The Scientific Bulletin of VALAHIA University
MATERIALS and MECHANICS –Vol. 20, No. 22

DOI 10.2478/bsmm-2024-0008

SURFACE ROUGHNESS PREDICTION TECHNIQUES IN TURNING PROCESSES

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Abstract: *Measuring and characterizing surface properties represents one of the most important aspects in manufacturing processes. In this paper, it has been shown that the factorial design of experiments combined with regression techniques can be applied to evaluate the roughness of machined surfaces with different cutting parameters.*

Keywords: *mathematical model, surface roughness, cutting parameters*

1. INTRODUCTION

In the present paper, a mathematical model is determined and validated, which reveals the quality of the surfaces of parts processed by turning.

The manufacturing processes do not allow the achieving of the theoretical surface roughness due to issues appearing on machined surfaces, which are mainly generated by the deficiencies and imbalances during the process. These aspects make these measuring procedures so necessary, allowing us to obtain a real state of the surfaces.

The errors occurring in the chipping process cause a decrease in the quality of the processed surfaces, including the roughness expressed by the Ra parameter. So, the manufacturing processes do not allow reaching the theoretical values of the Ra parameter, determined by using the proposed mathematical model. It is therefore necessary to measure the roughness values of the surfaces processed with different cutting regimes and to compare them with the theoretical ones, to validate the chosen model by statistical methods.

The surface roughness represents one of the most essential factors in the tribological areas and in the evaluation of the quality of machining operations. These studies prove that cutting parameters (feed rate, cutting speed, depth of cut) strongly affects the machined parts' roughness.

Ra is recognized and used as the main international parameter of roughness, with the greatest relevance in the case of the quality of chipped surfaces.

The Ra parameters, which is recognized as the arithmetic average of the roughness value, was established as a parameter, based on the ISO 4287 standard as the arithmetic average of the deviations from the central line of the roughness profile, along the profile. This definition is revealed by equation 1, where y(x) is the roughness of the profile and l is the evaluation length [4].

$$Ra = \frac{1}{l}\int_0^l |y(x)|dx \tag{1}$$

Factorial experiments offer an alternative to studying one factor at a time, allowing the study of interactions between these factors. They also allow the use of data from the experiment to analyze the influences of each factor [2], [6], [7], [8].

The purpose of this paper is to use the factorial design approach for a direct assessment of surface quality by analyzing the influences of the technological parameters, the parameters of the cutting regime on the roughness of turned surfaces.

Direct contact measurement of surface roughness before and after processing was carried out [1].

Further experimental research will pursue to optimize the turning technological processes by choosing those cutting regimes that allow obtaining the desired quality for the processed surfaces.

2. EXPERIMENTAL DESIGN

The experimental research was carried out by processing some cylindrical surfaces, with different cutting regimes, on a classic lathe, without cutting fluids. The effect of vibration occurring in the cutting process has not been quantified.

Then, the values of the roughness parameter Ra were measured for the turned surfaces with different cutting regimes. The roughness of the machined surfaces was measured using a Diavite rugosimeter.

The configurations and dimensions of the workpieces, turned parts, made of 42MoCr11 steel, are shown in figure 1.

Previous research has demonstrated that the geometrical parameters of the cutting tool can affect the roughness of the machined surface. These geometric parameters are: the primary rake angle γ, the nose radius r_ε, the back rake angle α, the entrance angle χ_r, the exit angle χ_r', the side relief angle λ.

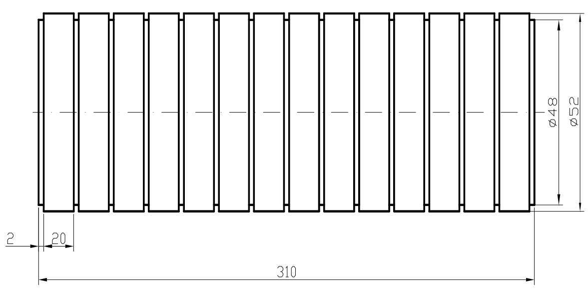

Figure 1. The workpiece

The changeable tool inserts were TNMG 22 04 08 – P15, chosen by CoroGuide - PC program and CoroKey - PC program. These have the following geometry: $\alpha = 7^o$; $\gamma = 6^o$; $\kappa_r = 93^o$; $\kappa_r' = 27^o$; $\lambda_s = -6^\circ$; $r_\varepsilon = 0,8$ mm.

The chosen experimental plan allows the determination of a mathematical model and the analysis of the influences of independent process variables on a certain dependent variable, a function.

$$y = f(x_{i_1}, x_{i_2}, ...x_{i_j}, ...x_{i_n}) \qquad (2)$$

where:
y is the dependent variable and x_{ij}, j = {1,2,….,n}are the independent variables.

The experimentally established functions are based on the measurement of the output quantities that are correlated with the input quantities in the process, by means of polynomial or polytropic regression functions [3], [5].

Full factorial designs involve analyzing all combinations of factors, independent variables and their corresponding levels. In the present work are adopted two levels of cutting parameters. Table 1 shows the factors studied and the corresponding levels.

Each step on the workpiece was used to carry out a specific test conditions in dry turning. The three parameters, feed rate f, cutting speed v_c, depth of cut a_p were varied at the levels reported in Table 1.

Table 1. Levels of arrangement of the natural and coded values of the independent variables

		Levels				
Independent Variables	Cod	-2	-1	0	+1	+2
		Naturals				
Cutting speed v_c [m/min]	x_{1i}	69.08	86.35	108.8	138.16	172.7
Feed rate f [mm/rev]	x_{2i}	0.132	0.167	0.208	0.250	0.353
Depth of cut a_p [mm]	x_{3i}	1	1.2	1.5	2	2.5

The experimental design was designed to significantly reduce the number of experiments. The number of experiments is expressed by the following equation:

$$K = 2^k + 2k + k_0 \qquad (3)$$

where:
k is the number of independent variables; k=3
k_0 is the number of experiments placed in the center of the cube, performed to keep the standard deviation of the dependent variable stable.

The experimental points corresponding to the 2^3 experiments are in the corners of a cube, as illustrated in Figure 2.

To verify the higher order influences, the experimental plan with 2k experiments at the distance α from the central value was used. The value of α is chosen according to the relationship:

$$\alpha = 2^{k/4}, \text{ pentru } k< 5. \qquad (4)$$

Table 2 illustrates the standard form of a design matrix with 15 different combinations [2],[3], [1].

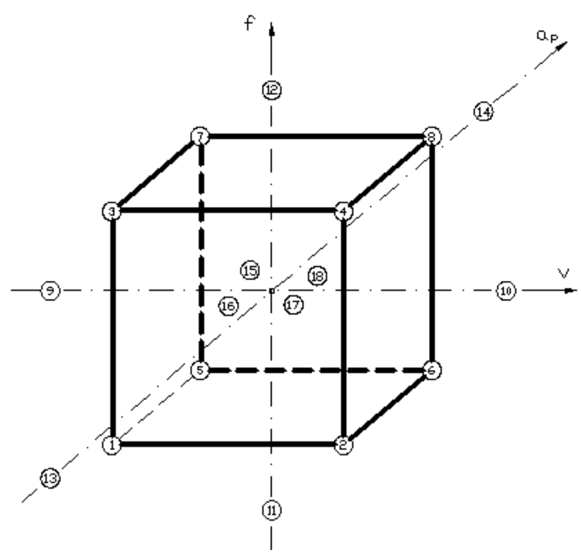

Figure 2. Experimental points

Table 2. Design matrix display

No. test	Independent variables						Response of surface
	Coding			Naturals			
	x_{1i}	x_{2i}	x_{3i}	v_c [m/min]	f [mm/rev]	a_p [mm]	R_a [μm]
1	- 1	- 1	- 1	86.35	0.167	1.20	2.25
2	+1	- 1	- 1	138.16	0.167	1.20	2.12
3	- 1	+1	- 1	86.35	0.250	1.20	3.50
4	+1	+1	- 1	138.16	0.250	1.20	3.37
5	- 1	- 1	+1	86.35	0.167	2.00	2.62
6	+1	- 1	+1	138.16	0.167	2.00	2.30
7	- 1	+1	+1	86.35	0.250	2.00	3.37
8	+1	+1	+1	138.16	0.250	2.00	3.25
9	- 2	0	0	69.08	0.208	1.50	4.00
10	+2	0	0	172.70	0.208	1.50	2.75
11	0	- 2	0	108.80	0.125	1.50	1.90
12	0	+2	0	108.80	0.353	1.50	4.25
13	0	0	- 2	108.80	0.208	1.00	2.30
14	0	0	+2	108.80	0.208	2.50	2.37
15	0	0	0	108.80	0.208	1.50	2.20
16	0	0	0	108.80	0.208	1.50	2.18
17	0	0	0	108.80	0.208	1.50	2.20
18	0	0	0	108.80	0.208	1.50	2.25

3. RESULTS ANALYSIS

3.1 Postulation of a mathematical model

In this work, the mathematical model that gives the influence of three independent variables (cutting speed vc, feed f and cutting depth ap) on the dependent variable - surface roughness Ra is experimentally determined. This is a polynomial function of the second degree [5], [7], [8], as in equation (5):

$$y = b_0 + b_1x1 + b_2x2 + b_3x3 + b_{12}x1x2 + b_{13}x1x3 + b_{23}x2x3 + b_{11}x1^2 + b_{22}x2^2 + b_{33}x3^2 \quad (5)$$

where:
y represents the response for surface roughness;
x_1, x_2, x_3 are: cutting speed v_c (in m/min), feed f (in mm/rev) and depth of cut a_p (in mm);
b_0, b_1, b_2, b_3, b_{12}, b_{13}, b_{23}, b_{11}, b_{22}, b_{33} are the regression coefficients, the parameters to be estimated, using the MathCad work, by the *method of least square* [2].

3.2 „Surface roughness” polynomial process function analysis

The form of the process function, the second degree polynomial function with three variables, obtained by using a program adapted to polynomial regression, is the following [5], [8]:

$$\begin{aligned} Ra = &-11{,}793 - 0{,}007 \cdot x1 + 92{,}506 \cdot x2 + 5{,}526 \cdot x3 - \\ &- 0{,}087 \cdot x1 \cdot x2 - 0{,}0082 \cdot x1 \cdot x3 - 3{,}002 \cdot x2 \cdot x3 + \\ &+ 0{,}00015 \cdot x1^2 - 156{,}379 \cdot x2^2 - 1{,}145 \cdot x3^2 \end{aligned} \quad (6)$$

[μm]

where: $x_1 = v_c$ (m/min); $x_2 = f$ (mm/rev); $x_3 = a_p$ (mm).

In Figure 3 is illustrated in 3D, using „Mathematica” software, the most important influences of the parameters of the cutting regime (v_c and f) on the roughness parameter Ra, under the following conditions: processing on a classic lathe, without coolants; ap = 1.5 mm.

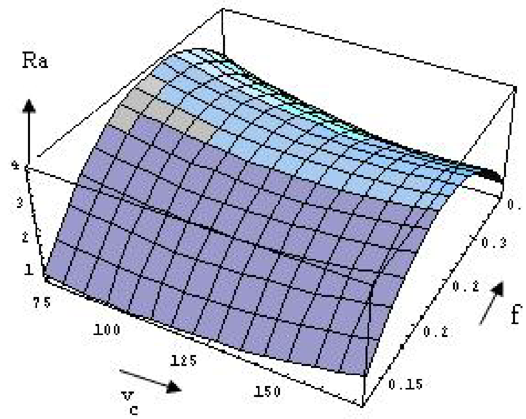

Figure 3. The influence of cutting speed v_c and feed rate f on roughness parameter Ra

3.3 Statistical evaluation

Proper proposed model were established after statistical analysis of data, using the classification predicted values within the limits of error covered by the standard.

The statistical study of the interdependent series was carried out in two stages:
- regression analysis, which aims to build a mathematical model which allows the identification of the link between variables;
- measuring the intensity of the link by using a numerical indicator that shows how strong the connection between the variables is.

The statistical verification in the second stage was done by analyzing data dispersion (*F* - test) or by calculating the homogeneity coefficient (*CO* - test).

F-test

In test F, for the hypostasis of the same variances

($s_1^2 = s_2^2$), the value of F is almost 1.

For $F < F_{0.95}$ or $F > F_{0.05}$ on accept the hypostasis.

For both data series, that of the measured values and that of the values estimated by the chosen model, the specialized literature recommends F0.95(3)= 2.40, in accordance with the number of experiments.

$$F = \frac{s_1^2}{s_2^2} = \frac{\frac{1}{n_1 - 1} \cdot \sum_{1}^{n_1} (X_i - \overline{x_{n_1}})^2}{\frac{1}{n_2 - 1} \cdot \sum_{1}^{n_2} (Y_j - \overline{y_{n_2}})^2} \quad (7)$$

For the number of experiments $n_1 = n_2 = n$, the equation (7) is:

$$F = \frac{\sum_{1}^{n_1} \left(X_i - \overline{x_n}\right)^2}{\sum_{1}^{n} \left(Y_j - \overline{y_n}\right)^2} \quad (8)$$

Homogeneity coefficient

It is used to validate the model obtained by the method of least squares. If the values of coefficient of homogeneity, CO are less than 30%, this indicates the homogeneity of data series. It is calculated with the following equation:

$$CO = \frac{\sigma_y}{\overline{y}} \cdot 100 \quad (9)$$

$$\sigma_y = \sqrt{\frac{\sum (y - \hat{y})^2}{n}} \quad (10)$$

where:

σ_y is the square root of variance [9]

y - measured values

$\hat{y}$ - estimated values (calculated by the function)

n - no. experiments, n = 15.

Applying the equations (8) and (9) for the data series measured and estimated by the presented model of the surface roughness parameter Ra, the values below are obtained.

$$F = \frac{9.9607}{6.3652} = 1.565 \le 2.40 = F_{0.95}$$

$$CO = 27.4\% < 30\%$$

It can be seen that the assumption of the regression analysis (normality and homogeneity of variance of residuals) were tested and verified with an acceptable error rate.

4. CONCLUSIONS

The experimental plan presented in this work allowed obtaining a mathematical model, a polynomial regression function for the roughness parameter Ra, which reveals the influence of the parameters of the cutting regime: v_c, f, a_p on the roughness of the turned surfaces.

The present work showed that the advance has the strongest effect on the surface roughness, among the parameters analyzed through the experimental research carried out.

The experimental results obtained show that turning with higher values of the advance causes a decrease in the quality of the turned surfaces, in terms of roughness.

The deviations revealed by 3D representations are caused by the vibrations that occur in the cutting process on conventional machine tools, vibrations that were not quantified by the model.

The proposed model for the surface roughness, expressed by the Ra parameter, was validated by the statistical analysis performed.

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