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DEVELOPMENT OF 3D SURFACE ROUGHNESS PREDICTION TECHNIQUE IN FINE TURNING

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ABSTRACT
Surface roughness plays an important role in production quality. To maintain the necessary production quality it is necessary to understand the formation of the surface roughness. This publication focuses on developing technique for prediction of 3D surface roughness parameters in fine turning. As the surface characterization parameters are used 3D surface roughness. However, theoretical base of calculating 3D surface parameters according to technological parameters is not well developed.
In the study for development of prediction technique are used empirical formulae and mathematical models. The aim is to find a theoretical base going out from practical results got in the fine turning.
Keywords: surface, roughness, machining, prediction

1. INTRODUCTION

To maintain a desired surface quality of a produced part it is necessary to use a finishing process like grinding, which is economically expensive process. One of the options to eliminate grinding is to use fine turning. Fine turning is a turning operation by which it is possible to reach the same surface quality as by grinding. Therefore it is necessary to develop the surface prediction techniques according to this technological process. Developing such techniques will help manufacturing engineers to set cutting machines without long-term adjusting. Material and time economy could be reached and also quality maintained. To describe the machined surface parameters the 3D surface roughness parameters are used, because in real life the part is made and it works in 3D environment.

2. BASICS OF SURFACE PREDICTION

2.1. Theoretical model of surface roughness

When starting the study on roughness parameters according to technological parameters revealed a very simple theoretical equation. Ideal surface roughness is a function of only tool feed and geometry. It represents the best possible finish, which can be obtained for a given tool shape and feed. It can be shown by the following theoretical expression:

$$R_{\max} = \frac{f^2}{32r} \qquad (1)$$

where R_{max} is the height of profile; f is feed and r is radius of rounded corner of cutting tool.

But it is also known that such R_{max} can be achieved only if built-up-edge, chatter, inaccuracies in the machine tool movements and other factors are eliminated completely. According to the model or equation (1) decreasing the feed or taking a bigger cutting tool radius will improve the surface roughness.

The most popular surface roughness parameter is R_a or average roughness parameter:

$$R_a = \frac{1}{L}\int_0^L |y(x)| dx \quad (2)$$

where L is a sampling length; y is the ordinate of the profile curve.

It is already known that roughness profile parameters can not give satisfied results. Many parameters are excluded, because profile is just a small piece of all machined surface. New parameters should be introduced. Since new metrology methods are developed, it is possible to measure the surface 3D parameters. Most popular surface 3D parameters are S_a, S_q and S_{sk}, and S_{ku}. These are amplitude parameters, which are extensions of those previously employed in the 2D characterisation methods, respectively R_a, R_q, R_{sk} and R_{ku} [2].

Average absolute deviation of the surface:

$$S_a = \frac{1}{MN}\sum_{j=1}^{N}\sum_{i=1}^{M} z(x_i; y_i) \quad (3)$$

where z is the height of the measured point in the coordinates x and y; MN is the measured surface (width and length).

All surface roughness 3D parameters (together 14) can be used for evaluation of the surface, but it is better to use S_a or S_q (Root-Mean-Square). Of course, for evaluation of honed surface it is better to use S_{sk}, because its better characterize honed surfaces. For example, for evaluating machining parameters in turning S_a is used, but for evaluating machining parameters in honing S_{sk} is used.

2.2. Machining variables

When the surface 3D parameters are chosen it is necessary to determine, which technological parameters should be considered. The final surface roughness can be considered as a sum of two technological parameters groups:

a) ideal surface roughness resulted from tool geometry and feed as mentioned previous;

b) natural surface roughness resulted from irregularities in the machining process. One of the main factors contributing to natural roughness is the occurrence of a built-up-edge.

The next thing is to determine the factors that affect the surface finish (shown in Table 1). Not all parameters should be considered for surface roughness prediction. Some parameters do not have a big influence on surface roughness or can be eliminated. It also should be kept in mind that not all parameters can be controlled by workshop operator. It means that for the prediction models it is preferably to take such parameters, which can be controlled by operator.

Table 1. Parameters affecting surface roughness

Machining / Setup variables Cutting speed Feed rate Depth of cut Approach angle	These parameters can be set up in advance. It means that these parameters are controllable. “Controllable” means that these parameters are known – set in advance. But it does not mean that knowing these parameters it is easy to predict the surface roughness.
Tool geometry and its properties Nose radius Rake angle Point angle Side cutting edge angle Cutting edge geometry Tool material Tool wear (effective time) Tool overhang	These factors depend on the tool to be chosen for exact machining process. If the tool is qualitative – predictable, then parameters are considered to be controllable. Anyway, it is necessary to keep in mind that such a factor like extensive tool wear can occur. In such a case tool geometry can not be considered as predictable parameter.

Workpiece Material Hardness Dimensions	If used materials are produced under quality control, the parameter (workpiece properties) can be considered as controllable.
Auxiliary tooling Machine rigidity Clamping system	Auxiliary tooling, for example clamping system, can be considered as controllable, if clamping process is done correctly. Clamping problems can be figure out by controlling machined parts waviness (vibrations).
Lubrication/cooling	In some processes like hard turning lubrication or cooling liquids are not used. In such a case the factor is omitted.
Vibrations Workpiece Cutting tool Machine	These factors also influence the waviness and form errors of the surface.

3. SURFACE MEASUREMENT

In the study for 3D surface measurements is used the Taylor Hobson surface measurement device (Taylor Hobson Form Talysurf Intra 50). For evaluation of surface roughness the Sa parameter is chosen. It was taken because it is quite similar to Ra parameter, but refers to surface nor profile. For the first time it is enough with Sa measurement. If there is some specific needs for machined part then it is possible to use another 3D surface roughness parameter for example S_{ku}, S_{sk}. Overall there are 14 3D parameters for measurement of surface roughness – the so called Birmingham 14.

4. ANALYSIS METHODOLOGY

4.1. Regression analysis

Various different methods have been used for evaluation of parameters of surface roughness. One of the most popular empirical methods is regression analysis. The regression analysis determines which factors and interactions are significant. It is one of the most important data mining techniques.

Doing research in surface prediction techniques, the following model was introduced – a functional relationship between surface roughness and the independent variables under investigation is postulated by:

$$Sa = C \bullet f^{a_1} \bullet v^{a_2} \bullet d^{a_3} \bullet H^{a_4} \bullet r^{a_5} \quad (5)$$

where S_a – surface roughness in mm, C – constant, f – feed in mm/rev., d – depth of cut in mm, H – workpiece hardness in HB (Hardness Brinell), r – tool nose radius in mm. Theses parameters were chosen after analysing the parameters shown in table 1.

A logarithmic transformation converts the nonlinear form of Equation (5) into the following linear form:

$$\ln Sa = \ln C + a_1 \ln f + a_2 \ln v + a_3 \ln d + a_4 \ln H + a_5 \ln r \quad (6)$$

For simplicity, Equation (6) is written as:

$$y = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + b_4 x_4 + b_5 x_5 \quad (7)$$

where y is the estimated surface roughness value after logarithmic transformation, b_0, b_1, b_2, b_3, b_4 and b_5 are the estimates of the parameters, respectively. x_1, x_2, x_3, x_4 and x_5 are the logarithmic transformations of feed (mm/rev), cutting speed (m/min), depth of cut (mm), workpiece hardness and tool nose radius respectively. Due to experimental error, the true response is y = z – E, where z is the logarithmic transformation of the measured surface roughness and E the experimental error.

After that the table of factors and variables is made (Table 2). Conducting experiment according these factors/parameters (v, f, d, HB, r) the surface roughness 3D parameter Sa is got.

Table 2. Factors and levels of experiments.

Level	**Factors**				
	Hardness	**Feed**	**Nose radius**	**Depth of cut**	**Cutting speed**
	A (H)	**B (f)**	**C (r)**	**D (d)**	**E (v)**
0	C45 (DIN)	0,1 mm/rev	0.4	0,5	120 m/min
1	X7Cr13 (DIN)	0,25 mm/rev	1.6	1,5	190 m/min

The next step is regression analysis according to these parameters. For regression analysis can be used Excel or MINITAB calculation programmes. From regression analysis are achieved indexes (constants). Then the transformed linear model (equation 6) can be returned into its original nonlinear form (equation 8) as follows:

$$Sa = C \bullet f^{\pm a_1} \bullet v^{\pm a_2} \bullet d^{\pm a_3} \bullet H^{\pm a_4} \bullet r^{\pm a_5} \quad (8)$$

where a_n are indexes (constants), which describe the empirical model. From that model it is possible to evaluate the influence of each parameter on the surface roughness 3D parameter.

4.2. Fuzzy logic

The most recent method for analysing cutting factors influence on surface roughness is the Fuzzy logic or system. Fuzzy logic is concerned with the continuous transition from truth to false states, as opposed to the discrete true/false transition in binary logic. Fuzzy logic is particularly attractive due too its ability to solve problems in the absence of accurate mathematical models [4]. Computational neural networks give a number of attractive properties for modelling complex manufacturing process or systems: universal function approximation capability, resistance to noisy or missing data.

Instead of operating with numeric values of variables and using mathematical functions to describe relationships, fuzzy logic uses common everyday language to describe variables and uses fuzzy linguistic rules to define relationships [1]. The fuzzy logic is quite a new method for building mathematical models and its still needs development.

4.3. Other methods

The next type of analysis, which can be used is Analysis of Variance also known as ANOVA. Some steps in this analysis are similar to Regression analysis.

Another method is Response Surface Methodology, which is also known from some publications. The next method which can be used is Taguchi Method Analysis. The Taguchi method is used to identify impact of various parameters on an output and figure out how to control them to reduce the variability in that output. These types of methods can be combined to compare the effectiveness of each other.

5. CONCLUSIONS

Fine turning allows a manufacturer to machine parts with wanted finish without the need for grinding or other similar finish operation. The paper gives approaches how to maintain the desired finish without additional experimentation or setup. Development of prediction techniques gives a time economy for manufacturer and therefore a possibility to cut the costs. The given models can also be transferred to other turning processes for example hard turning or even to other machining technologies keeping in mind the possible changes in input data.

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