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MONITORING OF SURFACE ROUGHNESS IN CNC TURNING PROCESS

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Abstract: *In order to realize the intelligent machine tools, the objective of this research is to propose a practical model to predict the in-process surface roughness during the turning process by using the cutting force ratio. The proposed in-process surface roughness model is developed base on the experimentally obtain result by employing the exponential function with six factors of the cutting speed, the feed rate, the rank angle the tool nose radius, the depth of cut, and the cutting force ratio. The multiple regression analysis is utilized to calculate the regression coefficients with the use of the least square method. The prediction accuracy of the in-process surface roughness model has been also presented to monitor and control the in-process predicted surface roughness. It is proved by the cutting tests that the propose and developed in-process surface roughness model can be used to predict the in-process surface roughness by utilizing the cutting force ratio with the highly acceptable prediction accuracy.*
Key words: *turning, monitoring, prediction, surface roughness, cutting force ratio.*

1. INTRODUCTION

Turning process is one of the most important processes which are widely used to produce the mechanical parts. However, the surface roughness cannot be measured while cutting at the same time as there are many factors affecting to the surface roughness of the machining parts. As the intelligent machines are expected to be realized in the future, the in-process monitoring and estimation of the surface roughness is hence proposed and developed in this research.

The effects of the cutting conditions are studied and investigated for the models (Cakir et al., 2009). The sensors and the methodologies have been developed to predict the surface roughness (Shiraishi, 1981). The feed force is most sensitive to the surface roughness while the main force is affected by the cutting conditions (Tlusty & Andrews, 1983). Hence, the main force and the feed force are adopted to estimate the surface roughness during the cutting.

The aim of this research is to propose a method of the in-process monitoring of cutting force ratio to estimate the in-process surface roughness. The in-process surface roughness model is developed under various cutting conditions by employing the exponential function with the aid of the multiple regression analysis and the use of the least square method.

2. IN-PROCESS PREDICTION OF SURFACE ROUGHNESS

2.1 In-Process Monitoring of Cutting Force

The method is proposed here to use the in-process monitoring to measure the in-process cutting forces during the process in order to predict the surface roughness under various cutting conditions.

The cutting forces are normalized and dimensionless by taking the the ratio of the corresponding time records of the feed force F_y to the main force F_z. The cutting force ratio $\left(\frac{F_Y}{F_Z}\right)$ is the important factor to estimate the in-process surface roughness during the cutting (Ignatov et al, 2008). It is expected that the cutting force ratio can be used to predict the in-process surface roughness even though the cutting conditions are changed.

2.2 In-process surface roughness model

The exponential function is adopted here to develop the in-process surface roughness model. The relations of the arithmetic average surface roughness, the surface roughness, the cutting force ratio, and the cutting parameters are proposed here as:

$$R_a = C_1 \cdot V^{a_1} \cdot f^{a_2} \cdot {R_n}^{a_3} \cdot D^{a_4} \cdot \left(\frac{Fy}{Fz}\right)^{a_5} \cdot e^{a_6 \gamma} \quad (1)$$

$$R_z = C_2 \cdot V^{a_7} \cdot f^{a_8} \cdot {R_n}^{a_9} \cdot D^{a_{10}} \cdot \left(\frac{Fy}{Fz}\right)^{a_{11}} \cdot e^{a_{12} \gamma} \quad (2)$$

Where R_a is the arithmetic average surface roughness in μm, R_z is the surface roughness in μm, V is the cutting speed in m/min, f is the feed rate in mm/rev, R_n is the tool nose radius in mm, D is the depth of cut in mm $\left(\frac{Fy}{Fz}\right)$ is the cutting force ratio, γ is the rake angle in degree, a_1, a_2, a_3, a_4, a_5, a_7, a_8, a_9, a_{10}, a_{11}, a_{12} and C_1, C_2 are the regression coefficients of the models.

3. EXPERIMENTAL CUTTING CONDITIONS AND PROCEDURES

Series of the cutting experiments are conducted on a commercially available small CNC turning machine as shown in Fig. 1. The carbon steel (AISI 1045) is adopted in the cutting experiments and The major cutting conditions are summarized in Tab 1.

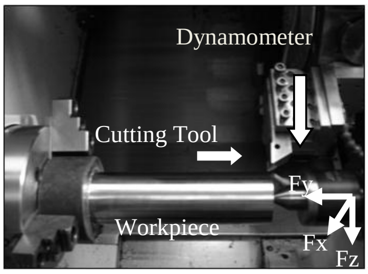


Fig. 1. Illustration of the experimental setup

Cutting tool	Coated carbide tool
Negative tool rake angle -6°	TNMG 160404 HQ TNMG 160408 HQ
Positive tool rake angle 11°	TPMR 160304 HQ TPMR 160308 HQ
Workpiece	AISI 1045 carbon steel
Cutting speed (m/min)	150, 250
Feed rate (mm/rev)	0.15, 0.18
Depth of cut (mm)	0.25, 0.5
Chip volume (cm^3)	0, 500, 1,000, 1,500, 2,000

Tab. 1. Major cutting conditions

4. RESULTS AND DISCUSSIONS

4.1 Effects of cutting force ratios on surface roughness

The experimentally obtained relation of the surface roughness and the cutting force ratio is shown in Fig. 2. It can be stated that the greater the cutting force ratios, the less the R_a and R_z It is interpreted that the surface roughness increases while the chip volume or the cutting time increases (Thamizhmanii et al, 2007). The relation between the surface roughness and the cutting force ratio shows the same trend even though the cutting conditions are different. It is understood that the cutting force ratio can be used to estimate the in-process surface roughness during the cutting.

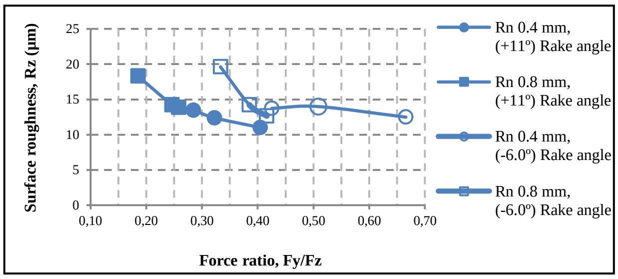


Fig. 2. Examples of experimentally obtained relations of surface roughness and cutting force ratio at V 250 m/min, f 0.18 mm/rev, D 0.25 mm

4.2 Surface roughness estimation

The experimentally obtained in-process surface roughness models are shown as below:

$$R_a = 53.52 \cdot v^{-0.122} \cdot f^{1.60} \cdot R_n{}^{-0.519} \cdot D^{0.108} \cdot \left(\frac{F_y}{F_z}\right)^{-0.296} \cdot e^{-0.0187\gamma} \quad (3)$$

$$R_z = 757.48 \cdot v^{-0.263} \cdot f^{1.59} \cdot R_n{}^{-0.205} \cdot D^{0.163} \cdot \left(\frac{F_y}{F_z}\right)^{-0.18} \cdot e^{-0.00998\gamma} \quad (4)$$

The models are valid at a high significance (P-value = 0.000) at 95% confident level.

4.3 Surface roughness model accuracy

The new cutting tests are conducted in order to verify the accuracy of the in-process surface roughness model by utilizing the new cutting conditions.

Fig. 3 shows the experimentally measured surface roughness, the ±10% measured surface roughness, and the in-process predicted surface roughness obtained from the equations (3) and (4). The prediction accuracy of the R_a and R_z is about 84.92% and 87.39%, respectively. The values of the in-process predicted surface roughness are within the ±10% measured surface roughness. It indicates that the proposed in-process surface roughness model can be effectively used to monitor and predict the in-process surface roughness.

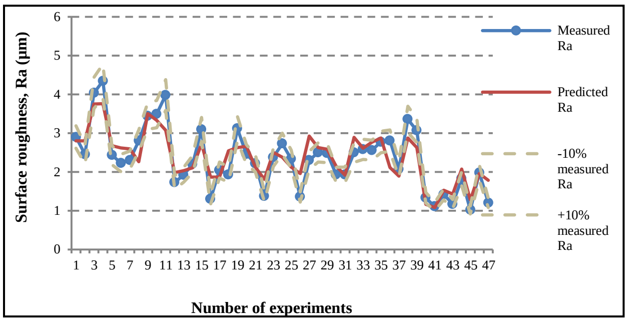
5. CONCLUSIONS

In order to realize the intelligent machine tools in the near future, the in-process monitoring is proposed to measure the cutting forces to predict the in-process surface roughness under various cutting conditions during the cutting.

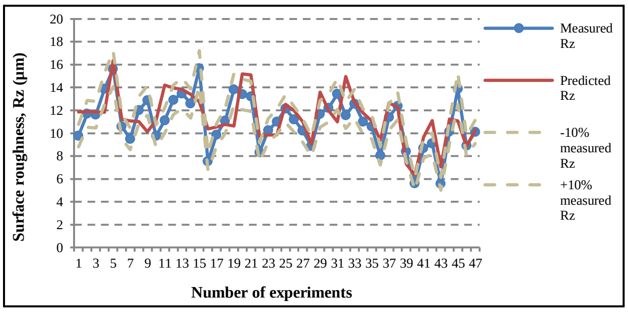
A cutting force ratio is utilized to predict the in-process surface roughness regardless of the cutting conditions, which is the ratio of the corresponding time records of the feed force to the main force.

The relations of the surface roughness, the cutting speed, the feed rate, the tool nose radius, the depth of cut, the rake angle, and the cutting force ratio are investigated to develop the in-process surface roughness models. The exponential function is employed to represent the relation of the arithmetic average surface roughness, the cutting force ratio, and the cutting parameters. The multiple regression analysis has been utilized to calculate the regression coefficients of the in-process prediction of surface roughness model by using the least square method.

It is proved by the cutting experiments that the in-process surface roughness can be predicted and obtained with the high accuracy by using the in-process surface roughness models proposed. However, another tool geometry should be studied and included in the models to obtain the higher prediction accuracy.



(a) Ra



(b) Rz

Fig. 3. Illustration of the measured surface roughness, the in-process predicted surface roughness, and the ±10% measured surface roughness

6. ACKNOWLEDGEMENT

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