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Experimental Analysis of the Influence of Depth of Cut, Time of Cut, and Machining Speed on Vibration Frequency during Turning of AL1060 Alloy

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ABSTRACT

Machining vibration is a significant concern in the manufacturing industry, as vibration cannot be eliminated during metal to metal turning operations. It can be controlled to the minimum when a proper study is carryout before the turning process. This study aims to experimentally analyse the effect of the individual parameters such as depth of cut (DOC) and cutting speed have on the machining vibration during turning of AL1060 alloy. A computer numerical control (CNC) program was applied to investigate the effects of the different depths of cut such as 1 mm, 1.5 mm, 2 mm, 2.5 mm, and 3 mm. Moreover, cutting speed of 200 m/min, 350 m/min, 500 m/min, and 600 m/min with a constant feed rate of 5 mm/rev have on the machining vibration during the turning process. DTO 32105 frequency analyser an MXC-1600 digital frequency counter was employed to measure the machining vibration for a specific time between 15 seconds to 500 seconds. The result shows that as the depth of cut continually increases, the machining vibration increases and the minimum machining vibration of 131.8 Hz was obtained at cutting speed of 600 m/min, depth of cut of 1 mm, and cutting time of 15 sec. The Pareto chart was further used to analysis the average vibration frequency at the optimised cutting speed of 600 m/min. The surface quality and the cutting tool life can be significantly enhanced with the study of the individual machining parameters.

Key words: Machining, Vibration, Time of cut, Depth of cut, Cutting speed, Aluminium alloy

1. INTRODUCTION

Machining is a process of removing unwanted chips from the workpiece [1]. This process faces many challenges due to the contact between metals to metals, which gives rise to vibration. Vibration is significant in machining operation and cannot be over emphases. The result of high vibration amplitude leads to high surface roughness and a high rate of damage to the cutting tool. Vibrations are induced in all cutting operations due to the deformation of the workpiece [2]. The machined component's dimensions and shape also influence the tool vibration, which is interpreted as a result of the machining parameters effects during turning operations. The machining variables, which improve cutting performance, are spindle speed, depth of cut, feed rate, and several others. During the turning process, it is essential to understand the relationship between machining parameters, cutting tool and machining vibration behaviour, to produce an excellent surface quality product, especially when applying the computer numerical control machine (CNC) [3].

Machining vibration, also known as chatter vibration, is as a result of the relative movement between the cutting tool, workpiece material, and the machining parameters such as spindle speed, depth of cut, length of cut, and feed rate [4-6]. The occurrence of vibration affects all machining methods, namely, turning operation, milling process, and drilling operation, grinding, and shaping process. Furthermore, it has led to research on machining vibration. Izelu *et al.* [7] studied feed rate, spindle speed, depth of cut effects on induced vibration, and surface finishing of machining of 41Cr4 alloy steel using composite factorial design of experiment (CFD). The result shows that feed rate increases the surface finishing and induces vibration, this result is in line with (Okonkwo *et al.*, [8]; Ogundimu *et al.*, [9]; Okokpujie *et al.*, [10]). The significant causes of tool wear are high vibration during the turning operations. Nwoke *et al.* [11] developed a model using the Taguchi method for three factors and three levels during turning of 4340 Alloy Steel. The Taguchi has nine (9) experimental runs. The analysis of variance shows that the feed rate is the most significant factor. Also, the model was able to predict the experimental result with 99.5 %, and the noise to signal ratio indicates that the increase of feed rate and depth of cut increases the vibration frequency, but the increase of cutting speed led to vibration reduction. The authors recommended that more study should be done on vibration analysis by studying individual parameters during machining operations.

Prasad and Babu [22] work on the relationship of vibration frequency and cutting tool wear, during dry machining of AISI4140 steel. The study made use of the DNMA 432 uncoated carbide tool. 3D finite element simulation was employed to study the relationship of the vibration induce turning operations. Doppler Vibrometer and Kistler 9272 dynamometer were used for the vibration and cutting force measurement. Also, the study used the second-order polynomial from response surface methodology (RSM) to analyse the effects of the turning parameters on the tool wear. The result shows that vibration has a significant impact on the cutting tool during the turning operations, and the increase of the induce vibration leads to a rise in the tool wear. The authors concluded that the RSM and the finite element method predicted the experimental result relatively.

Aluminium alloys are excellent corrosion-resistant material, which is widely used in the aerodynamic industry, auto-mobile, and foundry industry with exceptional strength to weight ratio. The density of aluminium is one-third of steel, and aluminium is mostly produced because of its full applications in the automobile, aerospace, and construction industry. Aluminium has excellent thermal, mechanical, and electrical conductivity characteristics. They are ductile and highly recommended for the production of internal combustion engines [12][13].

There is, however, the need to resolve the problem caused by vibration to enable manufacturers to have sustainable production of mechanical components for industrial use [14-20]. Therefore, this research work is focused on studying the variation of cutting speed and depth of cut on vibration frequency, when order parameters are kept constant. This study will enable manufacturers to understand the impact of the cutting speed, depth of cut, and time of cut during the turning operation of AL 1060 alloy.

2. MATERIALS AND METHODS

The materials employed for this experimental work are High-speed steel (HSS) cutting tool and AL1060 alloy round bar size of length 375 mm, and a diameter of 40 mm. The machining operations are orthogonal, and the workpiece regularly rotates with the two ends clamped. The experiment was performed on the WARCO GH-1440A CNC lathe machine in the department of mechanical engineering machining workshop, Covenant University. During each experiment, the data acquisition system comprises of a sound signal and vibration analyser was employed to measure the vibration occurrence, and the result was analyser to study the influence of the depth of cut, cutting speed, and time of cut during the machining operation. Tables 1 and 2 show the chemical composition, mechanical, thermal, and physical properties of AL1060 alloy.

Table 1: Chemical Composition of AL1060 Alloy [21]

Element	Fe	Si	Cu	V	Zn	Mg	Mn	Ti	AL
Weight %	0.4	0.25	0.05	0.05	0.1	0.03	0.03	0.03	Reminder

Table 2: Physical, Mechanical and Thermal Properties of AL1060 Alloy

Properties	Units
Density	2700 Kg/m^3
Melting Start (Solidus)	649 °C
Tensile Strength	130 MPa
Yield strength	94 MPa
Elastic modulus	80 GPa
Poisson's ratio	0.33
Thermal expansion	23.6 (10-6/ºC)
Thermal conductivity	234 /mK)

2.1 Experimental Set-Up for the Turning Operation of AL1060 Alloy

Table 3 presents the cutting parameters used for the experimental analysis of the different depth of cut (DOC) and cutting speed while the feed rate is kept constant. Figure 1, shows the workpiece clamped at one end with the 3-jaw chuck and the other end with the tailstock, the data acquisition system is mounted between the HSS cutting tool and the workpiece for effective monitoring of the machining vibration for some time measurement within 15 seconds to 500 seconds. The vibration measurement was taken within 5 seconds under the dry machining conditions.

Table 3: The Cutting Parameter used for the Experimental Study

Cutting Speed (m/min)	Feed rate (mm/rev)	Depth of Cut (mm)
200	5	1, 1.5, 2, 2.5, and 3
350	5	1, 1.5, 2, 2.5, and 3
500	5	1, 1.5, 2, 2.5, and 3
600	5	1, 1.5, 2, 2.5, and 3

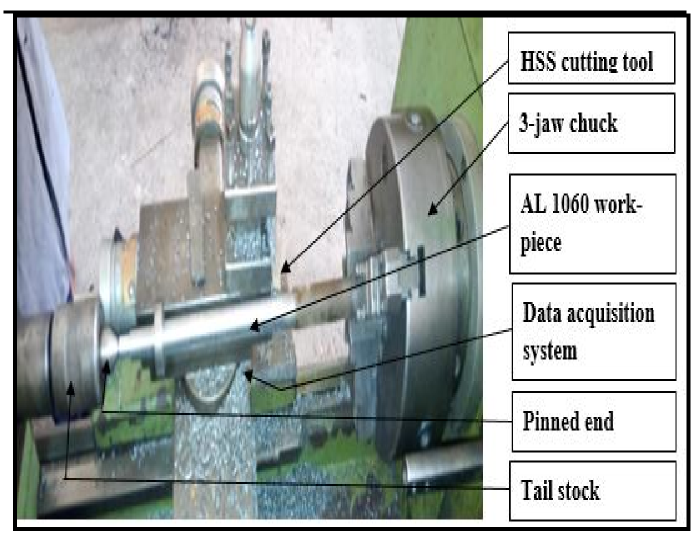

Figure 1: The Experimental Set-Up for the Turning of AL1060 Alloy.

3. RESULTS AND DISCUSSION

The result of the various depth of cut of 1 mm, 1.5 mm, 2 mm, 2.5 mm, and 3 mm and cutting speed at 200 m/min and 350 n/min, effects on the machining vibration during turning of AL 1060 alloy are shown in Figures 2 and 3. It can be seen that as the depth of cut is increased, the machining vibration increased, which is as a result of the friction between the starting points of the cutting tool having its way through the workpiece. This result is in line with [22-24]. From observation, at a middle point, where depth of cut is 1 mm, the machining vibration reduces from 197 to 167 Hz within the time of cut of 210 to 260 seconds because there was free flow of the cutting process without any discontinuity of the chips. However, as the turning process continues, the chips were falling back to the cutting zone, which results in a high occurrence of vibration. In Figure 3, the machining vibration reduces by almost 20 % due to the increase of cutting speed from 200 to 350 m/min. However, because of the constant increase in the depth of cut, machining vibration increases.

Figures 4 and 5 display the result of machining vibration with the time of cut at various depth of cut with a constant speed of 500 m/min and 600 m/min. Figure 4 shows that as the cutting speed increases, the chips formations on the cutting tool reduces, which lead to a reduction of the machining vibration. The cutting speed of 600 m/min, achieved the lowest machining vibration of 131.8 Hz. From the trend of the graphs in Figures 4 and 5, the highest machining vibration was recorded at 3 mm depth of cut. Furthermore, the machining vibrations reduced in Figure 5, from 333 Hz to 325 Hz due to the increase of the cutting speed from 500 m/min to 600 m/min. This result analysis is in line with [25-26]. The work of Zhang et al. [27] provides that as the cutting speed increase, the vibration frequency reduces, however, their study focus on the tool vibration effects on the surface integrity of the microstructural characteristics of the titanium alloy. However, the authors did not study the effects of depth of cut on vibration frequency, which this research has addressed. The depth of cut is significant machining parameters that need to be critically studied to avoid unwanted vibration during turning operations of aluminium alloy.

From the machining analysis with the various depth of cut, time of cut and cutting speed, the vibration frequency tend to be at a minimum in the cutting speed of 600 m/min. Furthermore, the authors carried out more optimisation to study the trend using the average depth of cut of all the experiment run under 1 mm, 1.5 mm, 2 mm, 2.5 mm, and 3 mm under the cutting speed of 600 m/min. Figure 6 shows the Pareto chart used to analyse the effects of the time of cut on the average vibration of the various depth of cut at a constant cutting speed of 600 m/min. The Pareto chart shows the variations of the vibration frequency as the time of cut increases, with the legend of various colours. At the cutting speed of 600 m/min., with a time of 15 seconds, the minimum average vibration frequency occurs at 190 Hz. However, as the time of cut increases to 360 seconds, the average vibration frequency increases to 257 Hz. This increase in vibration is a result of the weariness of the cutting tool over time. Also, it could be as a result of the point of contact between the cutting tool and the AL1060 alloy as patterned to rake angle defects. This finding from this research contradict the result of Lu et al. [16] the authors studied the shear-slip theory with frictional modeling of interface based tool-chip assisted swing vibration cutting process. The result shows that the cutting speed increases the vibration during their machining process because the authors did not consider the feed rate as a factor, and the time of cut was not varied. However, the authors only studied the interface of the tool-chips as they relate to temperature reduction, tool wear, and surface roughness through the swing vibration cutting process.

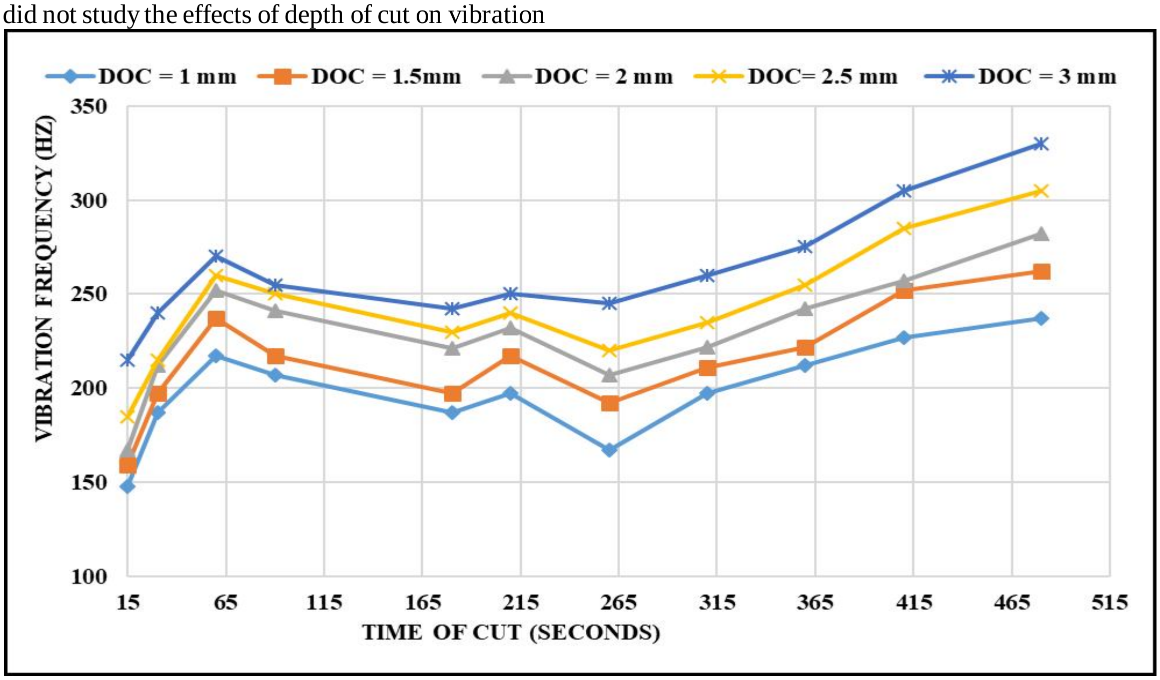

Figure 2: Influence of Time of Cut and Depth of Cut on the Machining Vibration at Constant Machining Speed of 200 M/Min.

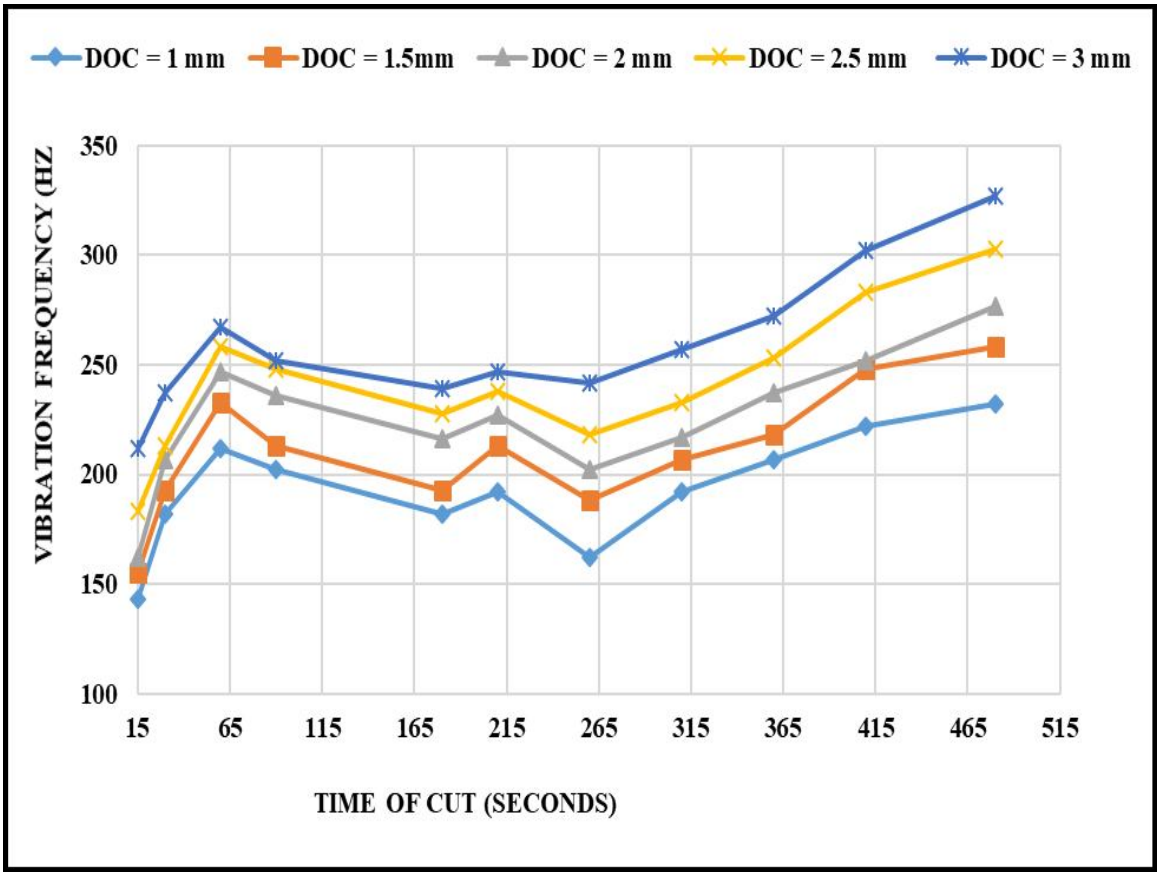

Figure 3: Influence of Time of Cut and Depth of Cut on the Machining Vibration at Constant Machining Speed of 350 M/Min.

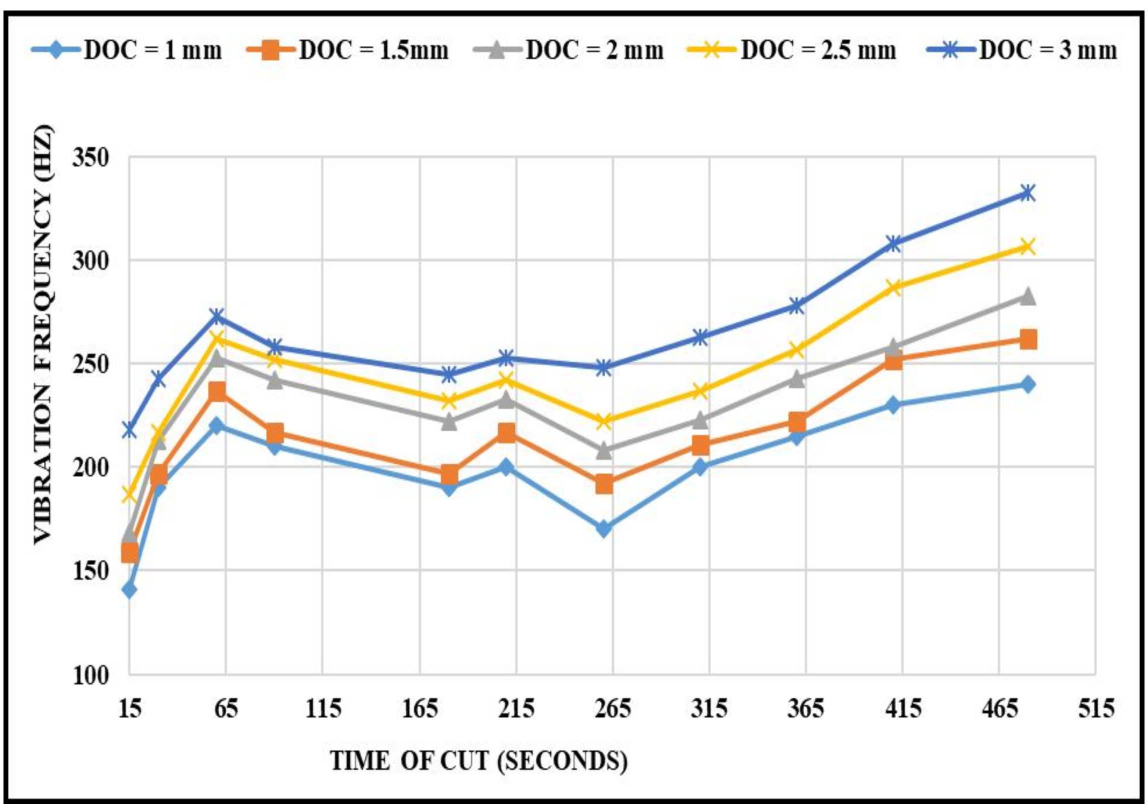

Figure 4: Influence of Time of Cut and Depth of Cut on the Machining Vibration at Constant Machining Speed of 500 M/Min.

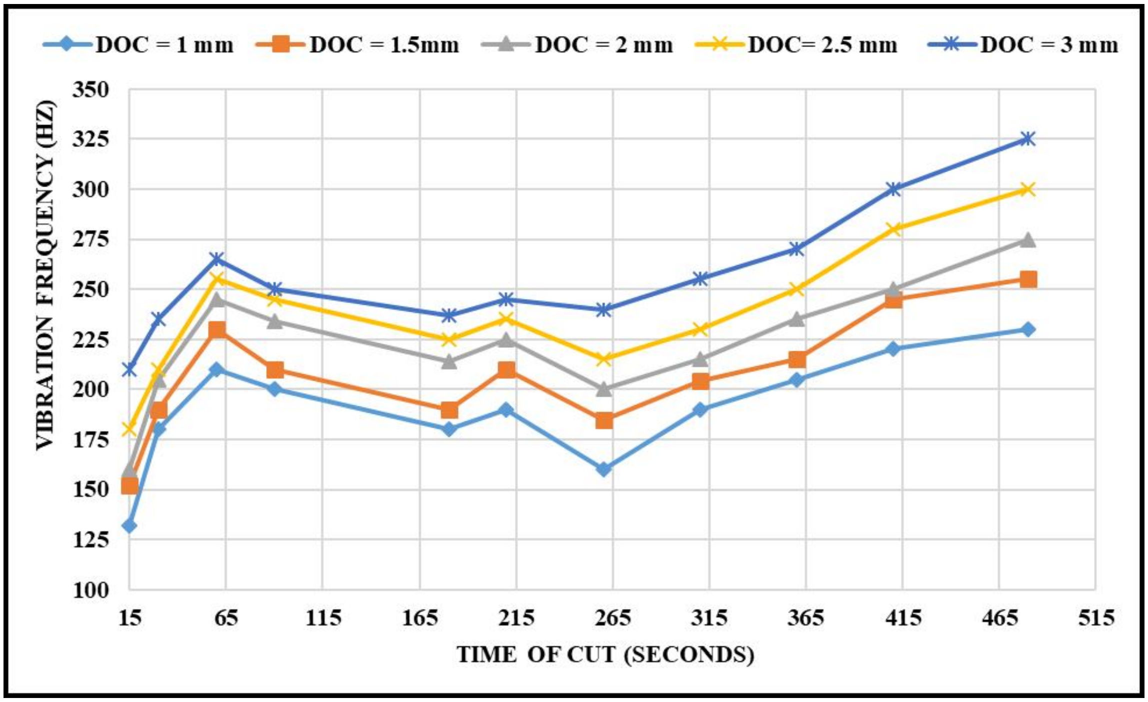

Figure 5: Influence of Time of Cut and Depth of Cut on the Machining Vibration at Constant Machining Speed of 600 M/Min

Furthermore, the increase in the time of cut leads to an increase in the vibration occurrence because of the more extended the turning operation, the higher the heat generation at the cutting region. Aluminium alloy during machining operations did not need high heat generation in the cutting zone. Because when the temperature at the cutting region increases, it affects the microstructure of the chips, which causes materials adhesion on the cutting tool, thereby lead to high vibration frequency during the turning operation. These findings are supported by the observation of Srinivasan et al. [28]. The significant of this study as shown that the time of cut increases also the energy consumption of the computer numerical control (CNC) machine, and the optimisation of the individual parameters will assist the time variation to reduce the energy consumption [29]. Al-Tawalbeh, and Feilat [30] shows that the power consumption in the economic system is very significant in sustainable development of manufacturing industry.

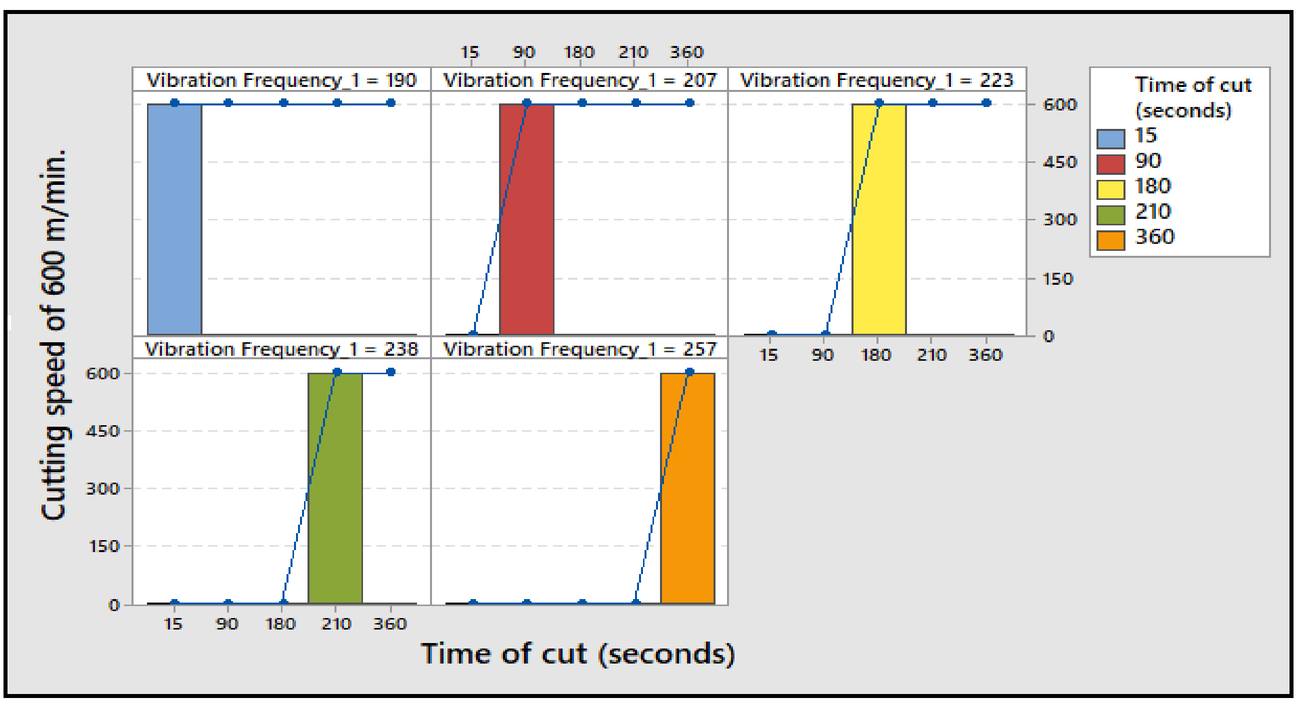

Figure 6: Pareto chart of the time of cut vs. vibration frequency at a constant cutting speed of 600 m/min.

4. CONCLUSION

The significance of the cutting speed and depth of cut effects on machining vibration has been experimentally studied, by employing various cutting speed and depth of cut within a specific time of cut during the turning operations of AL 1060 alloy. The experimental analysis shows that; the depth of cut has a significant influence on the machining vibration occurrence. As the depth of cut increases from 1 mm to 3 mm in all the analysis carried out, the machining vibration increases, only at some point where the cutting speed also increases significantly, it suppresses the depth of cut and reduces the machining vibration. The minimum machining vibration of 131.8 Hz occurs at the highest cutting speed of 600 m/min, with a depth of cut of 1 mm, at machining time of 15 seconds. The Pareto chart was also used to study the trend of the time of cut on the average vibration frequency at the cutting speed of 600 m/min. This is seen that the time of cut is a significant factor in studying machining vibration.

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REFERENCES

1. T. Ejieji, S. M. Adedayo, O. W. Bello, & S. Abdulkareem. Effect of machining variables and coolant application on HSS tool temperature during turning on a CNC lathe. In *IOP Conference Series: Materials Science and Engineering,* 2018, Vol. 413, No. 1, p. 012004.
2. I. P. Okokpujie, E. Y. Salawu, O. N. Nwoke, U. C. Okonkwo, I. O. Ohijeagbon, & K. O. Okokpujie. Effects of Process Parameters on Vibration Frequency in Turning Operations of Perspex Material. 2018
3. C. A. Ezugwu, U. C. Okonkwo, J. E. Sinebe, & I. P. Okokpujie. Stability Analysis of Model Regenerative Chatter of Milling Process Using First Order Least Square Full Discretization Method. *International Journal of Mechanics and Applications. 6*(3), 49-62, 2016.
4. I. P. Okokpujie, & Okonkwo, U. C. Effects of cutting parameters on surface roughness during end milling of aluminium under minimum quantity lubrication (MQL). *International Journal of Science and Research*. *4*(5), 2937-2942, 2015.
5. O. N. Nwoke, O. S. Okoli, I. P. Okokpujie, & U. I. Okoro. Criticality of Computer Aided Design Packages in Engineering Education & Professionalism for the Developing Countries. Pp. 390–400, 2018.
6. C. O. Izelu, S. C. Eze, B. U. Oreko, & B. A. Edward. Effect of depth of cut, Cutting speed, and Work-piece Overhang on Induced Vibration and Surface Roughness in the turning of 41Cr4 Alloy steel. *International Journal of Emerging Technology and Advanced Engineering*. *4*(1), 1-5, 2014.
7. U. C. Okonkwo, I. P. Okokpujie, J. E. Sinebe, & C. A. Ezugwu. Comparative analysis of aluminium surface roughness in end-milling under dry and minimum quantity lubrication (MQL) conditions. *Manufacturing Review. 2*(30), 1-11, 2015.
8. O. Ogundimu, S. A. Lawal, & I. P. Okokpujie. Experimental study and Analysis of Variance of Material Removal Rate in High Speed Turning of AISI 304L Alloy Steel. In *IOP Conference Series: Materials Science and Engineering,* 2018, Vol. 413, No. 1, p. 012030.
9. I.P. Okokpujie, O.M. Ikumapayi, U.C. Okonkwo, E.Y. Salawu, S.A. Afolalu, J.O. Dirisu, O.N. Nwoke, O.O. Ajayi. Experimental and mathematical modeling for prediction of tool wear on the machining of aluminium 6061 alloy by high speed steel tools. Open Engineering. 7(1):461-9, 2017.
10. O.N. Nwoke, U.C. Okonkwo, C.E. Okafor, I.P. Okokpujie. Evaluation of Chatter Vibration Frequency in CNC Turning of 4340 Alloy Steel Material. International Journal of Scientific & Engineering Research. 8(2):487-95. Feb., 2017.
11. I.P. Okokpujie, O.O. Ajayi, S.A. Afolalu, A.A. Abioye, E.Y. Salawu, M. Udo. Modeling and optimization of surface roughness in end milling of aluminium using least square approximation method and response surface methodology. International Journal of Mechanical Engineering and Technology (IJMET). 9(1):587-600, 2018.
12. U.C. Okonkwo, O.N. Nwoke, I.P. Okokpujie Comparative Analysis of Chatter Vibration Frequency in CNC Turning of AISI 4340 Alloy Steel with Different Boundary Conditions. Journal of Covenant Engineering Technology (CJET) Vol. 1(1). Mar., 2018
13. D.V. Sivareddy, P.V. Krishna, A.V. Gopal. Optimization of Machining Parameters for Vibration-Assisted Turning of Ti6Al4V Alloy Using Analysis of Variance. In Advances in Applied Mechanical Engineering. 713-724, 2020.
14. I. Dunmade, M. Udo, T. Akintayo, S. Oyedepo, I.P. Okokpujie. Lifecycle impact assessment of an engineering project management process–a SLCA approach. InIOP Conference Series: Materials Science and Engineering 2018 Sep (Vol. 413, No. 1, p. 012061). IOP Publishing.
15. I.P. Okokpujie, C.A. Bolu, O.S. Ohunakin, E.T. Akinlabi, D.S. Adelekan. A review of recent application of machining techniques, based on the phenomena of CNC machining operations. Procedia Manufacturing. 35: 1054-60. Jan., 2019
16. M. Lu, B. Chen, J. Lin, D. Zhao, J. Zhou, A. Yi, Z. Zhu. Friction modeling of tool-chip interface based on shear-slip theory for vibration assisted swing cutting. Journal of Manufacturing Processes. 55: 240-8. Jul., 2020
17. M. Kumar, V. Bajpai. Experimental investigation of top burr formation in high-speed micro-milling of Ti6Al4V alloy. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture. 234(4):730-8. Mar., 2020.

18. I.P. Okokpujie, O.S. Ohunakin, C.A. Bolu, K.O. Okokpujie. Experimental data-set for prediction of tool wear during turning of Al-1061 alloy by high speed steel cutting tools. Data in brief. 1;18: 1196-203. Jun., 2018.
19. I. Okokpujie, U. Okonkwo, C. Okwudibe. Cutting parameters effects on surface roughness during end milling of aluminium 6061 alloy under dry machining operation. International Journal of Science and Research. 4(7):2030-6. Jul., 2015
20. A.T. Abbas, D.Y. Pimenov, I.N. Erdakov, MA Taha, M.S. Soliman, M.M. El Rayes. ANN surface roughness optimization of AZ61 magnesium alloy finish turning: Minimum machining times at prime machining costs. Materials. 11(5):808. May, 2018
21. M.A. Chowdhury, U.K. Debnath, M. Kamruzzaman, D.M. Nuruzzaman, M. Mia. Analysis and Optimization of Turned Surfaces of AISI 1060 using ANOVA and Regression. Tribology in Industry. 41 (1). Mar., 2019 https://doi.org/10.24874/ti.2019.41.01.03
22. B.S. Prasad, M.P. Babu. Correlation between vibration amplitude and tool wear in turning: Numerical and experimental analysis. Engineering Science and Technology, an International Journal. 20 (1):197-211. Feb., 2017
23. A.T. Abbas, D.Y. Pimenov, I.N. Erdakov, T. Mikolajczyk, E.A. El Danaf, M.A. Taha. Minimization of turning time for high-strength steel with a given surface roughness using the Edgeworth–Pareto optimization method. The International Journal of Advanced Manufacturing Technology. 93 (5-8):2375-92. Nov., 2017
24. M. Mia, M.A. Khan, S.S. Rahman, N.R. Dhar. Mono-objective and multi-objective optimization of performance parameters in high pressure coolant assisted turning of Ti-6Al-4V. The International Journal of Advanced Manufacturing Technology. 90 (1-4):109-18. Apr., 2017
25. G. Urbikain, D. Olvera, L.L. de Lacalle, A. Elías-Zúñiga. Spindle speed variation technique in turning operations: Modeling and real implementation. Journal of Sound and Vibration. 383: 384-96. Nov., 2016
26. F. Kara, M. Karabatak, M. Ayyıldız, E. Nas. Effect of machinability, microstructure and hardness of deep cryogenic treatment in hard turning of AISI D2 steel with ceramic cutting. Journal of Materials Research and Technology. 9(1):969-83. Jan., 2020
27. M. Zhang, D. Zhang, D. Geng, Z. Shao, Liu Y, Jiang X. Effects of tool vibration on surface integrity in rotary ultrasonic elliptical end milling of Ti–6Al–4V. Journal of Alloys and Compounds. 821:153266. Apr, 2020
28. D. Srinivasan, R. Balasundaram, G. Rajkumar. Investigation on turning parameters on machining time and vibration of carbon fibre reinforced laminates. International Journal of Manufacturing Technology and Management. 2020; 34(1):78-96.
29. M.W. Yaw, K.H. Chong. Optimize Volume for Planetary Gear Train by using Algorithm Based Artificial Immune System. International Journal. International Journal of Advanced Trends in Computer Science and Engineering. 9(3). May, 2020 https://doi.org/10.30534/ijatcse/2020/191932020
30. M.I. Al-Tawalbeh, E.A. Feilat. A Comparative Assessment of Economic Viability of Off-Grid Generation Power Systems. International Journal of Advanced Trends in Computer Science and Engineering. 9(3), 3809-3815. May 2020 https://doi.org/10.30534/ijatcse/2020/199932020