show that the oils are well-blended cutting fluid that will hardly lose its cutting fluid values during the machining process thereby is good lubricant for reducing vibrations. The quality criteria for cutting fluid is that it must be able to reduce friction and vibration while still carrying out the cutting process (Okokpujie et al., 2017).

3.2 Results of Vibration Obtained from the Milling Machining of 4340 Alloy Steel

Table 5 shows the experimental results obtained during the milling of 4340 alloy steel under soluble oil, which is the control fluid, mineral oil, and sunflower oil. The machining parameters considered are cutting speed ranging from 1000 rpm to 2000 rpm, feed rate from 100 to 200 mm/rev, and depth of cut from 0.5 to 1.5 mm. The results show that mineral oil reduces chartered vibration by 13% when compared with soluble oil-cutting environments. This is a result of the mineral oil having high lubricity at the cutting region, which prevents the chips from attaching themselves to the cutting tool during the machining process (Ibrahim et al., 2023). Furthermore, sunflower reduces the vibration by 8% when compared with mineral oil and 20% when compared with soluble oil. Because of the soluble oil pour and cloud point, also from observation, the sunflower oil was able to penetrate the cutting region. It was able to create a sliding effect whereby, reducing the frictional effects between the cutting tool and the workpiece.

Table 5: The Vibration Results from the Milling of 4340 Alloy Steel under Various Cutting Fluids

Run	**Factor 1 A: Cutting Speed (RPM)**	**Factor 2 B: Feed - rate (mm/rev)**	**Factor 3 C: Depth-of-cut (mm)**	**Response 1 Vibration soluble oil (mm/sec)**	**Response 2 Vibration-mineral-oil (mm/sec)**	**Response 3 Vibration-sunflower-oil (mm/sec)**
1	1500	150	1	50	43.5	40
2	2000	200	1	46	40	36
3	1000	150	1.5	60	54	49.8
4	1000	150	0.5	56	50	46
5	2000	100	1	43	36.5	32.8
6	1500	100	1.5	55	48.5	44.8
7	1500	100	0.5	53	46.5	43.2
8	1500	150	1	50.9	45	41
9	1000	200	1	58	51.5	47.8
10	1500	150	1	51	45.5	40.8
11	2000	150	1.5	48	42	37.8
12	2000	150	0.5	40	33.5	28
13	1500	150	1	49	43	38.8
14	1500	200	0.5	46.5	40	35
15	1500	200	1.5	62	56.2	51.8
16	1000	100	1	59	52.5	48.8
17	1500	150	1	52	45.5	42.5

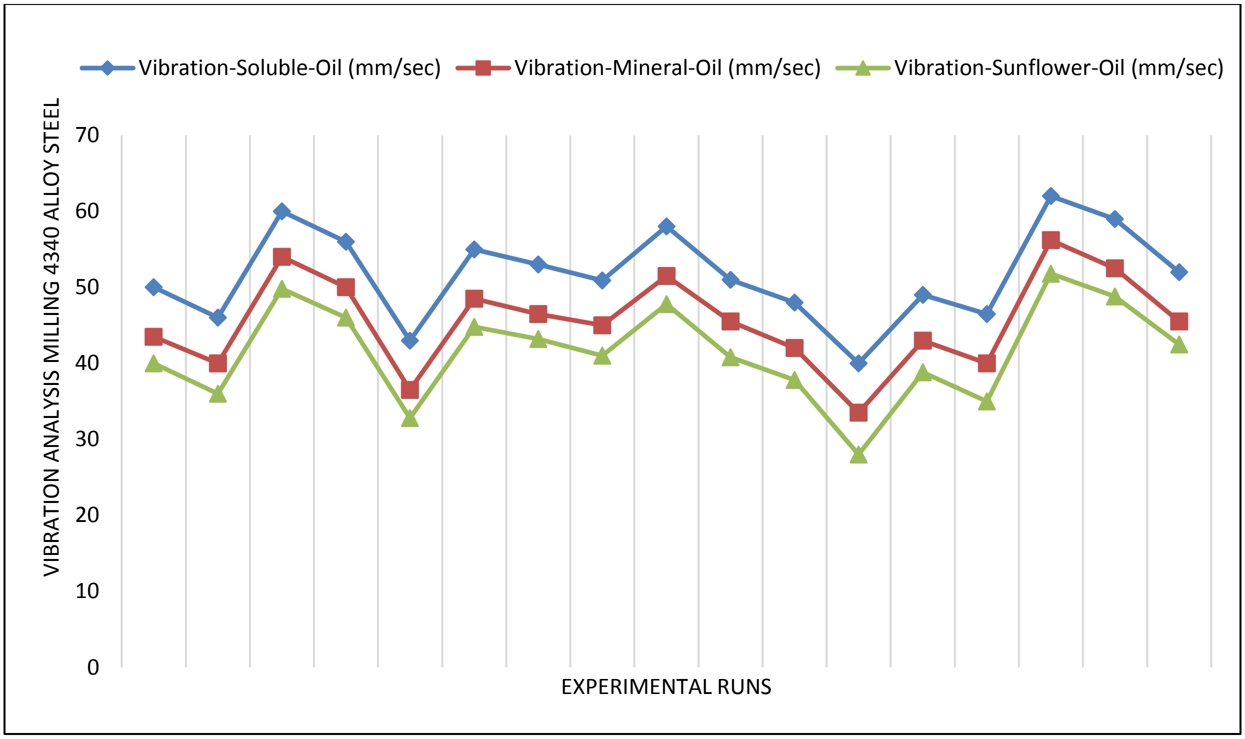

Figure 2: Comparative analysis graph of the vibration from the three-cutting fluid for Milling 4340 alloy steel

Figure 2 shows the comparative analysis graph of the vibration from the three-cutting fluid for Milling 4340 alloy steel demonstrates the performance of the soluble, mineral, and sunflower oil during the machining process. It can be seen from the results and the graph that sunflower oil reduces the vibration process much as when compared with other cutting fluids, such as mineral oil and soluble oil (Kazeem et al., 2024). From experimental observation, the soluble oil has good cooling properties, but its lubricity is low compared to the sunflower oil that is the sunflower there is lesser vibration than mineral oil and soluble oil.

3.3 Comparative Analysis of Cutting Speed and Feed Rate Effects on Machining Vibration Frequency under the Three Cutting Fluid

The analysis of this study involves three major machining parameters: cutting speeds, depth of cut, and feed rate. However, in this session, the cutting speed and the feed rate comparative effects were analysed using Box-Behnken via Design Expert 13 in order to study the combined effects of the two machining parameters on the machining vibration frequency during the milling of 4340 Alloy Steel under three lubrication condition, such as soluble oil, mineral oil, and sunflower oil. The contour plots and the contour lines explain the interaction effects of the cutting speed and feed rate on the machining vibration for the soluble oil, mineral oil and sunflower oil, as shown in Figures 3 to 5. From the analysis, it can be seen that as the feed rate increases from 100 (mm/rev) to 200 (m/rev) with a slight increase of the cutting speed between 1000 rpm to 1300 rpm, the machining vibration increases as a result of the movement of the machine parts in contact with the chips and the cutting tool this result is in line with the study from Gu et al. (2023). The vibration originates from the chip's thickness as a result of the depth of the cut. Also, the cutting condition has many effects on the machining vibration. From observation during the experimental study, the soluble oil, when applied, was a good cooling process because the component was mixed with water to form the soluble oil (Şap et al., 2024). However, its ability to improve the lubrication process was not as efficient as mineral oil and sunflower oil (Roy et al., 2024). Therefore, the study shows that sunflower oil has a great potential to reduce machining vibration compared to mineral oil (Zhang et al., 2023). Its physiochemical analysis shows that the sunflower has a lower pour point of -14^{0}C and cloud point of -8^{0}C when compared with the mineral oil pour point of -18^{0}C and cloud point of -10^{0}C

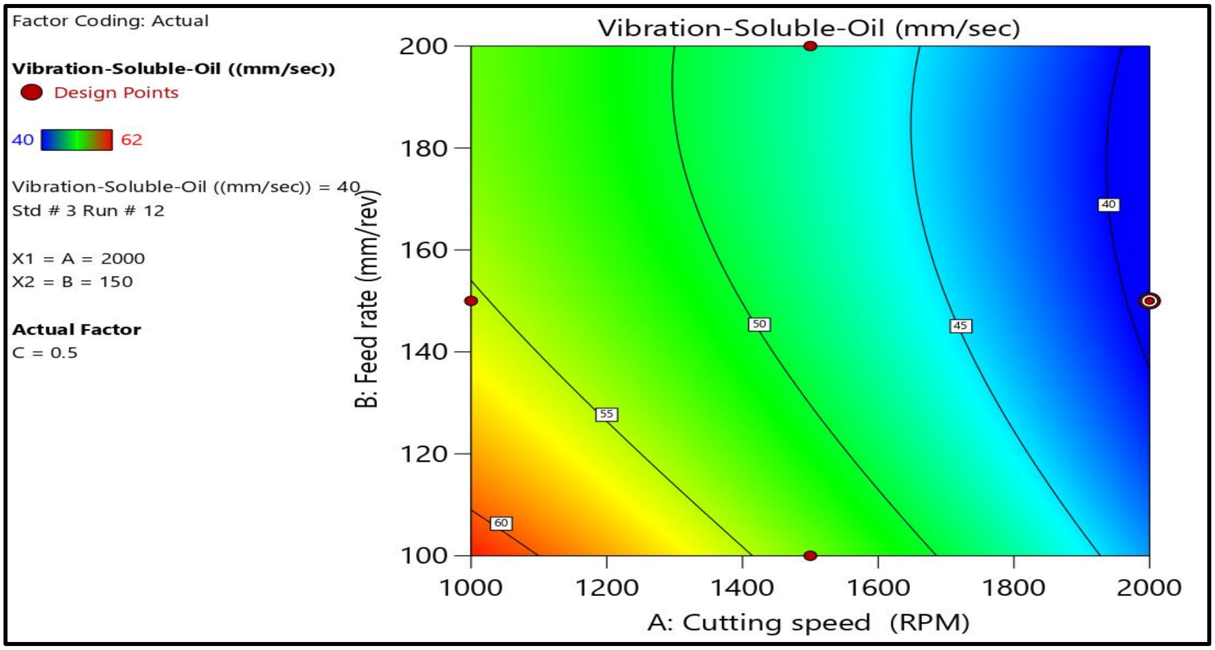

Figure 3: Cutting speed and feed rate impact on machining vibration frequency under soluble oil lubrication condition.

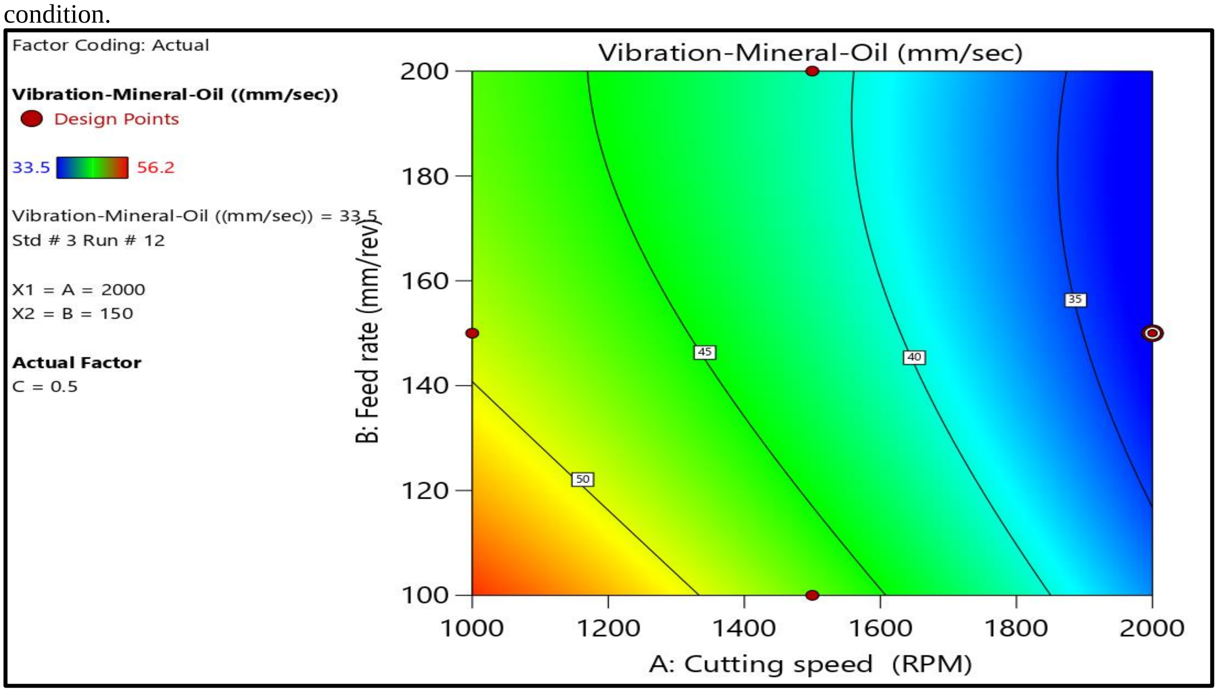

Figure 4: Cutting speed and feed rate impact on machining vibration frequency under mineral oil lubrication conditions.

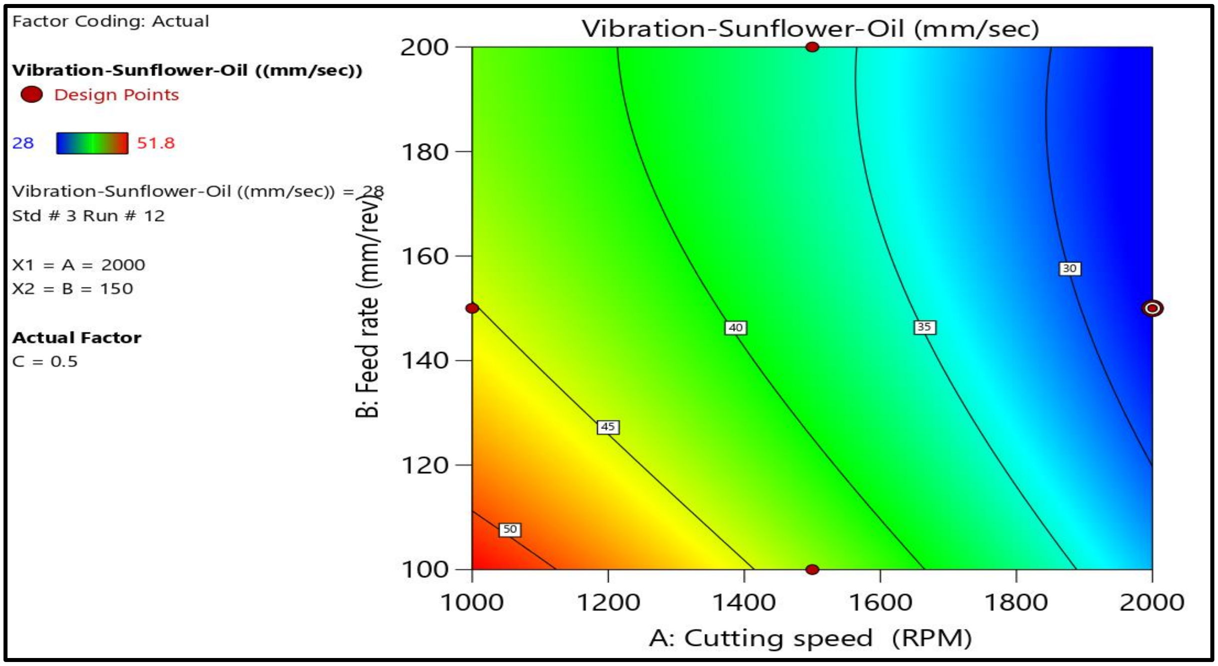

Figure 5: Cutting speed and feed rate impact on machining vibration frequency under sunflower oil lubrication condition.

Therefore, it can be seen in the three environments that at low cutting speed with average feed rate, the machining vibration increases having a cutting speed of 1000 (rpm), feed rate of 100 (mm/rev) and depth of cut at 1 (mm) as shown in Figures 4 to 5,this result is in line with Duman et al. (2024). Also, having a cutting speed of 1500 (rpm) with a feed rate of 200 (mm/rev) and a depth of cut 1.5 (mm) produces the highest machining vibration of 62 (mm/sec) for soluble oil, 56.2 (mm/sec) for mineral oil, and 51.8 (mm/sec) sunflower oil. The contour lines also assist in explaining the values of the machining vibration with the colour variations.

3.4 Comparative Analysis of Cutting Speed and Depth of Cut Effects on Machining Vibration Frequency under Various Cutting Fluid

The depth of cut in the study of vibration plays a great role because the depth of cut, when increased beyond some certain value during machining, can lead to chart machining vibration. However, from this study, the interaction effects of the cutting speed and depth of cut can be seen in Figure 6 for soluble oil analysis, Figure 7 for mineral oil, and Figure 8 for sunflower oil cutting conditions or environments. From the three-cutting condition, at a lower depth of cut of 0.5 (mm), the machining vibration is low, having a range between 48 to 50 (mm/sec), even with a low cutting speed of 1000 (rpm). This aligns with the study from (Zhao et al., 2024).

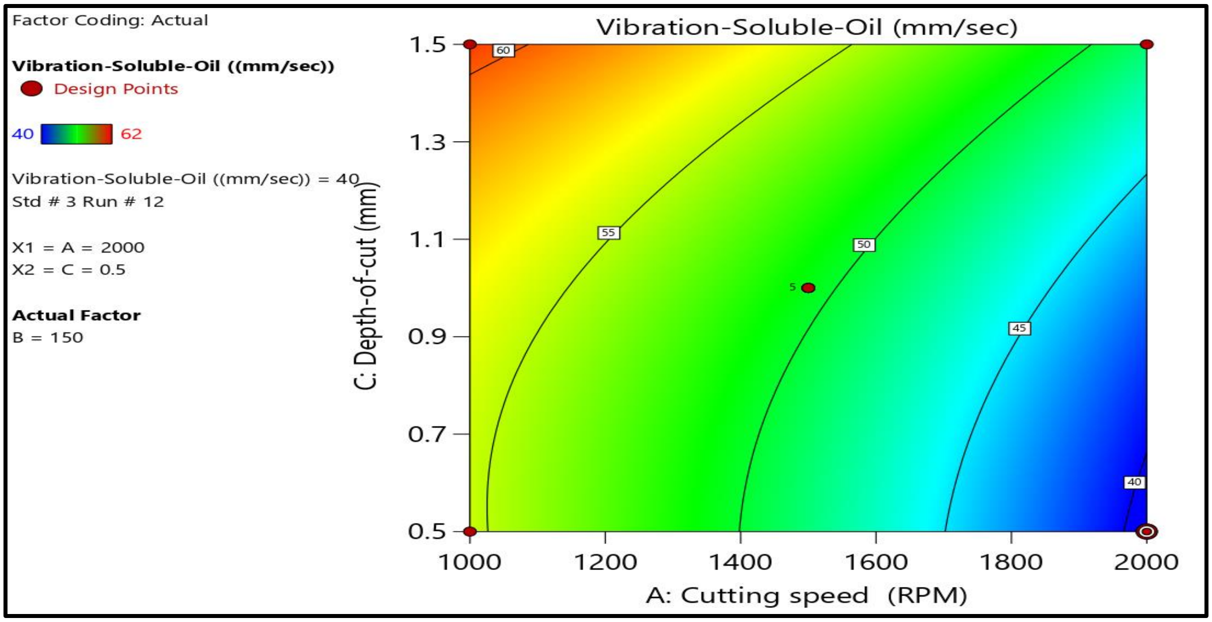

Figure 6: cutting speed and depth of cut impact on machining vibration frequency under soluble oil lubrication condition.

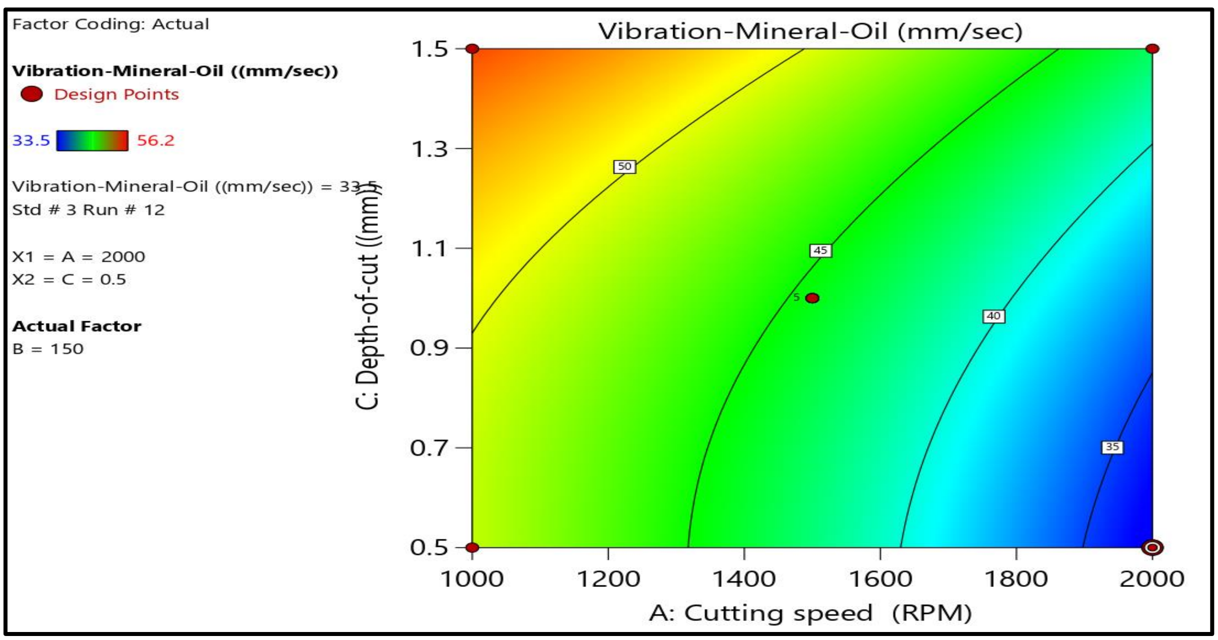

Figure 7: cutting speed and depth of cut impact on machining vibration frequency under mineral oil lubrication condition.

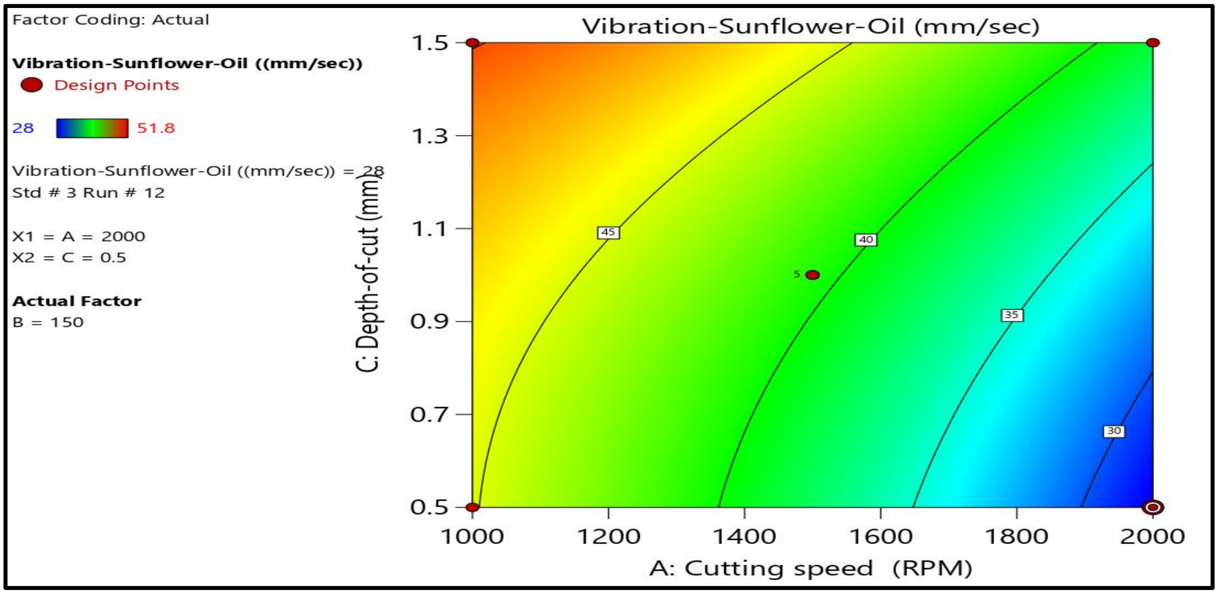

Figure 8: Cutting speed and depth of cut impact on machining vibration frequency under sunflower oil lubrication condition.

This implies that the thickness of the chip is reduced at a low depth of cut, which will enable the cutting tool to remove easily without much cutting force (Okokpujie & Tartibu, 2023b). When the cutting force is high due to the high depth of the cut, the machining vibration will also increase, leading to a rough surface of the developed mechanical component (Umasekar and Stalin John, 2023). Also, this vibration will increase the temperature at the cutting region due to excess contact between the chips, cutting tool and the workpiece. This temperature increase can affect how the materials will perform during operations.

3.5 Comparative Analysis of Feed Rate and Depth of Cut Effects on Machining Vibration Frequency under Various Cutting Fluid

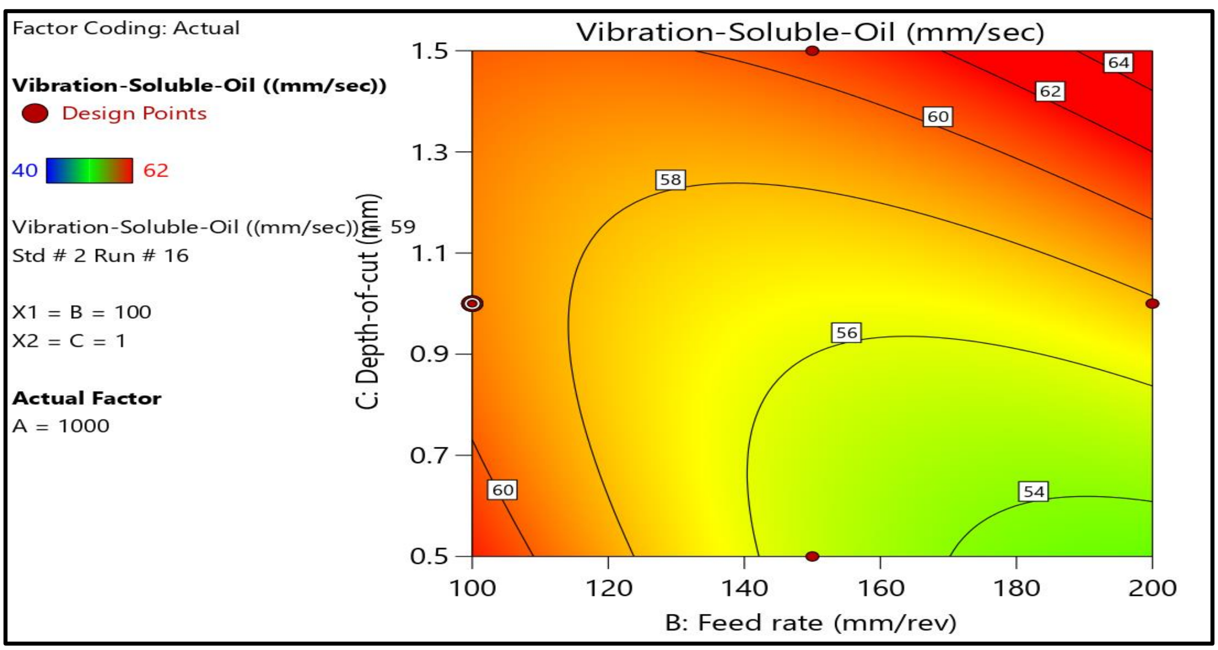

Figure 9: Feed rate and depth of cut impact on machining vibration frequency under soluble oil lubrication condition.

The interaction study of the cut and feed rate depth is a significant aspect of analysing milling machining process factors. Both parameters have their degree of freedom in the vibrational study with the tendency to increase machining vibration. The feed rate relationship with the depth of cut is shown in Figure 9, Figure 10, and Figure 11 under the three-lubrication process: soluble oil, mineral oil, and sunflower oil, respectively. The contour plot in this study shows that the feed rate is 100 (mm/rev), with a depth of cut of 1 (mm) and a constant cutting speed of 1000 (rpm). The study shows that the machining vibration increases with the increase in the feed rate and the depth of cut (Kodama et al., 2023).

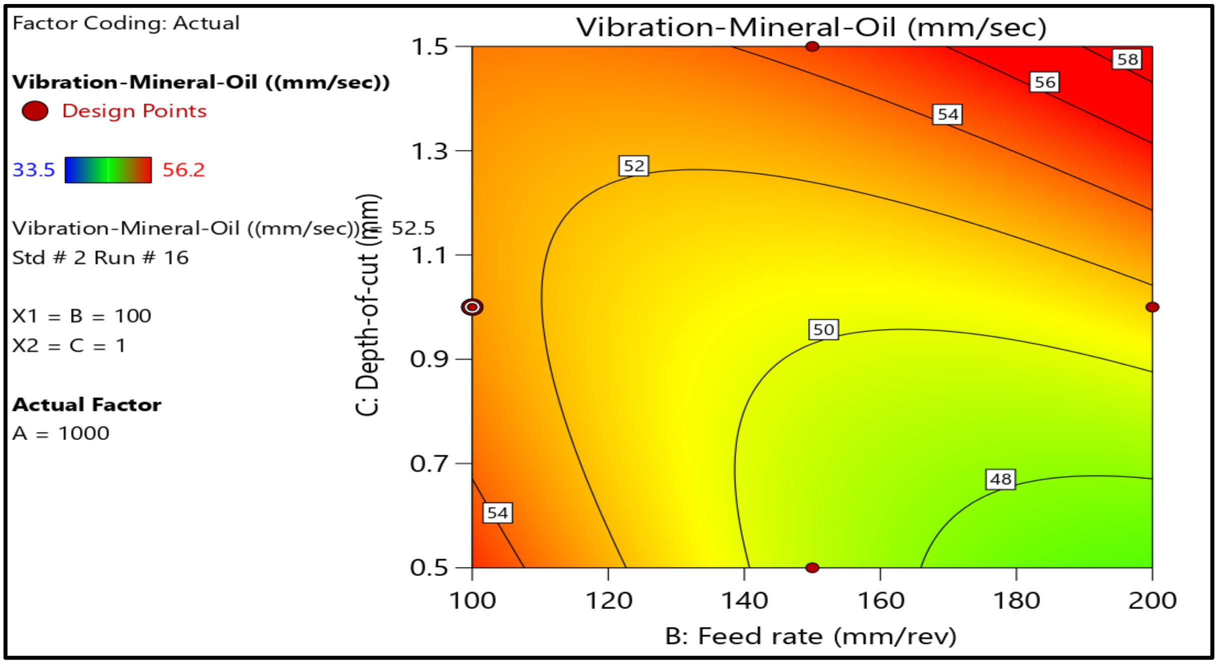

Figure 10: Feed rate and depth of cut impact on machining vibration frequency under mineral oil lubrication condition.

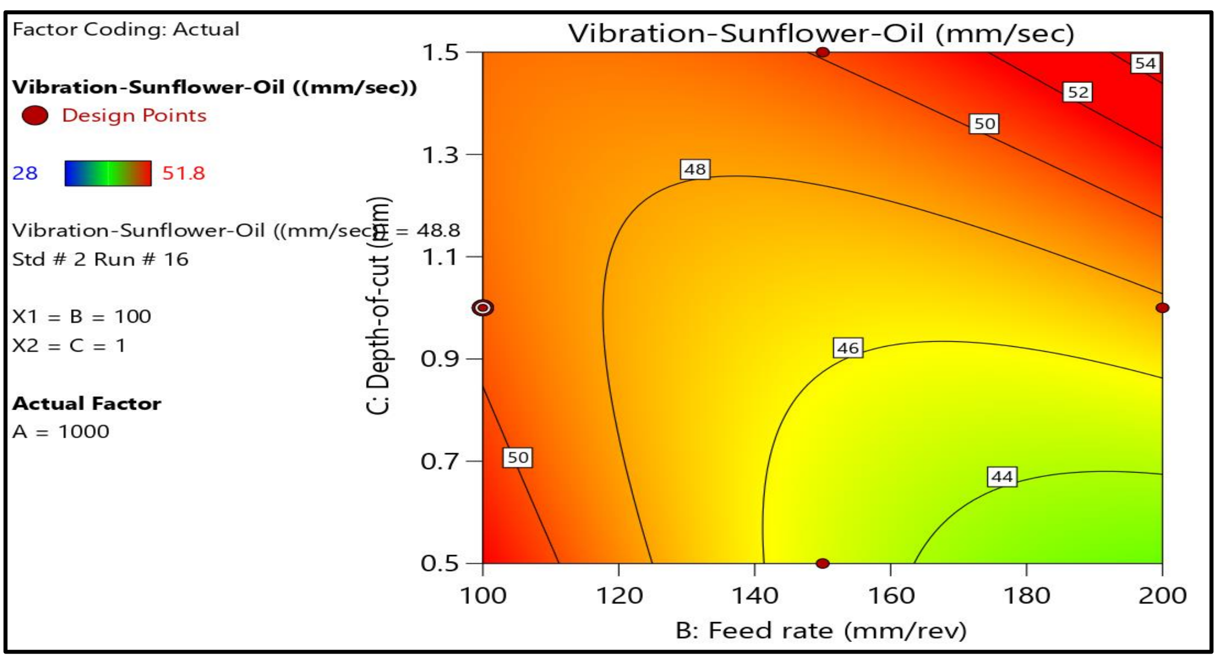

Figure 11: Feed rate and depth of cut impact on machining vibration frequency under sunflower oil lubrication condition.

However, the variation analysis results from the cutting speed's interference. The cutting speed assists in eliminating the buildup edge formed by the chips produced at the machining region; the cutting fluid also reduces it by flushing away the chips at the regional areas (Pimenov et al., 2023). From the graph analysis, the machining vibration reaches 62 to 64 (mm/sec) at the highest depth of cut of 1.5 (mm). Therefore, the difference between soluble oil, mineral oil, and sunflower oil results in sunflower oil being more compositional in terms of super-lubricity. This enables the cutting tool to slide across the workpiece without much effect on the surface analysis of the materials (Okokpujie et al., 2024).

4.0. Conclusion

This research employed the 4340 alloy steel for milling under different cutting fluids. The cutting fluids employed are soluble, mineral, and sunflower. The study considered three milling parameters: cutting speed, feed rate, and depth of cut to study the machining vibration. The Box-Behnken Design is employed for the prediction, interaction and optimisation study. From the results obtained, the study has the following conclusions.

i. The cutting fluids employed in this study are viable for the milling machining. The physiochemical properties results gotten shows that the cutting fluid can be able to reduce the temperature at the cutting region, which reduces the material adhesion that leads to high vibration due to chips discontinuity in machining process in CNC milling machine.

ii. From the analysis, it can be concluded that the spindle speed reduces the vibration. However, when the cutting speed was from 1500 to 2000 rpm, the minimum machining vibration was achieved, with 40 (mm/sec) for soluble oil, 33.5 (mm/sec) for mineral oil, and 28 (mm/sec) for sunflower oil. However, the feed rate increases with the increase of machining vibration; this is also in line with the depth of cut.

iii. For the interaction study, it can be concluded that as the cutting speed when increases with the increase of feed rate and depth of cut, the vibration reduces. However, the increase in depth of cut from oil 0.5 mm to 1.5 mm increases the machining vibration, and the highest vibration was observed at 62 (mm/sec).

5.0 Recommendation

The study will further recommend that more related works on machining vibration using a hybrid of two to three vegetable oil. Further work can also be carried out to include the flow rate of the lubricant/coolant, with different cutting tool materials and other geometric factors. It can also include cutting force, rake angles, all of which have effect on the vibration.

Acknowledgements

I wish to appreciate everybody that made direct or indirect contribution to the success of this work.

My exceptional thanks go to my Supervisor, Engr. Prof. Ugochukwu C. Okonkwo for his special assistance in this work; he took time out of his tight schedule to go through this work and made some recommendations that have helped improve the standard of this work.

I also wish to express my gratitude for the part played by Dr. Jude E. Dara, the Head of the Department of Mechanical Engineering.

My acknowledgment will not be complete without a heartfelt appreciation of the contributions made by Engr. Prof. C. E. Chinwuko and other lecturers in the department of mechanical engineering, as well as the technologists of the department.

My appreciation also goes to Engr. Dr.Imhade Princess Okokpujie, Department of Mechanical and Mechatronics, Afe Babalola University, Ado Ekiti State, for allowing me to use their facility for this research.

Much encouragement came from my family. I also thank my friends and classmates for their hospitality and encouragement.

Ultimately, I worship God almighty for making everything possible for me.

Nomenclature

W_1= weight of empty density bottle (Pycnometer)
W_2= weight of filled density bottle with water
W_3= weight of filled density bottle with the sample (oil)
RD= density

μ = dynamic viscosity
ν = kinematic viscosity
M = molarity of KOH

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