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Measuring Feed Force in Machining using A Strain Gage

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Abstract

Measuring the forces that work during machining has been being concerned by researchers for years. There are three main forces that work in turning: thrust force, axial force, and radial force. Thus, feeding force measurement is needed in machine manufacturing. This research attempts to develop measurement method through feeding force, using strain gauge sensor. The aim of measurement of feeding force in this research is to find out the influence parameter of machine towards feeding force. The research used experimental method with design experiment Taguchi to know the influence of machine parameters to feeding force in turning process. The measurement tool is strain gauge sensor connected to cutting tool. The workspace is alluminium 6061 with 15 mm in diameter and 150 mm in length. The parameters for this research are speed rate (140 rpm, 215 rpm, and 330 rpm), feed rate (0,043 mm/r , 0,065 mm/r , and 0,081 mm/r), and depth of cut (0,2 mm, 0,4 mm, and 0,6 mm). The result showed that speed rate is the most significant parameter, with the contribution percentage is 92 %. Speed rate and feed rate parameter have insignificant influence. The contribution percentage of speed rate is 2% while the feed rate has % contribution percentage. The conclusion of the research is that the bigger number of speed rate, the bigger feeding force it will have.

***Keywords**: feeding force; strain gauge; ANOVA;*

1. INTRODUCTION

In machining, there are some forces work during chips relieving, i.e. cutting force, thrust force, friction force and normal force. Cutting force (Fc) acts in the direction of cutting speed (V) and supplies energy required for cutting. Thrust force (Ft) acts in a direction normal to cutting velocity, perpendicular to workpiece (Fig.1b). The resultant force, R can be resolved into two components: friction force (Fs) along the tool-chip interface and normal force (N) that perpendicular to it. Friction force (F) and normal force to friction N. Shear force (Fs) and normal force to shear Fn (Fig. 1a). Forces F, N, Fs, and Fn cannot be directly measured. Forces acting on the tool that can be measured: cutting force (Fc) and thrust force (Ft) [1]. In other literatures cutting force was called as feed(ing) force due to this force mainly affected of, such as [2]. In this manuscript the term of feed force is used with the same meaning as cutting force.

The turning process requires feeding force in material feeding. Feeding force is influenced mainly by the feeding [2]. However, several parameters also affected it, including cutting speed, depth of feed, depth of cut, the geometry of tool, type of workpiece material, and how to cooling down the tool-workpiece interface [3]. Feeding force affects surface roughness, energy consumption, tool life, etc. Therefore, measurement of the feeding force in the machining process is essential. Laakso et al. [4] conducts research on feed force using parameters such as the edge geometry of the tool affects the plowing force. They considered that Coulomb friction also affects the change in feed force [4]. Thangarasu et al. conducted research on depth of cut, spindle speed, and feed rate on cutting forces. The results obtained from this study was that the spindle speed was out weight by 92.226% to cutting force [5]. Manjunatha and Umesh (2014) also conduced research on depth of cut, spindle speed, and feed rate to get the maximum value from feed force. The results obtained that the depth of cut contributed up to 78.3% toward the feed force [6]. In 2016, there was a conducted research on the design and development of semiconductor strain force sensors by Zhao et al. [7]. This research conducted development of direct measurement methods feed force using strains gauge. Selection of strain gauge sensors to measure cutting style because it has a higher accuracy and measurement results that can be directly seen and stored on PC / display. Measurements made in the turning process where the sensor will be put on the tool post to get a response feeding force concerning machining parameters [7].

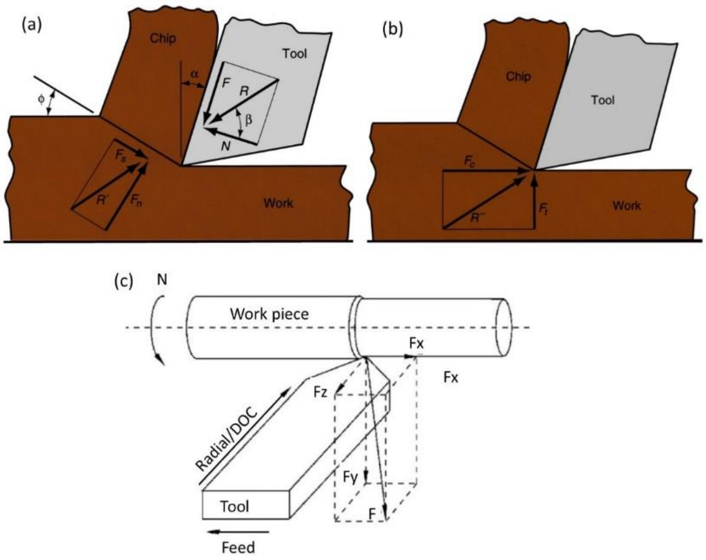

Figure 1. Forces that works in machining, (a) can not be measured forces, (b) can be measured forces, (c) other name of can be measured forces

2. METHODS

The measuring force used in this study is the strain gauge sensor connected to the tool. Detail of tool, devices and procedures of feed measurements would be described in the following section. Further observations toward measured feed force by modifying some machining parameters. To simplify the experiments and variation, yet keep the accuracy and confidential of results, the Taguchi experimental design was employed in this research.

2.1 Tools and Materials

2.1.1 Tools

a) C6236x1000 GUT Lathe Machine
b) Load Cell
c) Strain gauge sensor Type 10-120-C1-11 L1M 2 R
d) Amplifier
e) Data logger (ADAM 4018)
f) Laptop / Display

2.1.2 Materials

a) HSS (High Speed Steel) chisel size ¾ ”
b) Aluminum 6061 Ø15mm x 150 mm

2.2 Research Procedures

The working principle of the feeding force testing tool is that the load cell is clamped on the tool post and the tool is clamped to the load cell. The cutting process begins when the tool touches the workpiece and the strain gauge sensor will read then forward it to the

Wheatstone bridge to stabilize the incoming voltage. The output voltage from the Wheatstone bridge is passed on to the amplifier which then enters the data logger. The data logger then proceeds to the display or PC. The test equipment scheme is shown in Figure 2.

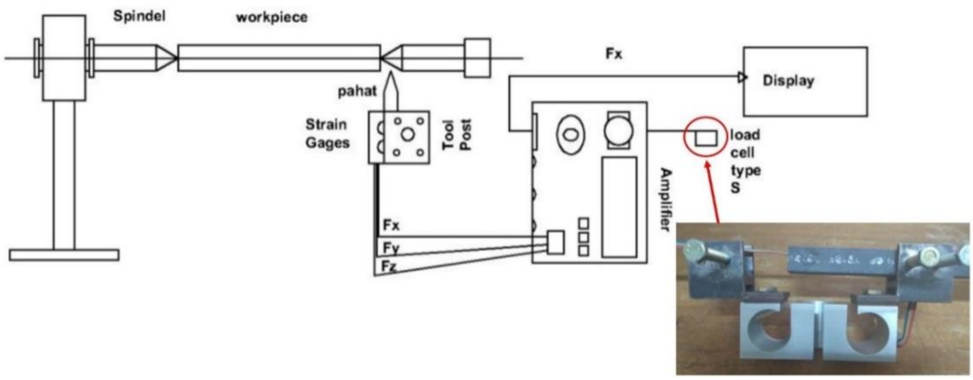

Figure 3. The schematic diagram for the feed force sensing and recording.

This study used 3 control factors with 3 levels for each factor. The control factors and levels used in this study is shown in Table 1.

Table 1. Control factors and research factor levels

Symbol	Control Factor	Factor Level		
		1	2	3
N	Spindle speed (rpm)	140	215	330
F	*Feeding* (mm/r)	0.043	0.065	0.081
D	Depth of cut (mm)	0.2	0.4	0.6

3. Result and Discussion

3.1 Verification Process

The verification process is used to determine the increase in voltage to the load. The results of the calibration are then changed in the form of a formula to convert from the electric voltage (mV) to mass units (grams). The calibration process uses vise to clamp the load cell so that the position can be adjusted in the direction of the feeding force. The loading process is carried out at the end of the load cell using a scale lead with a load increasing from 49.8 - 597.3 grams. Retrieval of this data takes 12 data with 3 repetitions. The plot of the verification graph, namely the linearity verification of mass with voltage, is shown in Figure 4.

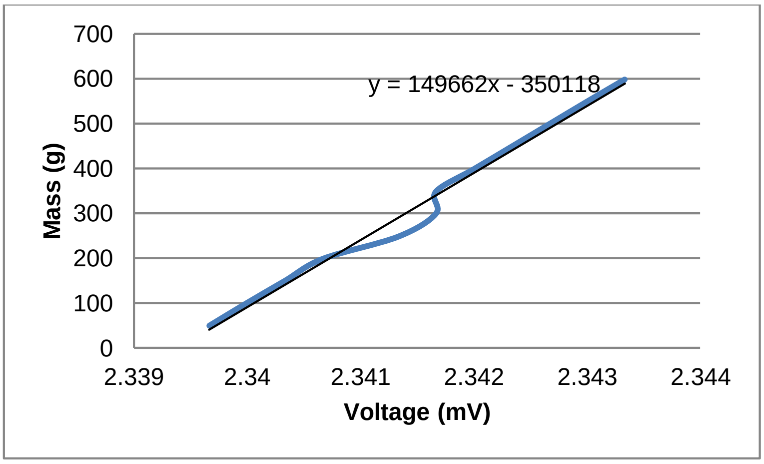

Figure 4. Linearity of mass with voltage

The linear equation is used to convert millivolt (mV) output data into grams (g) mass units, after which it is converted into Newton units (N) multiplied by the acceleration of gravity. The process of data conversion is done by changing the x variable in the formula into the output voltage during the turning process.

This results is adequate for a traditional system with a low cost sensor in compare to the more advantage system of force measurement using delicate sensor Luo (2018) [8] and artificial intelligent such as result of Li (2000) [9]. The result is also comparable to that of using dynamometer Wan (2016) [10] is term of sensitivity to the input signal.

3.2 Response Data Results

The results of the response data are the results of data in the turning process of the 6061 aluminum workpiece with the HSS tool. For the design of experimental data retrieval using orthogonal arrays tables of the Taguchi L9 method (3^4) with 3 times replication. When the data turning process is strived to have accurate sensitivity by adjusting the gain and offset of the amplifier. Each data collection from measurements that come out as many as hundreds of data. It is sufficiently represented by the mean data in each stable condition on the plot of the response graph for statistical calculations. The force response data graph is shown in Figure 5.

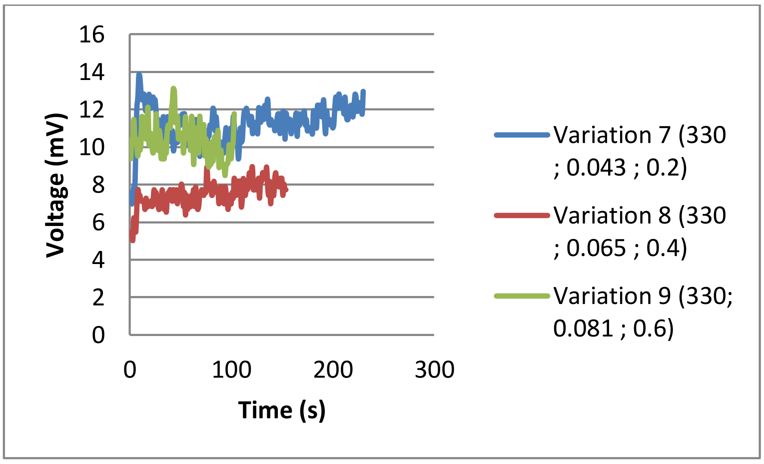

Figure 5. Graph of force response variations 7, 8 and 9

According to Figure 4, the response data for each variation experienced ups and downs. The graphs fluctuations were caused by a shift in the offset value of the strain gauge. The offset value can shift up to ± 0.07 mV. In the turning process, there is a vibration in the tool to allow a shift in the movement of the tool when cutting the workpiece.

3.3 Analysis of Variance (ANOVA)

3.3.1 Response from Average Results

Feeding force testing is done based on the L9 orthogonal matrix with each variation replicated three times. The average data of each variation that has been obtained in the test is used to find the percent value of the contribution which then can be used to determine the effect of the parameters on the target response to be achieved. In this study, the mean data for feeding force (Ff) is shown in Table 2.

The overall average feeding force data from 3 repetitions would be used to calculate the average response value of the speed rate, feed rate, and depth of cut parameters. The following Table 3 is the result of calculating the average response value of each level of the machining parameter.

Table 2. Mean feeding force data

No	N (RPM)	Feed Rate (mm/rot)	Depth of Cut (mm)	Average
1	140	0.043	0.2	112.143
2	140	0.065	0.4	54.004
3	140	0.081	0.6	94.780
4	215	0.043	0.4	273.180
5	215	0.065	0.6	263.458
6	215	0.081	0.2	333.237
7	330	0.043	0.6	131.726
8	330	0.065	0.2	72.101
9	420	0.081	0.4	107.588

Table 3. Average response values for each level

Machining Parameters	Level		
	1	2	3
n (rpm)	86.975	289.958	102.018
f (mm/r)	172.349	129.854	129.854
d (mm)	172.494	143.137	163.322
Average	154.440		

The followings are ANOVA results with S/N ratio along with the F value with a significant level of 5% α = 0.05 with a value of F (0.05; 2; 2) = 19.00, overall is shown in Table 4.

Table 4. ANOVA results with an average S/N ratio for the cutting force

Parameter	DF	SS	MS	F	P
N	2	76994.176	38497.088	335.995	92%
F	2	4589.023	2294.511	20.026	2%
D	2	1597.725	798.862	6.972	2%
Residual error	2	229.152	114.576		4%
Total	8				

The percentage contribution shows the portion of the parameter to the total variation of responses observed. In this Table 4, the error is only 4 %, therefore the results is acceptable for further analysis [11], [12]. This research evident that spindle rotation contributes 92% toward the feed force. In contrast, Manjunatha and Umesh (2014) obtained that the feed force mainly affected by the depth of cut by 78.3% [6]. Another research shown cutting force was influenced in order by feed rate, depth of cut and cutting, as described by Sivaraman et al. [13]. The difference result may because the different material and being machined and the tools used and other condition which is assumed as the constant in fact these variables influence the forces.

The most possible cause of difference is the low sensitivity of the load cell. Another possible cause is the zero point shifting (gain and offset) in the data acquisition system arrangement which result in alteration of range result of measurement. It keeps fluctuate up and down. Sensitivity is a measurement specification which measure the smallest absolute amount of change that can be detected by a measurement [14]. It can be identified by changing of gradient to the time. The shorter the range of the alteration the better is the sensitivity of the measuring device. In this experiments, sensitivity and zero (datum) was manually controlled by gain and offset. Calibration shows that increased range was 0.0006 mV and dropping of -12.34 mV.

4. CONCLUSION

Based on the results of experiments measuring feed force in the turning process, the following conclusions can be drawn:

1) Measurement with a strain gauge sensor produces an average output data with a maximum sensitivity of 0,0007 mV by producing a linearity equation from the calibration process that is y = 149662x - 350118.
2) The most optimal feeding force response is at spindle speed 140, feed rate 0.065, and depth of cut 0.4.
3) The speed rate parameter has a significant effect from other parameters by contributing 92% using ANOVA. Besides, the feed rate and depth of cut parameters are the second parameters with a contribution of 2% each.

This research discusses how the influence of the speed rate, feed rate and depth of cut parameters on the force of feeding direction on the axial axis. However, in the process of measurement, there was a technical error which caused an inaccurate data collection process. Suggestions for further research are expected to ensure the sensitivity of the measuring instrument sensor and set a zero point (offset) so that the shifting of data can be minimized.

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