HUNGARIAN JOURNAL
OF INDUSTRIAL CHEMISTRY
VESZPRÉM
Vol. 39(2) pp. 189-193 (2011)

# METHOD FOR DETERMINATION OF THE EXPECTED ROUGHNESS OF CUT SURFACES

C. FELHO✉, J. KUNDRAK

University of Miskolc, Department of Production Engineering, H-3515 Miskolc, Egyetemvaros, HUNGARY
✉E-mail: csaba.felho@uni-miskolc.hu

Nowadays the manufacturing companies create stricter and stricter demands on quality requirements of surfaces machined by cutting. The fulfilment of these requirements is often not an easy task, and in addition technologists should deal with the economic aspects too. Surface roughness indexes are important parameters in characterization of the quality of parts, especially in case of engaging and sliding one another machine elements influences remarkably their tribological properties and lifespan. Therefore it is indispensably important to completely satisfy the surface roughness requirements. It can mean a great help, if the prospective value of roughness indexes can be predicted in advance for the actual machining environment, since the selection of the optimal tool-geometrical and technological parameters become possible. Such a method will be introduced in the paper, by the help of which theoretical values of surface roughness can be determined for single point cutting by the help of an analytical model. A general mathematical model is introduced, by the help of which edge geometry of every realistically evolving tool can be described. Theoretical values of the relevant roughness indexes used in practice can be calculated by the application of this model. The connection with the real roughness data gained by experiments can be written down after this, hereby the surface roughness can be predicted, and thus the planning of technology can be faster and more efficient.

**Keywords:** surface roughness, theoretical roughness.

## Introduction

The accelerated technological evolution, the higher and higher quality requirements demanded for machine parts are provoked increased claims also against manufacturing technologies. This fact is especially prevalent in the automotive industry. More and more tasks are automated, and increasing number of characteristics is described by theoretical and computer models. One important factor for the characterization of surface quality is the microgeometry of the surface profile. The microgeometry can be quantified by practically selected roughness indexes. The determination of theoretical values of surface roughness in different metal cutting processes has been in focus since about a half century. A variety of theories were created, and the problem was examined by many kinds of aspects. The determination of theoretical roughness is important for technologists, since the expectable value of real roughness can be predicted for a given procedure, and thus it can provide help for the computer aided planning of manufacturing processes. Benardos and Vosniakos [1] have made a good review about the research works created in this field. They have classified the papers to four categories: analitical, based on designed experiment, experimental and AI-based works. Based on their work, main research groups dealing with surface roughness are shown In *Table 1* As it can be seen from the table, there are several different solutions to this problem, and each has its own advantages and drawbacks [2]. The set of parameters that are thought by Benardos and Vosniakos in [1] to influence surface roughness and thus have been investigated by researchers is diagrammatically represented in *Fig. 1*.

A theoretical model is introduced in the article by the help of which the theoretical value of roughness indexes used in practice can be determined for every realistically feasible cutting tool design. Through the examination of theoretical roughness it is assumed, that the imprint (negative) of the part of the tool which is near to the nose will remain in the machined surface, and that will form the surface roughness profile, and this geometry can be calculated from the tool-geometrical and technological parameters.

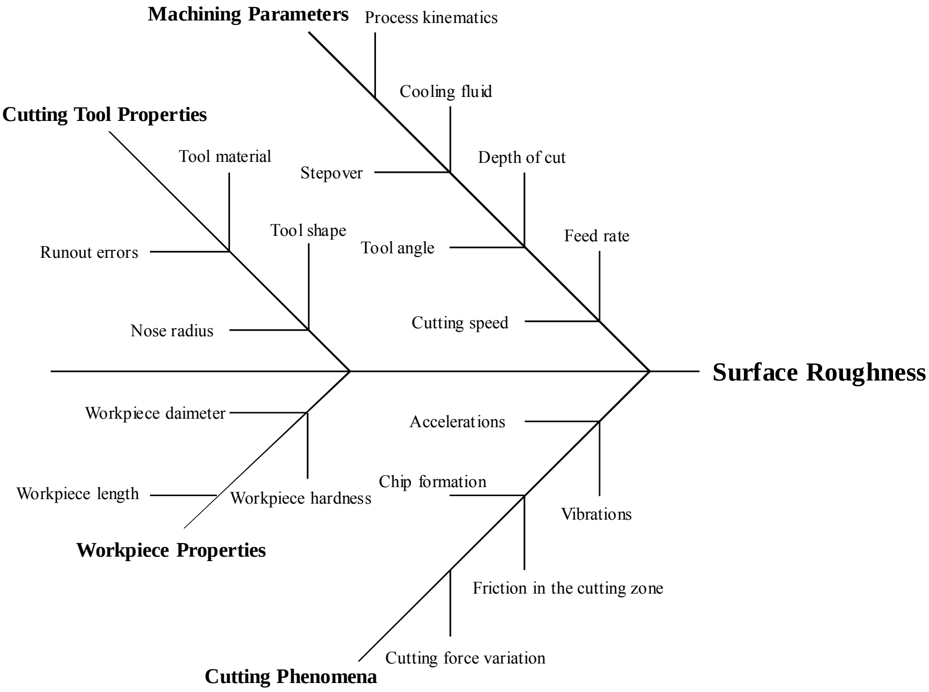


*Figure 1:* Fishbone diagram with the parameters that affect surface roughness [1]

*Table 1:* Main research groups dealing with modelling of surface roughness according to Benardos&Vosniakos [1]

| **Modelling procedures and techniques** | **Currently active research groups** | **Summary of the present status** | **Main disadvantages of the method** |
|---|---|---|---|
| **Analytical models or computer algorithms** | Grzesik; Lin and Chan; Baek et al.; Chen et al.; Ehmann and Hong; Kim and Chu; Lee et al. | • These ones simulate the cutting process in terms of kinematics and cutting tool properties.<br>• Often includes other parameters (e.g.. vibration)<br>• The obtained results are fairly good. | A lot of other factors that contribute to the roughness formation mechanism are not considered (wear and deflection of the cutting tool or certain thermal phenomena). |
| **Based on experiments** | Abouelatta and Madl; Ghani and Choudhury; Jang et al.; Beggan et al.; Dhar et al.; Munoz-Escalona and Cassier; Thielle and Melkote; Baptista and Antune Simoes; Coker and Shin; Diniz and Filho; Heisel | • This is the most conventional approach adopted.<br>• It is not difficult to implement and depending on the level of understanding of the participating phenomena, it can produce very good results. | The obtained conclusions have little or no general applicability. |
| **Based on designed experiments** | Davim; Choudhury and El-Baradie; Feng and Wang; Kopac and Bahor; Thomas and Beauchamp; Alauddin et al.; Fuh and Wu | • The response surface methodology (RSM) and the Taguchi techniques for design of experiments (DoE) are the mostly used methods. | The obtained relation has no general applicability. |
| **Based on artificial intelligence (AI)** | Azouzi and Guillot; Varghese and Radhakrishnan; Chien and Chou; Suresh et al.; Lee et al.; Li et al.; Oxley; Lin et al.; Matsumura et al.; Benardos and Vosniakos; Tsai et al.; Lou and Chen; Ho et al. | • Generally the artificial neural network (ANN) models or genetic algorithms (GA) are used.<br>• These can produce very good results and simultaneously offer the possibility for on-line monitoring and/or control of the process. | • It is very demanding on computational power.<br>• There is no guarantee for their resulting performance in an application. |

## Model for the calculation of theoretical roughness indexes in single point cutting

A new mathematical model was developed for the analytical calculation of theoretical roughness indexes in turning operations [3]. The examined roughness parameters were $R_{max}$, $R_z$, $R_a$ and the $t_p$ bearing ratio, however, one great advantage of this model is, that it is possible to calculate virtually all roughness parameters used in practice. The calculation method is introduced for turning cylindrical surfaces, but the model can be easily transformed for cutting other types of surfaces and for other processes, e.g. to face milling.

As it was observed from the literature overview, all of these analytical models were created with several simplifications, since there are too much factors affecting the real roughness profile [4]. The most important simplifications which were applied to our model are:

- the workpiece material is un-deformable in the machined surface;
- the cutting system is fully rigid;
- the cutting edge of the tool is a defined geometrical line.

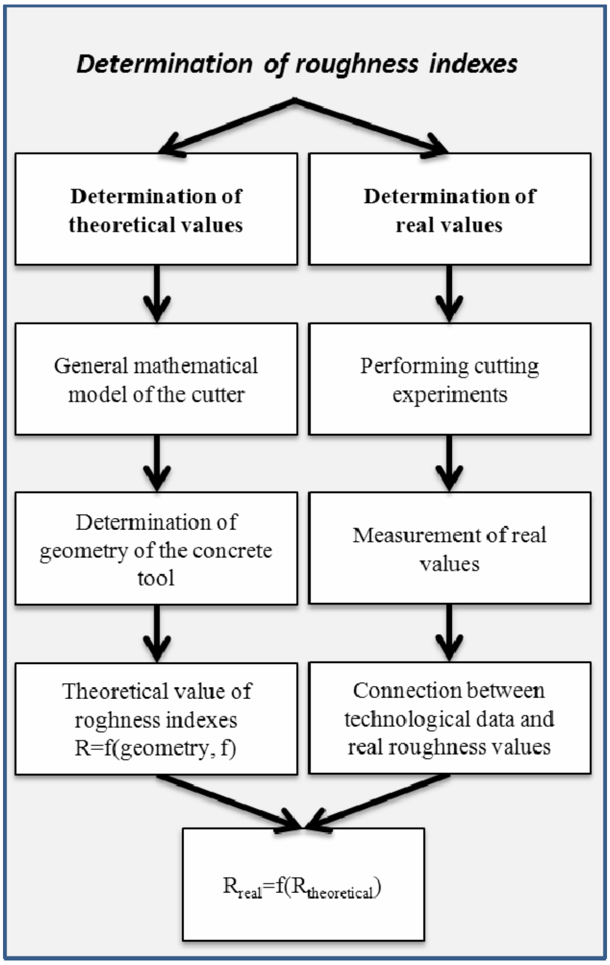


*Figure 2:* The overview of the applied method

The effect of these parameters can be built into the model by modifier factors. Series of experiments has to be performed for this, and the effect of the actual parameter can be measured and quantified. An overview of the applied calculation method is depicted in *Fig. 2.*

The essence of this calculation method is to create the general mathematical model of the single point cutting tools which have all of the possible edge sections a practically feasible tool can have. By putting this imaginary tool to an x-y coordinate system with the intersection point of the main and the auxiliary edge (the tool peak point) in the origin, the respective edge sections of the tool can be described by coordinates and emplacement angles *(Fig. 3)*.

The general cutter profile can be described with the following equation:

$$L = f\left(\ell, \ell', \ell'', \ell_1, \ell_1', \ell_1''\right) \tag{1}$$

where:

$\ell$, $\ell'$, $\ell''$ – sections of the main edge;

$\ell_1$, $\ell_1'$, $\ell_1''$ – sections of the auxiliary edge.

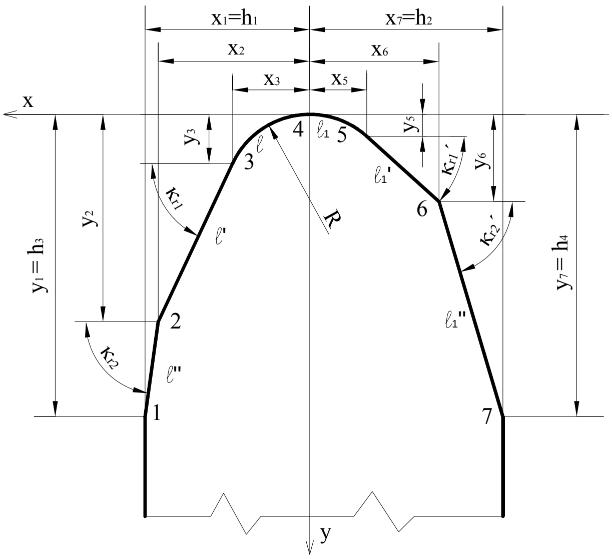

*Figure 3:* The general tool in the coordinate system

Edge sections of the main edge can be described with the following equations:

$$\begin{aligned} \ell &= R - \sqrt{R^2 - x^2}\ ; x_4 \le x < x_3 \\ \ell' &= tg\kappa_{r1} \cdot x + b\ ; x_3 \le x < x_2 \\ \ell'' &= tg\kappa_{r2} \cdot x + b_2\ ; x_2 \le x < x_1 \end{aligned} \tag{2}$$

Edge sections of the auxiliary edge can be written as:

$$\begin{aligned} \ell_1 &= R - \sqrt{R^2 - x^2}\ ; x_5 \le x < x_4 \\ \ell_1' &= tg\kappa_{r1}'\left|x\right| + b_1 ; x_6 \le x < x_5 \\ \ell_1'' &= tg\kappa_{r2}'\left|x\right| + b_3\ ; x_7 \le x < x_6 \end{aligned} \tag{3}$$

The geometry of the actual tool can be deducted from this general model by the appropriate substitution of function parameters.

The roughness profile can be calculated by making a profile shift in the feed direction by the feed rate value *(Fig. 4)*. As it can be seen from the picture, the auxiliary edge sections of the forwarded tool ($y_{aux1}$, $y_{aux2}$ and $y_{aux3}$, depending on the feed value) and the main edges of the tool in the origin ($y_{main1}$, $y_{main2}$, $y_{main3}$) are forming the roughness profile. The presented model assumed that a cylindrical surface will be generated. In case of conical turning, the profile shift has to follow the taper edge.

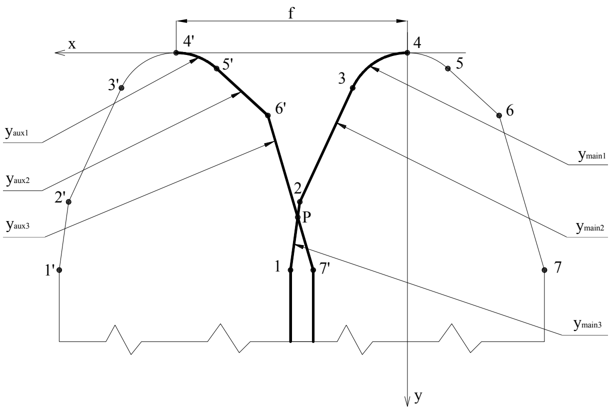


*Figure 4:* Typical points of the idealized roughness profile, main and auxiliary edges

The next step is to calculate the intersection point P of the main and auxiliary edges. This can be performed by calculating the x,y coordinates, where the equations of the respective edge sections have equal values: $y_{aux\ n} = y_{main\ m}$. The $y_p$ ordinate of this *P* point gives the maximal height of roughness profile ($R_{max}$) if the depth of cut ($a_p$) is greater than the ordinate of this point, or if $a_p > y_p$, then $R_{max} = a_p$. In conical turning, the distance of the $R_z$ value (ten-point height of the profile) is equal to this calculated $R_{max}$ value in the theoretical profile, since there are no deviations. The calculation of the mean line of the profile, which has equal areas below and above is needed for the determination of $R_a$ and $t_p$ values. This can be done by the least-square approximation method. The $R_a$ value can be calculated from the generalized equation

$$R_a = \frac{1}{l} \cdot \int_0^l \left| y(x) \right| dx \qquad (4)$$

The material ratio $t_p$ can be calculated from the following equation:

$$t_p = \frac{\left( x_{pm} - x_{pf} \right)}{f} \cdot 100 \qquad [\%] \qquad (5)$$

where:

$x_{pm}$, $x_{pf}$ – intersection points of the profile sectioning level *p* with the main and the auxiliary edges respectively.

The actual surface micro-profile is significantly different from the theoretical value, and it loses its regular character. This can be accounted by the following [5]:

- the material is plastically flows in the near of the peaks of the profile, the bigger is the plastic strain, the greater is the surface roughness;
- the workpiece and the tool are in mutual vibration during the cutting;
- the flank surface of the tool is rubbing against the machined surface;
- the tool edge is differing from the geometrical line which was taken as basis, and it has its own irregularities, and the tool wear is just amplifies this effect;
- in case of built-up-edge the quality of the surface is usually deteriorating.

The real (expected) value of the surface roughness can be calculated (forecasted) from the theoretical value [6]. The method for this forecasting is the following:

- Perform experiments with the tool geometries and technological data according to our needs, and then measure the generated profile by surface tester equipment.
- The connection between the measured and the calculated roughness data can be calculated by regression analysis.

The most accurate approximation can be made by power functions in the form [7]:

$$R_{real} = A \cdot R_{theoretical}^{B} \qquad (6)$$

where:

$R_{real}$ – the dependent variable;
$R_{theoretical}$ – the independent variable;
A, B – coefficients.

It can be seen from the introduced method, that this is a very computing-demanded task, and therefore it is advisable to make a computer program for the calculation of theoretical values. Thus the calculation can be automated. The software is still under development, and at the time of writing this article, it is able to calculate the theoretical values in turning cylindrical surfaces. It is important to verify the theoretical calculations by experiments; therefore the accuracy of the prediction can be determined. The experimental validation of the introduced model will be the next step of this research work.

## Conslusions

The theoretical value of surface roughness in single point cutting can be determined by the method introduced in the article for turning cylindrical surfaces, and for turning conical surfaces with little modifications. The experimental validation can confirm the accuracy of the model. The method can be also improved for multi-point cutting procedures. The calculated theoretical roughness values can be used to predict the real roughness values for a given procedure, and for the tool/material pairs which were experimentally investigated.

ACKNOWLEDGEMENTS

The described work was carried out as part of the TÁMOP-4.2.1.B-10/2/KONV-2010-0001 project in the framework of the New Hungarian Development Plan. The realization of this project is supported by the European Union, co-financed by the European Social Fund. The work was presented by the support of the Hungarian Scientific Research Fund (Number of Agreement: OTKA K 78482 and OTKA 84177), which the authors greatly appreciate.

REFERENCES

1. P. G. BENARDOS, G.-C. VOSNIAKOS: Predicting surface roughness in machining: a review, International Journal of Machine Tools and Manufacture 43, (2003), 833–844
2. C. LU: Study on prediction of surface quality in machining process, Journal of materials processing technology 205, (2008), 439–450
3. J. KUNDRAK: Increasing the Effectiveness of Machining by Application of Composite Tools in boring of Cylindrical and Polygon Surfaces (in Russian). CSc Dissertation, Tula 1986, p. 315
4. M. C. SHAW: Metal cutting principles, Oxford University Press, New York, USA, 1984, p. 256
5. J. BALI: Forgácsolás, Budapest, Tankönyvkiadó, 1988, p. 538
6. V. BANA: Manufacturing of high precision bores, PhD Dissertation, Delft, 2006, p. 149
7. J. KUNDRAK, C. FELHO: Roughness Designeability of Surfaces Machined by Cutting, ICPM2009, September 15-19, 2009, Stara Lesna, Slovakia, 107–112