International Journal of Scientific and Technical Research in Engineering (IJSTRE)
www.ijstre.com Volume 7 Issue 2 ǁ Mar-Apr 2022.
ISSN: 2581-9941

Prediction Of Vibration During Turning Of SAE 5160 Steel

Michael Kwabena Boadu[1], Isaac Foli Amuzu[2], Haruna Abdul-Fatawu[3], Ebenezer Omari Abankwa[4]
[1,2,3,4]Department of Mechanical and Industrial Engineering, University for Development Studies, Ghana
mboadu@uds.edu.gh[1]

Abstract. *The manufacturing industry's fierce competition has resulted in a never-ending search for cost-effective cutting operations. Faster machining and shorter cycle times are thus, required for increased productivity. This study presents an analysis and optimization of the vibration induced in SAE 5160 steel during a turning operation. The effect of cutting conditions comparatively, cutting speed, feed rate, and depth of cut on resultant vibration were studied on M300 Harrison Lathe in a Dry Turning environment using SAE 5160 Steel as workpiece and HSS cutting tool. The design of the experiment was implemented by utilizing the* 2^3 *factorial design method with confirmatory tests to verify the findings. The study indicated the depth of cut as the principal factor on the resultant vibration while turning SAE 5160 Steel. The* R^2 *value for vibration was 97.13% which showed that the model fitted the data well. The average percentage error for predicting the vibration was* -0.23706 *which fell within the range of* ± 5.0 *and thus, renders its corresponding model valid for subsequent predictions of vibration. The optimal cutting conditions for minimum vibration were obtained at low cutting speed (40 m/min), low feed rate (0.0.1 mm/rev), and low depth of cut (0.5 mm).*

Keywords – *Prediction, SAE 5160 Steel, Turning, Vibration*

I. Introduction

Vibration and its debilitating potential are at the forefront of every mechanical engineer's mind throughout the design and analysis period, thanks to ever-increasing advances in automation and the development of powerful machinery around the world. It is possible for all bodies with mass and elasticity to vibrate [1]. Undesired vibration in machine tools such as lathes is a major issue because it reduces the accuracy of machined components, shortens tool life, and generates noise during the machining process [2]. The ardent rivalry in the manufacturing industry has instigated a persistent search for efficient cutting procedures to minimize costs. Faster machining and shorter cycle times are required for increased productivity. To meet these exigencies, it is desired that variables such as cutting speed, feed, and depth of cut are increased [3]. However, increases in material removal rates, productivity, surface finish, and dimensional accuracy of machined components continue to be hampered by chatter. Chatter vibrations, which can occur in any metal cutting process, are a common productivity limiting problem in metal machining. For a long time, the issue has afflicted the industrial sector and it has been a prominent topic for academic and industry inquiry. Process optimization using modeling and analysis is possible if the vibrational properties of the tool are known [3]. As a result, the ability to anticipate these vibrations using the combined outputs of the machine tool and cutting tool is critical. The selection of optimal cutting parameters such as feed rate, depth of cut, and cutting speed, as described by Thomas [4], creates ideal machining conditions by minimizing the resulting vibration signal. This has several advantages including reduced tool wear, improved surface finish, longer tool life and increased reliability due to reduced machine setup time, and thus, has become a manufacturing industry requirement. Tobias [5] described three different forms of mechanical vibrations as free, forced, and self-excited. Free vibrations are caused by shock whereas forced vibrations are caused by imbalances in machine tool assemblies. Vibrations, both free and forced, could be effortlessly recognized and eradicated. Rahman et al. [6] in their work, conducted dry turning tests on S45C steel using carbide insert tool to find a correlation between dimensional anomalies against cutting conditions and vibration during dry turning. Variance (ANOVA) and regression analysis were utilized to examine the influence on dimensional deviation due to the cutting parameters and vibration. According to the study, machine tool vibration has a notable influence on dimensional anomalies. A verification experiment with variable levels of machining parameters was done to validate the credibility of the built model. According to the results, machine rigidity, as well as amplitude of vibration in the x-axis and y-axis and the cutting depth are key variables which affect dimensional differences. Raza [7] employed Taguchi L16 and L9 orthogonal array algorithm of design to investigate the consequences of cutting variables on turning of chromium 4140 steel. The main cutting conditions considered were cutting speed, feed rate, and depth of cut. They recommended that the quality of the work can be improved by employing a variety of operational conditions including cutting tool and material type. Pawar [8] performed some test to examine the influence of machining conditions like cutting speed, feed rate, and depth of cut on resultant vibration in a dry turning environment for hard 62-64HRC AISI M2 utilizing the Taguchi method and analysis of variance (ANOVA). The Author validated the results by taking confirmation experiments. The study concluded that feed rate was the highest influencing variable for resultant vibration for turning hard AISI M2 material. Using the Taguchi design of experiments, Raju et al. [9] examined the impact of cutting conditions on cutting force, tool wear, and surface finish during continuous dry turning of AISI 4340. It was discovered that feed had a considerable impact on tool wear whiles the cutting depth had the least influence. Cutting speed of 140 m/min, feed of 0.125 mm/rev, and depth of cut of 0.8 mm were found to be optimal cutting conditions. The primary goal of this work is to predict the vibration produced during turning of SAE 5160 steel using factorial design technique.

II. Material

SAE 5160 Steel was selected as the test material due to its availability and extensive usage in industry. It is remarkably strong and durable. It also has high resistance to fatigue, high ductility and has good spring features which makes it suitable for applications which requires flexibility. SAE 5160 steel is used for the production of anti-roll bars, coil and leaf springs etc. [10], [11]. The chemical composition is shown in Table 1.

Table 1: Chemical Composition of SAE 5160 Steel

Element	C	Si	Mn	P	S	Cr
Content %	0.59	0.22	0.96	0.016	0.018	0.86

Source: [12]

III. Method

Turning operations were executed by employing the cutting speeds, 40 - 260 rpm; depths of cut, 0.5 mm – 1.0 mm; and feeds, 0.1- 0.2 mm/rev. Test samples were secured by altering cutting speeds, depth of cut, and feed rate, using the 2^3 factorial design matrix as shown in Table 2. The corresponding vibrations for each of the samples were measured using Keuwlsoft Accelerometer Counter version 1.2 software on an android device (SM-G900W8) attached to the tool-post as displayed in Figure 1. The speed, feed rate and depth of cut were selected to relate to specific interval of values utilized during the operation. A total of 16 experiments were conducted and the corresponding vibration was recorded for each setting.

Table 2: Experimental matrix

Input Parameters	Low (-)	High (+)
Speed	40	260
Feed	0.1	0.2
Depth of cut	0.5	1.0

Figure 1: Experimental Setup

IV. Results and Discussion

4.1: Experimental Results

The results obtained from the experiments for this research with varying cutting variables are displayed in Table 3. From Table 3, it can be found that the highest vibration (0.104 m/s^2) was recorded at a speed of 260 rpm, at a feed of 0.2 mm/rev and at a depth of cut of 1.0 mm. It can also be observed that the lowest vibration (0.048 m/s^2) was recorded at a speed of 40 rpm, at a feed of 0.1 mm/rev and at a depth of cut of 0.5 mm. The symbols N, d and f represent cutting speed, depth of cut and feed rate respectively. The symbol 'V' represents the vibration generated.

Table 3: Experimental Values for Resultant Vibrations

S/N	N	f	d	N (rev/min)	f (mm/rev)	d (mm)	V (m/s^2)
1	-	-	-	40	0.10	0.50	0.048
2	-	-	+	40	0.10	1.00	0.099
3	-	+	-	40	0.20	0.50	0.068
4	-	+	+	40	0.20	1.00	0.091
5	+	-	-	260	0.10	0.50	0.067
6	+	-	+	260	0.10	1.00	0.073
7	+	+	-	260	0.20	0.50	0.077
8	+	+	+	260	0.20	1.00	0.104
9	-	-	-	40	0.10	0.50	0.052
10	-	-	+	40	0.10	1.00	0.103
11	-	+	-	40	0.20	0.50	0.065
12	-	+	+	40	0.20	1.00	0.086
13	+	-	-	260	0.10	0.50	0.053
14	+	-	+	260	0.10	1.00	0.077
15	+	+	-	260	0.20	0.50	0.080
16	+	+	+	260	0.20	1.00	0.110

4.2 Analysis of Variance

To appreciate the effects and significance of the individual machining variables on the induced vibration signal, the ANOVA technique was employed to correlate the relative contributions of each factor to the total observed response as displayed in Table 4.

Table 4: Analysis of Variance (ANOVA)

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Interpretation
Model	7	0.005458	0.000780	38.62	0.000	Significant
Linear	3	0.004188	0.001396	69.15	0.000	Significant
N	1	0.000053	0.000053	2.60	0.145	Insignificant
f	1	0.000743	0.000743	36.78	0.000	Significant
d	1	0.003393	0.003393	168.08	0.000	Significant
2-Way Interactions	3	0.000818	0.000273	13.51	0.002	
N*f	1	0.000541	0.000541	26.78	0.001	Significant
N*d	1	0.000218	0.000218	10.78	0.011	Significant
f*d	1	0.000060	0.000060	2.98	0.123	Insignificant
3-Way Interactions	1	0.000452	0.000452	22.37	0.001	
N*f*d	1	0.000452	0.000452	22.37	0.001	Significant
Error	8	0.000162	0.000020			
Total	15	0.005619				

4.3 Generation and Validation of Model

4.3.1 Generation of Model

The intent of the current work was to appreciate the impact of the cutting variables such as cutting speed, cutting depth and feed rate on vibration. The uncoded model which was generated by Minitab 19.0 for the vibration response is as shown in Equation 1.

Regression Equation in Uncoded Units

$$V = -0.0622 + 0.000393\,N + 0.529\,f + 0.1885\,d - 0.001841\,N\,x\,f - 0.000714\,N\,x\,d - 0.735\,f\,x\,d + 0.003864\,N\,x\,f\,x\,d \quad (1)$$

Where V = vibration, N= cutting speed; f = feed rate and d = depth of cut. The R^2 value for the response was found to be 97.13%. This implies that the model for vibration fits the data well.

4.3.2 Validation of Model

During the validation process, Minitab 19.0 was also utilized to produce the predicted values to evaluate the authenticity of the uncoded model. The values obtained from the experiment for vibration were compared to the predicted values. The reference percentage error utilized for this study was ± 5.0. In a situation where the mean percentage error falls within ± 5.0, then it actually connotes that the uncoded model is useful and can be employed for subsequent predictions of vibration. The percentage error was computed as:

$$Percentage\ Error = \{(\frac{exp\ value - predicted\ value}{\exp value})\ x\ 100\%\} \quad (2)$$

Table 5: Comparison between Predicted and Experimental Values

N	f	d	Experimental Value	Predicted Value	%Error
40	0.1	0.5	0.048	0.05	-4.16667
40	0.1	1.0	0.099	0.101	-2.0202
40	0.2	0.5	0.068	0.0665	2.205882
40	0.2	1.0	0.091	0.0885	2.747253
260	0.1	0.5	0.067	0.0600	10.44776
260	0.1	1.0	0.073	0.0750	-2.73973
260	0.2	0.5	0.077	0.0785	-1.94805
260	0.2	1.0	0.104	0.107	-2.88462
40	0.1	0.5	0.052	0.05	3.846154

40	0.1	1.0	0.103	0.101	1.941748
40	0.2	0.5	0.065	0.0665	-2.30769
40	0.2	1.0	0.086	0.0885	-2.90698
260	0.1	0.5	0.053	0.0600	-13.2075
260	0.1	1.0	0.077	0.0750	2.597403
260	0.2	0.5	0.080	0.0785	1.875
260	0.2	1.0	0.110	0.107	2.727273

$$\text{Average percentage error} = \frac{\sum_{n=1}^{n} P_e}{n} \quad (3)$$

$$= \frac{-3.79297}{16}$$

$$= -0.23706$$

From Table 5, the mean percentage error for prediction of vibration is -0.23706 which lies within the range of ± 5.0. This means that the uncoded model is actually valid and can be utilized to generate predicted results of vibration during a turning process of SAE 5160 Steel.

4.3 Optimization of Cutting Parameters

Cutting parameters play an important part in the generation of chatter. In this case, the variables such as cutting speed, feed, and depth of cut must be optimized to minimize the resultant vibration signal to enhance the tool life. Figure 3 shows an optimization plot of vibration during the turning operation.

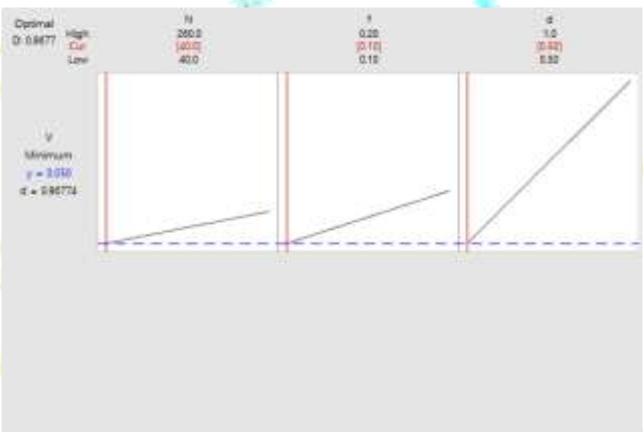

Figure 2: Optimization Plot for Resultant Vibration

It can be found from the plot that the optimal turning parameters for minimum vibration are recognized to be at low cutting speed (40.0 rpm), low feed (0.10 mm/rev) and low depth of cut (0.5 mm). On the figure, the optimal results are indicated in red. The primary goal is to reduce the vibration. Decreasing the vibration would improve the cutting operation which would eventually reduce tool wear, and improve surface quality and integrity. The composite desirability is 0.96774.

V. Conclusions

At the end of this research, the following conclusions were reached:

i. The model generated satisfactorily predicted the response parameter. The R^2 value for vibration was 97.13% and this connotes that the uncoded model fits the data well.
ii. Predictive equations for vibration were found to be valid due to the fact that their average percentage error lies within ± 5.0.
iii. The depth of cut was found as the principal parameter influencing the vibration level, and thereafter feed rate whiles cutting speed had the least effect on vibration.
iv. Lastly, the optimal cutting conditions for minimum vibration were found to be at low cutting speed (40m/min), low feed rate (0.0.1mm/rev) and low depth of cut (0.5mm).

REFERENCES

[1] Hanly S.W., (2016). "Shock & Vibration Testing Overview eBook," pp. 69.

[2] Salokyová Š., Krehel R., Pollák M., and Koačiško M., (2016). "Research on impacts of mechanical vibrations on the production machine to its rate of change of technical state," *Adv. Mech. Eng.*, vol. 8, no. 7, pp. 1–10. doi: 10.1177/1687814016655778.

[3] Liljerehn, A., (2016). Machine Tool Dynamics - A constrained state-space sub-structuring approach.

[4] Thomas, T. R. (1982). *Rough surfaces*. London: Longman.

[5] Tobias S.A., (1961). "Machine tool vibration research," *Int. J. Mach. Tool Des. Res.*, vol. 1, no. 1, pp. 1–14. doi: https://doi.org/10.1016/0020-7357(61)90040-3.

[6] Rahman M.A., (2013). "Dimensional deviation affected by cutting parameters and machine tool rigidity in dry turning of S45C steel," in *Applied Mechanics and Materials*, vol. 315, pp. 749–754, doi: 10.4028/www.scientific.net/AMM.315.749.

[7] Raza A., (2020). "Determining the effects of selected cutting parameters on Circularity and Cylindricity in turning operations for steel 4140 using Taguchi methods," doi: 10.13140/RG.2.2.18328.21768.

[8] Pawar K., (2017). "Experimental Investigation to Minimize Resultant Vibration Signal in CNC Turing Operation of Hard AISI M2 Tool Steel," *Int. J. Res. Appl. Sci. Eng. Technol.*, vol. V, no. VIII, pp. 307–318. doi: 10.22214/ijraset.2017.8042.

[9] Paul B. K. M., Raju T., and Biju B., (2014). "Optimization of Cutting Parameters in Hard Turning of AISI 4340 Steel," *Int. J. Innov. Res. Adv. Eng.*, vol. 1, no. 8, pp. 93–98.

[10] Lozano D., (2013). "Effect of Interrupted Quenching on the Fatigue Resistance of an AISI/SAE 5160 steel," PhD Thesis, Universidad Autónoma De Nuevo León.

[11] Ramakrisna S., Reddy B. R. H., Akhil B., and Kumar B.P., (2017). "A Review on Anti-Roll Bar used in Locomotives and Vehicles," Int. J. Curr. Eng. Technol., vol. 7, no. 3, pp. 838–841.

[12] Ruy M., Tarpani J., Milan M., Spinelli D., and Bose W., (2005). "The Effect of Warm Shot Peening on the Fatigue Performance of a Sae 5160 Spring Steel,'' 11th International Conference on Fracture (ICF11), Vol 1 of 8, pp. 2453.