## Chapter 1.6

# INVESTIGATION OF THEORETICAL AND REAL SURFACE ROUGHNESS IN FACE MILLING OF 42CRMO4 STEEL

Felho C., Kundrak J.
University of Miskolc, Hungary

***Abstract***: *Roughness indexes have a highlighted role in the investigation of the characteristics of cut surfaces. The calculation of these indexes by theoretical way and by this the prognostication of the expected values has been in the interest of researchers for a long while. Such a new analytical model has been developed which is suitable for the determination of the theoretical value of surface roughness in turning and face milling. The functioning of the developed model is introduced briefly in the paper as well as the algorithm of the investigation method based on the theoretical value of surface roughness. The theoretical roughness values calculated by the help of the model are presented. Real, measured data of roughness are determined on the basis of cutting experiments in the case of face milling of 42CrMo4 tempered steel, later on those approximation relations are defined, by the help of which the expected value of real roughness can be estimated on the basis of theoretical values in the case of a given tool-material pairing.*

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

## 1. Introduction

One important parameter in the qualification of cut surfaces is their roughness, and its indexes. The roughness has great significance primarily at mating, sliding surfaces. This has been one more reason for the researchers' increased interest for a long time to predict these indexes for a given process within the specified cutting conditions. Several modeling procedures and techniques were worked-out, which essentially can be classified into four groups: 1) analytical models, 2) experimental methods, 3)DoE (Design of Experiment)-based methods and 4) AI (Artificial Intelligence)-based methods [1]. In case of application of an analytical model the determination of theoretical value of roughness is made on the basis of the relative motions which are characterized to the respective process and on the geometry of the cutting edge. One notable work which used this modeling technique is the so-called "Surface Shaping System" developed by Ehmann and Hong [2]. It is such a complex description of cut surfaces, which can be applied to practically any single- and multipoint tool, and in addition it also takes the higher order motions into account (viz. vibrations, tool run-out, etc.). Likewise these kinds of models were used by Franco [3], Baek et. al [4], Kim and Chu [5]. The essence of the approach which is based on experiments is to perform a great number of cutting tests to formulate the relation between technological or other data and surface roughness. Such investigations were performed by Thiele and Melkote [6], Izol, Beno and Miko [7], Zębala and Siwiec [8] among others. However, a drawback of this method can be that a huge number of experiments may be required to obtain acceptable results, which needs a lot of money and time too, so it seems practical to decrease the required number of cutting tests by the use of DoE (Design of Experiments) techniques in order to limit the parameters to operative ones. Such an approach was used by Routara, Bandyopadhyay and Sahoo [9], Muñoz-Escalona and Maropoulos [10] among others. In the present days the role of the so-called soft computing techniques is more and more important, from which the Artificial Neural networks and the Genetic Algorithms are the most frequently used methods. Both of these are essentially computerized representations of the decision making, selection and evolution processes which take place in the nature. An important element of the implementation is the so-called "training" in the course of which the model will "learn" how it can reach its goal as fast and accurate as it is possible for it, in this case it is the most precious prediction of surface roughness. A great number of researchers have been engaged in the implementation of these techniques at surface roughness prediction, among others Azouzi and Guillot [11], Benardos and Vosniakos [12], Lou and Chen [13], Vrabel, Mankova, Beno and Tuharský [14].

## 2. Investigation on the basis of the theoretical value of surface roughness

In case of cutting with tools having specified edge geometry, periodical topography is generated on the machined surface, and the periodicity is usually corresponds to the feed value. By taking this law into account, such an analytical model can be created expediently, by the help of which this periodical topography can be determined by theoretical way on the basis of the tool geometry and technological parameters. The values determined in such a way can be used to predict the expected values of surface roughness in a real cutting process by the application of the method outlined in Fig. 1. The method which was applied during the investigations is based on a model which formerly was developed for turning [15]. The essence of this method is to create such a cutting tool model with general profile which contains all of the possible cutting edge sections. Thus, the geometry of all cutting tools which are used in practice can be derivate from this theoretical cutter model. By putting this created geometrical model to a Cartesian coordinate system, the respective edge sections can be described by mathematical equations with lines and arcs. Hereupon, a profile shift is performed with the feed value, and then the intersection point of the original and the shifted profile is calculated. The required surface roughness parameters can be determined on the basis of this method. The theoretical value of practically any roughness parameter can be obtained by this method. Furthermore, it can be used to calculate roughness values in face milling, in the case if the respective parameter should be determined in the centerline of the milling head and in parallel with the direction of the feed rate. Such a computer program was developed on the basis of the model which is capable to determine the theoretical values of surface roughness parameters in face milling not only along the centerline of the milling head, but in an arbitrary distance from it.

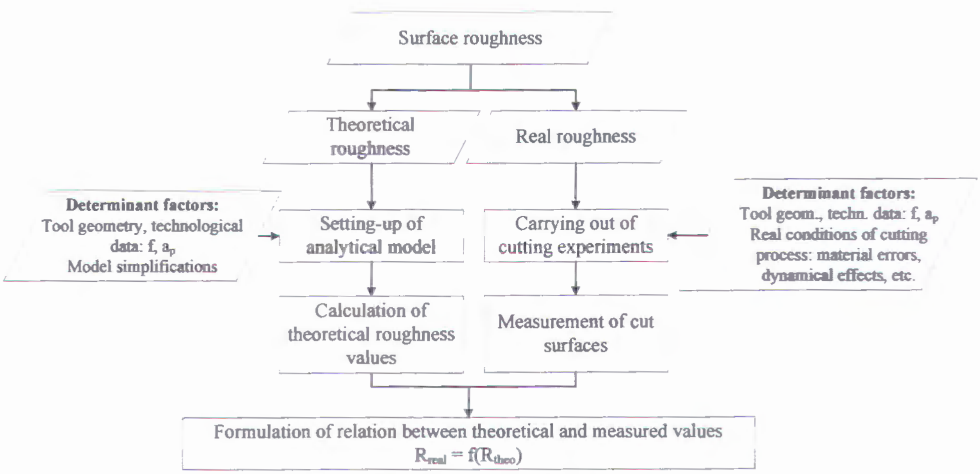



Fig. 1. The investigation method

## 3. Experiments

Real roughness data were obtained by performing cutting experiments and by measuring the generated surface topography. The investigated roughness parameters were the Ra, Rz and Rt characteristics during the research, which are fairly commonly used in practice.

### Experimental conditions

The main conditions of the performed cutting experiments will be shortly introduced in the following.

### Machine tool

The applied machine tool was a MAHO MH600E type CNC milling machine; its main properties are summarized in Table 1.

Table 1. Technical specifications of the
MAHO MH 600E CNC432 milling machine

| | |
|---|---|
| Motor power | 8kW |
| Working area in X / Y / Z | 600x450x450 mm |
| Spindle speed range | 20-4000 1/min |
| Feed rate range | 1-4000 mm/min |
| Magazine capacity | 30 pcs |
| Max. tool diameter | 100 mm |
| Max. tool length | 250 mm |
| Tool holder type | SK40 |
| Control | CNC 432 |

### Workpiece

The workpiece material was 42CrMo4 alloyed tempering steel, its chemical composition is shown in Table 2. The material was cut in hardened and tempered state, according to this its measured hardness was around 320 HB, while its tensile strength was about 1000-1100 N/mm$^2$ which was estimated from the hardness. The specimens were shaped as 50x50x100 mm prisms, and its four long sides were machined. The clamping was applied on its end faces, thus the deformation of the previously machined surfaces was possible to be prevented.

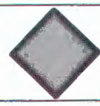
Table 2. Chemical compostion of the 42CrMo4 steel

| C | Si | Mn | Cr | Mo | S | Other |
|---|---|---|---|---|---|---|
| 0.42 | 0.25 | 0.75 | 1.1 | 0.22 | <0.035 | (Pb) |

### Tool

The applied tool is a special milling head with replaceable shafts (bits) which contains different sockets for the various cutting inserts. In the current experiments only one insert was used concurrently. The basic size of the milling head is ∅80 mm, while its working diameter is ∅67.5 mm. This milling head was developed at the Otto-von-Guericke University in Magdeburg [16], where the actual tests were performed too. Two different insert geometries were used during the experiments; their specifications are summarized in Table 3. Two different data are indicated in the nose radius row in the table: one catalogue and one measured value. While the size of the nose radius is essentially influencing the surface roughness value, this parameter was measured for the square insert by a stereo microscope, and these measured data were taken into account in the calculation of theoretical values.

Table 3. Cutting inserts used in the experiments

| Insert shape | Square insert | Circular insert |
|---|---|---|
| Type | LMT FETTE<br>SPKX 120508 LW225 | LMT FETTE<br>RCKX 1606MO-TR LC240T |
| Mark |  |  |
| Cutting edge length | 12 | 16 |
| Nose radius<br>catalogue (measured) | 0.8 (0.736) | - |
| Side and end cutting edge angles | $\kappa_{r1} = 45°$<br>$\kappa_{r1}' = 45°$ | - |

### Technological data

The applied technological data were as follows:

- cutting speed: $v_c = 100$ m/min, the spindle speed which was set on the machine according to this was $n = 470$ rotation/min
- depth of cut (axial): $a_p = 0.5$ mm
- width of cut: $a_e = 50$ mm $(0.75 \times D_m)$

The varied technological parameter was the feed rate value, it was set on the following values: $v_f = 100; 300; 500; 700; 900$ mm/min. The respective feed-per-tooth values are presented in Table 4.

Table 4. Feed rate values applied in the experiments and the respective feed-per-tooth data

| **Feed rate, mm/min.** | **Feed per tooth, mm/tooth** |
|---|---|
| 100 | 0.2127 |
| 300 | 0.638 |
| 500 | 1.06 |
| 700 | 1.48 |
| 900 | 1.915 |

### The applied measurement devices

The AltiSurf 520 three-dimensional roughness tester equipment was used to measure the surface roughness, which can be found at the Department of Production Engineering of the University of Miskolc. This instrument is capable to measure by both optical and mechanical way. The actual measurements were carried out by the use of the mechanical probe, while the optical sensor could not trace the sides of the roughness profiles at greater roughness values as the intensity values were out of range. The applied probe was an inductive measuring head with a 2 μm sphere tip. Its maximum measurement range is 2.5 mm, vertical resolution is 40 nm, while the lateral is 2 μm. Both 2D profile and 3D areal measurements can be realized with this instrument. The measurement parameters were as according to ISO 4288 during our investigations.

### Results of experiments

The roughness characteristics (Ra, Rz, Rt) are summarized in Table 5, and the measured profile data were compared with the calculated theoretical roughness indexes. The theoretical values of the investigated 2D surface roughness parameters were determined by the help of the previously introduced model. The measurement of the profiles on cut surfaces was performed on the feed rate direction. This method is appropriate for all that while the surface roughness is decreasing by moving off from the centerline of the milling head [17], so the maximum expected value can be always found at the centerline.

### Evaluation of results

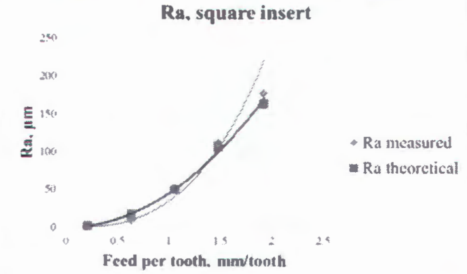
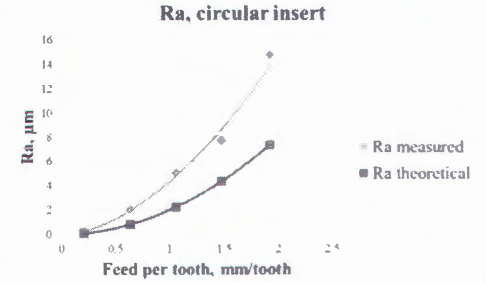
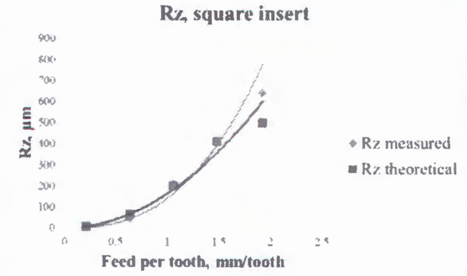
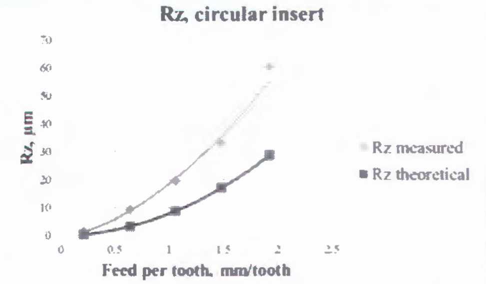
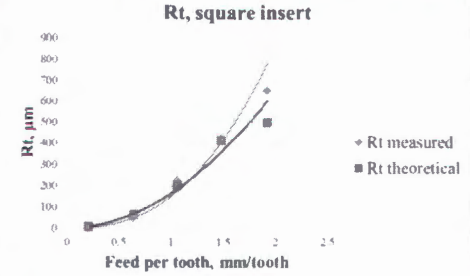
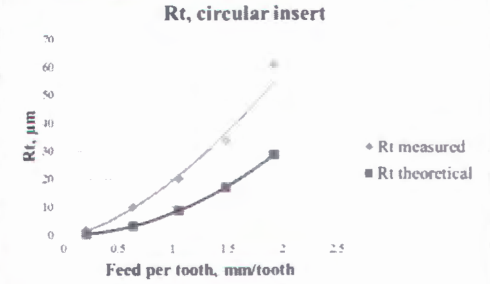
On the basis of the comparison of experimental and calculated values it can be stated, that the theoretical and the real values of roughness vary in similar trend as function of the feed per tooth value, thus the relation can be formulated between them by the help of the regression analysis. Experience shows [18] that it is practical to search the relation in the following power function form for the approximation (1):

$$R_{real} = A \cdot R_{theo}^{B} \tag{1}$$

where:

- $R_{real}$: real (expected) value of the examined surface roughness parameter (Ra, Rz, Rt)
- $R_{theo}$: theoretical (calculated) value of the examined surface roughness parameter
- A, B, constants

Table 5. Comparison of theoretical and real roughness parameters

| Square insert | Circular insert |
|---|---|
|  |  |
|  |  |
|  |  |

Values of the A, B constants calculated for the respective cases and the coefficients of determination ($R^2$) are included in Table 6. The validity domain of the formulated equations is the range of feed per tooth values applied in the experiments. However, it should be noted here, that the roughness has a minimal value, which is determined by the minimal uncut chip thickness value. Its primary influential factor is the edge rounding of the cutting insert, which is, however, hardly ever publicized by the manufacturers, and it is also not so easy to measure, so it is usually neglected in the practice. By using the introduced equations in the domain which is limited by the experiments this problem will not arise.

Table 6. Values of the regression constants and coefficients
for the respective inserts and roughness parameters

| **Insert geometry** | **Roughness parameter** | **A** | **B** | **$R^2$** |
|---|---|---|---|---|
|  | Ra, µm | 0.1715 | 1.3935 | 0.996 |
| | Rz, µm | 0.1782 | 1.3093 | 0.998 |
| | Rt, µm | 0.227 | 1.2725 | 0.998 |
|  | Ra, µm | 2.3313 | 0.8919 | 0.998 |
| | Rz, µm | 3.3414 | 0.8352 | 0.998 |
| | Rt, µm | 3.8166 | 0.7935 | 0.997 |

## 4. Conclusion

The theoretical value of surface roughness can be determined by the method outlined in the paper with good approximation accuracy. By the help of the introduced formulas the expected value of surface roughness can be predicted in face milling of 42CrMo4 steel on the basis of the previously calculated theoretical values.

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