DIMENSIONAL ACCURACY PREDICTION BASED ON MACHINING PARAMETER AND MACHINE TOOL VIBRATION IN TURNING OPERATION

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ABSTRACT : *Dimensional accuracy is an important aspect in producing good quality product. The reason is that nowadays many manufacturers try to produce good machining parts or components with good dimensional tolerance in order to fulfil customer requirement. Normally, dimensional accuracy of the machining parts depends on the machining process that involves in the selection of cutting parameters, vibration and other factors. The aim of this study is to investigate the correlation between cutting parameters and machine tool vibration against dimensional accuracy in lathe machine operation. The experiment were conducted using the Computerized Numerical Control (CNC) lathe. The VBMT 160404 carbide insert is used as cutting tool and mild steel as specimen. The vibration data are collected by using data acquisition system found in the VibDAQ Software. Through the obtained data, the statistical analysis was used to analyse and test the experimental data. The regression model was then developed from the analysis. In this case, the developed regression model based on the machine tool vibration and machining parameters during turning process can be used for estimating the dimensional accuracy of the machined parts. This finding will be useful for manufacturers to identify the level of achieving the optimum cutting condition. It was found that the feed rate, depth of cut, cutting length, workpiece diameter, vibration x and z axis have a significant influence on the dimensional accuracy.*

KEYWORDS: dimensional accuracy, vibration, machine tool vibration, rigidity, turning, chatter.

1.0 INTRODUCTION

Nowadays, for the manufacturers of precision components, dimensional accuracy is considered as one of the important aspects when evaluating the quality of the machine finished product. The dimensional accuracy is the important key to ensure the achievement of correct functioning of parts machining. This can avoid failure during assembly processes. Suleiman Abdulkareem et al. [1] has claimed that there are many factors affecting the dimensional accuracy, such as the cutting parameters, tool geometry, workpiece material, machine tool rigidity and cutting fluids used. Therefore, according to O.B. Abouelatta [2], many studies have been done to improve the chatter and increase the quality of the machined product.

The occurrences of the vibration in long term period can lead to machine failure and reduce the efficiency of the machine tool itself, thus leading to poor productivity [3]. The manufacturer tries to avoid the chatter because it results in an adverse effect, such as the reduction of tool life, lack dimensional accuracy, poor surface finish and inconsistent in tool wear [3, 4, 6]. This barrier can make a big challenge for manufacturers of precision components to produce good quality parts in order to fulfil the customers' need. In fact, the vibration cannot be eliminated, but it can be reduced. Beauchamp et al. [5] investigated the effect of machine tool vibration and cutting parameter in turning machining process. The vibration analysis revealed that the dynamic force related to the chip thickness variation acting on the tool is related to the amplitude of the tool vibration at certain resonance and the tool's natural frequency during cutting.

Recently, in order to reduce vibration, online control vibration using closed loop feedback system together with advanced computers, sensors and actuator was used [4,7]. In addition, chatter monitoring is more useful approach in identifying, avoiding, preventing and controlling the machine tool vibration in machining process [3]. Therefore, the focus of the present study are to find the correlation between the cutting parameter and the machine tool vibration on dimensional accuracy in the turning process and, subsequently to derive a mathematical model for predicting the dimensional accuracy based on both variables.

2.0 METHODOLOGY

Turning experiments were performed by using HAAS CNC lathe machine in order to acquire data that can be used to assess dimensional deviation based on machining parameters and machine tool rigidity as shown in Fig 1. The independent variables were known as the depth of cut, feed rate, spindle speed, cutting length and workpiece diameter, while the dependent variable was the machine tool rigidity (vibration amplitude in x, y, and z direction). The experiment was conducted by carrying out the turning process using a mild steel as the specimen with carbide insert as the cutting tool. In the experiment, the cutting fluid was used and the selection of cutting parameters followed the common industrial practice. 126 samples were used in this study, which involved 2 replications of each independent factor. In order to measure the effectiveness of vibration during machining, 3 accelerometers were attached on the lathe chuck. The data signals generated by the accelerometer were directly sent and stored in the data acquisition system in the VibDAQ Software. The statistical analysis was used to analyze the obtained data in order to find the interaction between cutting parameters and machine tool vibrations on the dimensional accuracy of the workpiece. In addition, the data was used to develop the regression model that can predict the dimensional accuracy of the parts. All the independent and dependents variables including the responses are shown in Table 1.

The experiment conducted included all ranges of the input parameters. All sample data obtained from this experiment had gone through different combinations of level of parameters, and the result of this experiment was analyzed using the Minitab Software. Based on 95% confidence interval (α=0.05), the samples of experimental data were computed and analyzed. From the analysis, the model for dimensional accuracy using regression method was developed. The developed model can be

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

In general, the regression model is used to identify the main and correlation effect for any independent and dependent factors. The parameters in the regression model do not have any limitation as long as the variables influence the response. The general regression model could be written as:

$Y=\beta o+\beta 1X1+ \beta 2X2+ \beta 3X3+ \beta 4X4+ \beta 5X5+ \beta 6X6+ \beta 7X7+ \beta iXi +\varepsilon$

Where βo known as intercept while parameters βi, i=1, 2, 3… n are called as the regression coefficient

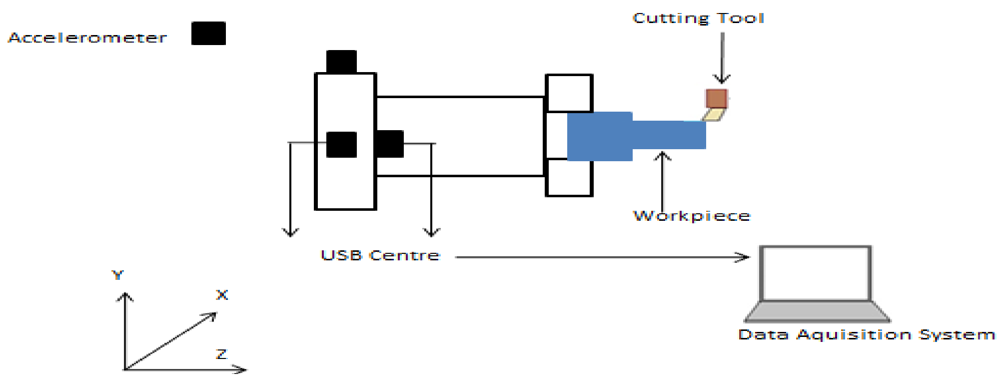

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Figure 1: Schematic diagram of the hardware setup

Table 1: Summary of the experimental design

Cutting Tool	VBMT 160404 (Carbide Insert)
Work piece	Mild Steel
Independent Variable	A=Feed Rate (µm/min) f1=500 f2 =600 f3=700
	B= Cutting Speed (rpm) c1=1270 c2=1600 c3= 1700 c4=1910 c5=2120 c6=2550 c7=3180 c8=3820
	C= Depth of Cut (µm) d1= 200 d2=300
	D=Workpiece Diameter (µm) wd1=10 000 wd2=15 000 wd3=20 000
	E=Workpiece Length (µm) wl1=25 000 wl2=30 000 wl3=35 000
Dependent Variable	F= Ave. Vibration y-axis measured in g(RMS)units
	G= Ave. Vibration x-axis measured in g(RMS)units
	H= Ave. Vibration z-axis measured in g(RMS)units
Responses	Diameter Accuracy (µm)

3.0 RESULT AND DISCUSSION

The developed regression equation from the statistical analysis are shown as below:

Y = 0.201 + 0.000002 (Cutting Speed) + 0.00393 (Feed Rate) + 0.0120 (Depth of Cut) + 0.000044 (Cutting Length) - 0.000316 (Diameter) + 0.000001 (Vibration X) - 0.000001 (Vibration Z).

Based on the equation above, it shows that the feed rate (0.00393), depth of cut (0.0120), cutting length (0.000044), workpiece diameter (-0.000316), vibration x (0.000001) and z (- 0.000001) axis have a significant influence on the dimensional accuracy. It has been verified by doing the statistical analysis of data gathered as shown in Table 2 and Table 3. Other parameter like the cutting speed, and vibration in y axis do not have significant factor in this experiment expressed based on the following expression.

According to Table 2, the p-value for the six predictors are less than α=0.05, which indicates that the variables has direct significant influence to the response of this experiment, which is known as the dimensional accuracy. The p-value for the cutting speed is greater than α=0.05, which means that there is no significant influence to the developed regression model. The developed regression model has several null hypothesis, which are Ho: $\beta i =0$, $i=1,2,3,4,5$; where H_1: *at least one of* $\beta i \neq 0$, $i=1,2,3,4,5$. By referring to the p-value, it shows that the null hypothesis Ho: $\beta i =0$, $i=1,2,3,4,5$ is rejected and the alternative hypothesis H_1: *at least one of* $\beta i \neq 0$, $i=1,2,3,4,5$ is accepted. The value of R^2 (64.6%) and adjusted R^2 (62.4%) is used to determine the percentage of variation of response

Table 2: Statistical analysis of individual regression coefficients

Predictor	Coef	SE Coef	T	P
Constant	0.2015	0.9529	0.21	0.833
V	0.00000162	0.00000504	0.32	0.748
FR	0.0039268	0.0008306	4.73	0.000
DOC	0.011979	0.002956	4.05	0.000
FL	0.00004358	0.00001614	2.70	0.008
D	-0.00031628	0.00003147	-10.05	0.000
Vib X	0.00000061	0.00000023	2.67	0.009
Vib Z	-0.00000081	0.00000021	-3.86	0.000

S = 0.733836 R-Sq = 64.6% R-Sq(adj) = 62.4%

Table 3: Analysis of variance

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	7	106.340	15.191	28.21	0.000
Residual Error	108	58.160	0.539		
Total	115	164.500			

	N	Mean	StDev	SE Mean
DAact	116	1.886	1.196	0.111
DAmodel	116	1.826	0.897	0.083
Difference	116	0.0601	0.7431	0.0690

95% CI for mean difference: (-0.0766, 0.1968)
T-Test of mean difference = 0 (vs not = 0): T-Value = 0.87 P-Value = 0.386

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

. The value of R^2 which is 0.646 indicates that the parameter is 64.6% closeness of the data with the fitted line in the model. Based on the result, it has proven that the developed model is useful in providing the prediction of the dimensional accuracy. The feed rate, depth of cut, cutting length, diameter workpiece, and vibration in x and z-axis are the main factors that contribute to the vibration during the turning operation.

4.0 VALIDATION

The final stage is to validate the model in order to ensure the developed model is reliable in predicting the dimensional accuracy of machining parts. The model was validated by using different level of parameters. Then, the dimensional accuracy from the developed regression model as in equation 3 was compared to the actual dimensional accuracy that was taken from the experiment. The result shows that there was a small gap between these values. This outcome shows the developed regression model is reliable and gives good prediction of the dimensional accuracy. Moreover, the two samples t-test were carried out in order to validate the actual dimensional accuracy taken from experimental data. The purpose of this action is to identify whether or not, there is a significant difference from the value of the dimensional accuracy of the model. The results of two samples t-test are shown in Table 4.

In this experimental, it can be seen that the 95% confidence interval for the mean difference is (-0.07661, 0.1968) included zero. Therefore, there is no significant difference between the dimensional accuracy of model with actual dimensional accuracy from experiment. Besides, the test value is 0.87, together with p-value is 0.386. Since the P-value is greater than the chosen alpha, which is α=0.05, there is no significant difference between the responses from the experiment data and from the calculated model.

5.0 CONCLUSION

The statistical analysis revealed that the machine tool rigidity and machining parameters has great effect on the dimensional accuracy of the machining parts. According to the result of the study, the feed rate, depth of cut, cutting length, workpiece diameter, vibration x and z axis are the factors that contribute to the vibration and subsequently, affecting the quality of the dimensional accuracy of the machining process. Additionally, the developed regression model proved to be reliable for providing a good prediction of the dimensional precision in turning process ,and it can be used as an indicator for precision machining manufacturers to produce high quality parts with good dimensional accuracy.

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