Monitoring of Surface Roughness in Aluminium Turning Process

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Abstract. As the turning process is one of the most necessary process. The surface roughness has been considered for the quality of workpiece. There are many factors which affect the surface roughness. Hence, the objective of this research is to monitor the relation between the surface roughness and the cutting forces in aluminium turning process with a wide range of cutting conditions. The coated carbide tool and aluminium alloy (Al 6063) are used for this experiment. The cutting parameters are investigated to analyze the effects of them on the surface roughness which are the cutting speed, the feed rate, the tool nose radius and the depth of cut. In the case of this research, the dynamometer is installed in the turret of CNC turning machine to generate a signal while turning. The relation between dynamic cutting forces and the surface roughness profile is examined by applying the Fast Fourier Transform (FFT). The experimentally obtained results showed that the cutting force depends on the cutting condition. The surface roughness can be improved when increasing the cutting speed and the tool nose radius in contrast to the feed rate and the depth of cut. The relation between the cutting parameters and the surface roughness can be explained by the in-process cutting forces. It is understood that the in-process cutting forces are able to predict the surface roughness in the further research.

1. Introduction
A turning process is widely used to produce the parts in industry such as the automotive parts. It is known that the CNC turning machine can manufacture the complicated mechanical parts in large volume and high accuracy, which can reduce cost and production time, including the high efficiency production rate. Normally, the surface roughness is an important indicator to decide the workpiece quality before sending to the customer. Owing to, the surface finish of the workpiece impacts the assembly process, especially the shaft of the spindle motor parts that have high precision. In fact, there are many factors affecting the surface roughness. However, surface roughness cannot be measured during the turning process.

However, the relation among the surface roughness, the cutting conditions and the cutting force in CNC turning process had been studied so far. There are many researches that have analyzed and investigated the surface roughness in the turning process. Thamizhmanii, Saparudin, and Hasan [1] analyzed of optimum cutting conditions to find the lowest surface roughness in turning SCM 440 alloy steel. The experimental results showed that the depth of cut and the feed rate affected the surface roughness. Rao, C.J., D.N. Rao and Srihari [2] studied the significance of cutting speed, feed rate and
depth of cut on cutting force and surface roughness in the turning process. It has been proved that the feed rate has a significant influence on both the cutting force and the surface roughness. The depth of cut has influenced on the cutting force. Lalwani, Mehta, and Jain [3] investigated the effect of cutting parameters on feed force, thrust force, cutting force and surface roughness in finish hard turning of MDN250 steel. It was known that the effect of feed rate is the most significant factor on the surface roughness. The feed rate and the depth of cut affected cutting force and feed force.

The surface roughness models have been proposed by many researchers [4-7]. Tangjitsitcharoen [7] developed the in-process surface roughness model that uses the cutting force ratio by employing the exponential function. It has been proved that the cutting force can be used to predict the in-process surface roughness under various cutting conditions during the cutting.

The previous researches had focused on the parameters of carbon steel turning process and predicted the surface roughness using the cutting force ratio which consists of the main force and the feed force [6, 7]. The quality of surface roughness subjected to the feed rate, the cutting speed, the depth of cut and the tool nose radius [7]. Hence, the aim of this research is to study the relations among the surface roughness, the cutting conditions and the cutting forces during the turning process using the coated carbide tool and the work material of aluminium (Al 6063).

2. Relations of Cutting Condition, Cutting Forces and Surface Roughness
The important cutting conditions relate to the surface finish in CNC turning process are the feed rate, the cutting speed, the depth of cut and the tool nose radius. As the theory of surface roughness, the feed rate and the tool nose radius are directly concerned in the surface finish. The larger tool nose radius results in the low theoretical surface roughness while the higher feed rate causes the high theoretical surface roughness [8, 9].

The high cutting speed leads to an increase in the cutting temperature so the work material becomes soft. It means that the cutting forces are lower and easy to cut, which results in a good quality of surface finish [7, 10, 11]. The large depth of cut brings about the larger cutting area and the higher dynamic cutting force which affects the vibration of cutting tool and workpiece during the cutting. Furthermore, it leads to an increase in the surface roughness [7]. Consequently, the relationship between the surface roughness and the above cutting parameters is considered due to the improvement of the quality of surface finish.

3. Experimental Setup and Procedure
The experiments are tested on the CNC turning machine. The aluminium alloy (Al 6063) is adopted for this experiment with the coated carbide tool, which is the different tool nose radiuses of 0.4 and 0.8 mm. The cutting tool’s rake angle is 11°. The dynamometer (Kistler, model: 9121) is installed in the turret to generate a signal while turning. The cutting forces are amplified through the charge amplifier (Kistler, model: 5083) and demonstrate the result by the oscilloscope (Yokogawa, DL750) before digitization in the computer as shown in figure 1. The arithmetic mean surface roughness (Ra) and the surface roughness depth (Rz) are measured by the surface roughness tester (Mitutoyo, SJ-400). The cutting conditions are summarized in table 1.

The experimental setup and procedures are presented as follows:
1. To prepare the dimensional cylindrical workpieces.
2. To set the oscilloscope (at the sampling rate of 1kHz and the low-pass filtered of 500 Hz)
3. To start turning and monitoring the in-process cutting forces which consist of the feed force, the main force and the radial force.
4. To examine the relation between the surface roughness and the cutting forces in the time and frequency domains.
5. To calculate the cutting forces with the personal computer.
6. To analyze the effect of cutting conditions on the surface roughness by plotting the relations of them.
4. Experimental Results and Discussions

4.1 Relation of Surface Roughness Profile and Cutting Forces

The relation between surface roughness profile and dynamic cutting forces which corresponds with time record of the surface roughness profile in time domain as shown in figure 2. It is explained that the cutting force signals are resembling the surface roughness profile. Figure 3 shows the frequencies of the dynamic cutting forces and the surface roughness profile which are the same frequency at 16 Hz by applying the Fast Fourier Transform (FFT). It is also proved that the dynamic cutting forces conform to the surface roughness profile. Thus, the dynamic cutting forces are able to predict the surface roughness during the turning.

![Figure 1. Illustration of experimental set up.](image)

Table 1. Cutting conditions

| Cutting tool      | Tool geometry | Tool nose radius (mm) | Workpiece       | Cutting speed (m/min) | Feed rate (mm/rev) | Depth of cut (mm) |
|-------------------|---------------|-----------------------|-----------------|-----------------------|---------------------|------------------|
| Coated carbide    | TPMR160304 HQ | 0.4                   | Aluminium (Al 6063) | 150                   | 0.100               | 0.1              |
| tool              | TPMR160308 HQ | 0.8                   |                  | 200                   | 0.125               | 0.2              |
|                   |               |                       |                  | 250                   | 0.150               | 0.3              |

![Figure 2. Illustration of experimentally obtained dynamic cutting forces and surface roughness profile in time domain at cutting speed of 150 m/min, feed rate of 0.125 mm/rev, depth of cut of 0.1 mm and tool nose radius of 0.8 mm.](image)
Effects of Cutting Conditions on Surface Roughness

Figure 4 shows the relation between the surface roughness and the cutting speed in which both of them are contrary. The cutting speed increases while the surface roughness decreases because the higher cutting speed causes the higher cutting temperature. Hence, the work material becomes softer that leads to the lower cutting forces [7]. The surface finish would be improved at the higher cutting speed. However, too high the cutting speed in aluminium turning causes the built-up edge (BUE) that results in the poor surface finish.

Figure 4. Illustration of experimentally obtained relation between surface roughness and cutting speed at feed rate of 0.125 mm/rev, depth of cut of 0.1 mm and tool nose radius of 0.8 mm.

4.2 Effects of Cutting Conditions on Surface Roughness

Figure 3. Illustration of experimentally obtained dynamic cutting forces and surface roughness profile in frequency domain at cutting speed of 150 m/min, feed rate of 0.125 mm/rev, depth of cut of 0.1 mm and tool nose radius of 0.8 mm.

(a) Cutting forces

(b) Surface roughness profile

Cutting forces frequency

Surface roughness frequency

(a) Arithmetic mean surface roughness (Ra)

(b) Surface roughness depth (Rz)

Figure 4. Illustration of experimentally obtained relation between surface roughness and cutting speed at feed rate of 0.100 mm/rev, depth of cut of 0.3 mm, tool nose radius of 0.4 and 0.8 mm.

Figure 5 shows that the different three feed rates comparing with the same tool nose radius, the depth of cut and the cutting speed. In this case, an increase in feed rate brings the poor surface roughness which corresponds to the theoretical surface finish. The higher feed rate causes the larger cutting area that leads to the higher cutting forces. The cutting tool will be vibrated which can result in pronounced waviness on the workpiece surface. Consequently, the surface finish is poor [9].
Figure 5. Illustration of experimentally obtained relation between surface roughness and feed rate at cutting speed of 250 mm/min, depth of cut of 0.3 mm, tool nose radius of 0.4 and 0.8 mm.

Figure 6 represents the relation between the surface roughness and the depth of cut which are consistent. An increase in depth of cut will go up to the surface roughness. These a raised cutting area which means that giving the larger of cutting forces resulting in an increase the surface roughness. However, the vibration of cutting tool during cutting is involved by the high depth of cut.

From the principles of surface roughness, it is widely known that the tool nose radius affects the quality of surface finish. With the same feed rate, the better surface finish of the tool nose radius of 0.8 mm can be obtained as compared to the tool nose radius of 0.4 mm as shown in figure 7. It can be concluded that the larger tool nose radius helps to improve the surface finish because it can reduce the feed marks on the turned surface.
5. Conclusions
The relation among the surface roughness, the cutting condition and the cutting forces is studied. Based on the experimental results, the dynamic cutting forces are correspondent with the in-process surface roughness in time and frequency domains. The cutting results have demonstrated that the surface roughness become lower when the feed rate and the depth of cut are low which is in contrast to the cutting speed and the tool nose radius. Since the cutting forces are decreased by a decrease in the feed rate and the depth of cut, the work material is soften by an increase in the cutting speed. The large tool nose radius can reduce the feed marks on the turned surface that it helps to improve the surface finish.

It is implied that the in-process cutting forces are able to predict the surface roughness during the aluminium turning process.

References
[1] Thamizhmanii, S., S. Saparudin, and S. Hasan (2007) Analyses of surface roughness by turning process using Taguchi method. *Journal of Achievements in Materials and Manufacturing Engineering*, 20, 503-506.
[2] Rao, C.J., D.N. Rao, and P. Srihari (2013) Influence of Cutting Parameters on Cutting Force and Surface Finish in Turning Operation. *Procedia Engineering*, 64, 1405-1415.
[3] Lalwani, D.I., N.K. Mehta, and P.K. Jain (2008) Experimental investigations of cutting parameters influence on cutting forces and surface roughness in finish hard turning of MDN250 steel. *Journal of Materials Processing Technology*, 206, 167-179.
[4] Thammasing, V. and S. Tangjitsitcharoen (2014) In-Process Prediction of Surface Roughness in Grinding Process by Monitoring of Cutting Force Ratio. *Applied Mechanics & Materials*, (627).
[5] Tangjitsitcharoen, S., K. Samanmit, and S. Ratanakuakangwan (2014) Development of surface roughness prediction by utilizing dynamic cutting force ratio. *Applied Mechanics and Materials*, 490: p. 207.
[6] Tangjitsitcharoen, S. and S. Damrongthaveesak (2013) Advance in monitoring and process control of surface roughness. *World Academy of Science, Engineering and Technology*, 7, 07-29.
[7] Tangjitsitcharoen, S. (2010) In-process prediction of surface roughness by utilizing the cutting force ratio. *Trans NAMRI/SME*, 38, 307-315.
[8] Serope Kalpakjian, S.R.S. (2001) *Manufacturing engineering and technology 4th Edition*, USA: Prentice-Hall, Inc.
[9] Mikell P. Groover (2010) *Fundamentals of modern manufacturing : materials, processes, and system*. Vol. 4th Ed.ition, USA: John Wiley & Sons, Inc.
[10] Tangjitsitcharoen, S. (2013) Advanced prediction of surface roughness by monitoring of dynamic cutting forces in CNC turning process. *Applied Mechanics and Materials*, Trans Tech Publ.
[11] Somkiat, T., A. Somchart, and T. Sirichan. (2010) In-process monitoring and prediction of surface roughness on CNC turning by using response surface analysis. *Proceedings of the 36th International MATADOR Conference*. 2010. Springer.