Applied Mechanics and Materials Vol. 761 (2015) pp 93-97
© (2015) Trans Tech Publications, Switzerland
doi:10.4028/www.scientific.net/AMM.761.93
Submitted: 21.11.2014
Accepted: 21.11.2014

Investigation of Cutting Parameter and Machine Tool Vibration Effects Using Regression Analysis to Enhance Part Dimensional Accuracy

M.A. Rahman[a], Nur Atiqah Md. Sadan[b], Mohamad Minhat[c], Isa H.[d] and Baharudin A.B.[e]

Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

[a]abrahman@utem.edu.my, [b]m051220043@student.utem.edu.my, [c]mohdm@utem.edu.my, [d]isa@utem.edu.my, [e]baharudin.abubakar@utem.edu.my

Keywords: Machine tool vibration, Rigidity, Dimensional accuracy, Sustainability, Machine tool development

Abstract. Dimensional accuracy plays important criteria in producing high quality machined parts. This is a big challenge to manufacturers of precision components to produce good quality parts with minimum manufacturing error. The focus of this paper is to study the influence of the machine tool rigidity and cutting parameters on dimensional accuracy in turning operation. A method was prepared for identifying the factors effecting dimensional accuracy in a turning process. Experimental setup involved computerized numerical control (CNC) lathe machine, with VBMT 160404 carbide insert and mild steel, as cutting tool and workpiece respectively. The statistical analysis was used for analyzing and determining the accuracy of experimental data through Minitab statistical software. The regressions model was developed. The developed regression model could be used to predict the dimensional precision of the parts based on machine tool vibration and machining parameters during turning process. This is the aspect to be seriously considered and be applied in attaining sustainable machine tool development during design and development stage and its usage. This finding provides useful guidelines for manufacturers to produce high quality machined parts at minimum manufacturing cost. It was found that the cutting speed, feed rate, final part length, vibration x and vibration z have significant effects on dimensional accuracy of the machined parts.

Introduction

In this study, among factors influence the dimensional accuracy of the part is known as machine tool vibration or chatter. This vibration caused the limitation for manufacturer to produce a good quality product. Cheng Long Bo et al. [1], claimed machinery problem that caused vibration includes unbalance of rotating components, looseness, gear wear, and deterioration of rolling elements bearings. This happens due to engagement between the workpiece and cutting tool. The machine tool vibration occurs during metal removal process such as turning, milling, drilling, boring, broaching and grinding. According to Quintana [2] the chatter can be the root cause for machine and workpiece damage, and it can result in a lower productivity and precision of the product. In order to reduce this chatter, many studies have been done using different methods [3]. One of the methods used is using automatic reduction in cutting tool or stabilization position of the cutting parameter and the workpiece [4]. The control of machine tool vibration during machining process is utmost important because chatter occurrence bring several negative effects such as lack of dimensional accuracy, diminishing of tool life, poor surface finish, machine tool damage, and inconsistent tool wear [2,4-6]. The dimensional deviation occurs when the finished product does not meet desired tolerance and it can lead to poor dimensional accuracy of product. However, poor dimensional accuracy that caused by vibration can be improved by considering a formula or guidelines of mathematical model in order to know at what level of machine conditions are still suitable to produce quality components [3]. Incorporation of rigidity feature in machine tool development can produce the machine tool that can provide a lot of benefits to industries. The benefits gained such as good surface finish, improved product accuracy, etc. within efficient machining operation will benefit the industries in gaining high quality product with minimum resources. Moreover, all this attainment is crucial to ensure the sustainability of machine tool industry.

Methodology

The turning experiment was performed using HAAS CNC turning machine for assesing dimensional deviation for calculating dimensional accuracy based on cutting parameters and machine tool rigidity as shown in Fig. 1. The independent variables in this study were: cutting speed, feed rate, depth of cut, workpiece diameter and workpiece length. Other variables were vibration amplitude in x, y and z direction. Experiment was conducted using mild steel as specimen with VBMT 160404 carbide turning insert as cutting tool. Experiment were performed with cutting fluid on, and a range of machining parameters commonly practiced by the manufacturers in real industrial applications. The experimental run using 126 samples with 2 replications, was conducted. In this experiment, 3 accelerometers were attached on fixed points near lathe chuck in order to effectively measure the vibration during machining process. The vibration signals generated by accelerometers sent and stored in data acquisition in Vibdaq Sofware. The statistical analysis were used in order to study the effect of the cutting parameters and machine tool vibrations on demensional accuracy of the workpiece. A regression model was developed, and validation test was carried out for ascertaining the reliability of the model. The independent and other variables represented by A, B, C, D, E, F, and G and the experimental data are summarized in Table 1.

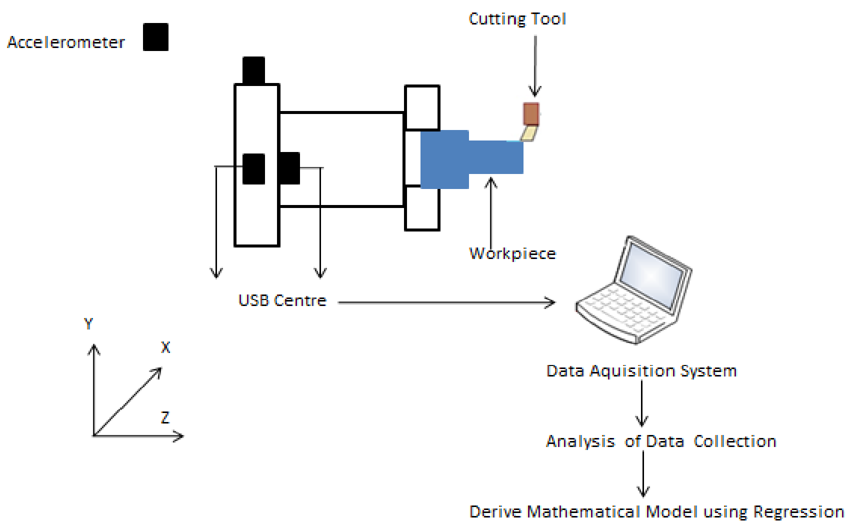

Fig. 1 Schematic diagram of experimental setup.

Table 1 Summary of experiment.

Cutting Tool	VBMT 160404 (Carbide Insert)								
Work piece	Mild Steel								
Independent Variable	A=Feed Rate (mm/min)	f1=0.5	f2 =0.6	f3=0.7					
	B= Cutting Speed (rpm)	c1=1270	c2=1600	c3= 1700	c4=1910	c5=2120	c6=2550	c7=3180	c8=3820
	C= Depth of Cut	d1= 0.2	d2=0.3						
	D=Workpiece Diameter (mm)	wd1=10	wd2=15	wd3=20					
	E=Workpiece Length (mm)	wl1=25	wl2=30	wl3=35					
Dependent Variable	F= Ave. Vibration y-axis measured in g(RMS)units								
	G= Ave. Vibration x-axis measured in g(RMS)units								
Responses	Diameter Accuracy (mm)								

The experiment was designed in this way in order to make the range of data uniformly distributed in complete ranges of the input parameters. 126 samples of data collection were obtained from different combinations of parameter levels. The data obtained were analyzed using the Minitab Statistical Software. The analysis was used to derive a model for dimensional accuracy using regression method. The developed model response represented by “Y” as dimensional accuracy could be expressed as follows:

$$Y = f\,(A, B, C, D, E, F, G) \quad (1)$$

The regression model normally showed the main effects and the interaction effect if any of all independent and dependent variables. The factors in regression model could consist of many as long as they do influence the responses. The general regression model could be written as follows:

$$Y=\beta_0+\beta_1X_1+ \beta_2X_2+ \beta_3X_3+ \beta_4X_4+ \beta_5X_5+ \beta_6X_6+ \beta_7X_7+ \beta iXi +\varepsilon \quad (2)$$

where β_0 known as intercept while parameters βi, i = 1, 2, 3… n were called as regression coefficient.

Result and Discussion

The following regression model as shown below is established from the experimental results and statistical analysis.

$$Y = - 0.00325 + 0.000001 \text{ (Spindle Speed)} + 0.00442 \text{ (Feed Rate)} + 0.000042 \text{ (Actual Final Length)} - 0.000458 \text{ (Vib. X)} - 0.000574 \text{ (Vib. Z)} \quad (3)$$

According to above regression model, it shows that the cutting speed (shown as spindle speed), feed rate, actual final length and amplitude of vibration in x and z-axis are the significant factors on dimensional accuracy Y. It has been proven by result of the statistical analysis of experimental data. Other independent variables such as depth of cut, and vibration y has shown no significant effect on dimensional accuracy. The test of significant of developed model involved the null hypothesis is $Ho{:}\beta i = 0,\ i$=1,2,3,4,5. While alternative is H_1: at least one of $\beta i \neq 0$, i=1,2,3,4,5. The summary of the statistical analysis of regression model is shown in Table 2 and Table 3.

Table 2 Statistical analysis of individual regression coefficients.

Predictor	Coef	SE Coef	T	P
Constant	-0.0032484	0.0008138	-3.99	0.000
V	0.00000101	0.00000016	6.39	0.000
FR	0.0044184	0.0009600	4.60	0.000
ActFinLength	0.00004225	0.00001639	2.58	0.011
Vib X	-0.0004578	0.0001687	-2.71	0.008
Vib Z	-0.0005737	0.0002306	-2.49	0.014

S = 0.000855961   R-Sq = 47.7%   R-Sq(adj) = 45.4%

Table 3 Analysis of variance.

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	5	0.000074322	0.000014864	20.29	0.000
Residual Error	111	0.000081326	0.000000733		
Total	116	0.000155648			

Based on the Table 2, it shows that the p-value for five independent variables are less than α=0.05, which means there has a significant influence of that factors of study in the dimensional accuracy, which are spindle speed (0.000), feed rate (0.000), followed by actual final length (0.011), vibration x-axis (0.008) and vibration z-axis (0.014). Those p-value also show that the null hypothesis Ho: $\beta i = 0$, i=1,2,3,4,5 is rejected and alternative hypothesis H_1: at least one of $\beta i \neq 0$, i=1,2,3,4,5 is accepted. The cutting speed, feed rate, actual final length, and vibration in x and z-axis have effect in influencing the dimensional accuracy of the machined parts. The value of R^2 and adjusted R^2 is used to determine the percentage of variation response. The value of R^2 which is 47.7 %, indicates the percentage of the closeness experimental data to the model. This findings prove the developed model is useful in providing the predicting of dimensional accuracy. The cutting speed, feed rate, actual final length, and vibration in x and z-axis are the main factors that contribute to the vibration and effecting the quality of dimensional accuracy of the machining process.

Validation Test

After the regression equation (model) is developed and significant factors are identified, the final stage is to validate the model using the experimental test with different levels of parameters. The dimensional accuracy of the model which is gained from developed regression model as in equation 3 is compared with the actual dimensional accuracy using Pearson approach. The result shows the developed regression model is reliable and provide good estimation of dimensional accuracy. Additionally, the two sample t-test are performed in order to ensure the actual dimensional accuracy taken from experimental data has no significantly different from the value of dimensional accuracy of the model or not. Table 4 below shows the result of two sample t-test.

Table 4 Two-sample t-test for dimensional accuracy.

```
Difference = mu (Dimensional Acc Model) - mu (Dimensional Acc Actual)
Estimate for difference:  -0.000209
95% CI for difference:  (-0.000591, 0.000174)
T-Test of difference = 0 (vs not =): T-Value = -1.08  P-Value = 0.283  DF = 164
```

From the Table 4, it can be seen that for a 95% confidence interval, difference (-0.000591, 0.000174) includes zero, thus suggest that there is no significant difference between the dimensional accuracy of model with actual dimensional accuracy from experiment. Besides, the test statistic is -1.08, with p-value of 0.283, and 164 degrees of freedom. Since the P-value is greater than the chosen alpha levels (0.05), this also indicates that there has no significant differences between response from actual data and from model.

Conclusion

This study has shown that the machine rigidity and cutting parameters has a great influence on dimensional accuracy of the machined parts. Based on the data analysis, the significant factors affecting the dimensional accuracy are known as spindle speed, feed rate, actual final length, vibration amplitude in x and z-axis direction. Futhermore, this analysis is supported by regression model that proved to be reliable for providing a good prediction of the dimensional precision in cutting (turning) process. This finding which is the developed regression model is found to be useful guidelines for machine tool builders as well as parts manufacturers to produce high quality parts with sustainable machine tool industry.

Acknowledgement

The authors gratefully acknowledge the financial support from the ministry of higher education under fundamental research grant scheme (FRGS/1/12011/FKP/TK03/1-F00116). The authors would like to acknowledge the Universiti Teknikal Malaysia Melaka (UTeM) for technical supports.

References

[1] C.L. Bo, G.J. Lin, Z.T. Rui, J. Tao, Vibration control in turning machining, Adv. Mater. Res. 706-708 (2013) 1672-1675.

[2] G. Quintana, J. Ciurana, Chatter in machining processes: A review, Int. J. Mach. Tools Manuf. 51 (2011), 363-375.

[3] O.B. Abouelatta, J. Madl, Surface roughness prediction based on cutting parameters and tool vibration in turning operations, J. Mater. Process. Technol. 118 (2001) 269-277.

[4] S.K. Choudhury , N.N. Goudimenkos, V.A. Kudinov, On-line control of machine tool vibration in turning, Int. J. Mach. Tools Manuf. 37 (6) (1997) 801-811.

[5] A.A. Cardi, H.A. Firpi, M.T. Bement, S.Y. Liang, Workpiece dynamic analysis and prediction during chatter of turning process, Mech. Syst. Sig. Process. 22 (2008) 1481-1494.

[6] M. Siddhpura, R. Paurobally, A review of chatter vibration research in turning, Int. J. Mach. Tools Manuf. 61 (2012) 27-47.

[7] Y. Norfadzlan, M.Z. Azlan, M.H Siti Zaiton, Evolutionary techniques in optimizing machining parameters: Review and recent application, Expert Syst. Appl. 39 (2012) 9909-9927.

[8] M. Thomas, Y. Beauchamp, A.Y Youssef, J.Masounave, Effect of tool vibrations on surface roughness during lathe dry turning process, J. Comput. Ind. Eng. 31 (1996) 637-644.

[9] Z. Hessainia, A. Belbah, M.A. Yallese, T. Mabrouki, J.F. Rigal, On the prediction of surface roughness in the hard turning based on cutting parameters and tool vibrations, Meas. 46 (2013) 1671-168.

[10] S. Kalpakjian, S.R. Schmid, Manufacturing Engineering and Technology, sixth ed., Prentice Hall, New Jersey, 2010.

[11] D.C. Montgomery, Design and Analysis of Experiments, seventh ed., John Wiley & Sons Inc., Asia, 2009.

[12] S.G. Kelly, Fundamentals of Mechanical Vibrations, second ed., McGraw-Hill, New York, 2000.

[13] D.C. Montgomery, E.A. Peck, G.G. Vining, Introduction to Linear Regression Analysis, fourth ed., Wiley & Sons Inc., Hoboken, New Jersey, 2006.

[14] R. J. Freund, W.J. Wilson, Regression Analysis: Statistical Modelling of a Response Variable, first ed., Academic Press, San Diego, 1998.