ECONOMICAL EFFICIENCY APPRAISAL OF THE NEW MODELS REGARDING THE SURFACE QUALITY FROM THE POINT OF VIEW OF THE COSTS OF THE CUTTING PROCESS

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Abstract. The present paper continues the series of papers published by the author regarding the importance of some new mathematical models presented in some previous papers [1, 2, 3]. Concretely, this paper approaches the economical aspects of the cutting process from the point of view of the costs involved, trying to determine the influence of some cutting parameters upon the costs of the cutting process and to establish the cost of the cutting process taking into consideration roughness R_a of the surface processed. Within the papers mentioned above the author determined two new mathematical models for appraising roughness R_a, unlike the specialized literature that presents some models regarding roughness $R_{\max}$ or R_z. It is very important to have a mathematical model that refers to R_a roughness because this type of roughness appears on all working drawings and to pass from other types of roughness to R_a could be subjective and uncertain. The mathematical model refers to the case of turning using a nose ray cutting tool. The present paper starts from the mathematical model of appraising roughness R_a and has two important parts. The first part presents a mathematical model regarding the costs of the cutting process and the second part shows an application based on statistical processing of some data, regarding some cutting parameters and analyses its influence upon the economical efficiency expresses through the costs of the cutting process.

Keywords: economical efficiency, costs, cutting feed

1. Introduction

One important issue met in product engineering refers to obtain the surface quality requested by the working drawing but also to minimize the costs involved within the cutting process involved. For this reason it is necessary to start from a mathematical model that appraises the roughness R_a and also to express the costs of the cutting process in accordance with this roughness.

Specialized literature [4, 5] presents a mathematical model for appraising roughness $R_{\max}$ or R_z:

$$R_{\max} / R_z = 125 \cdot \frac{s^2}{r}, \tag{1}$$

where s-cutting feed [mm/rot], r-nose ray of the cutting tool [mm].

Passing from $R_{\max}$ or R_z roughness to R_a roughness could be difficult because specialized literature presents a conversion formula, but that is quite vague and inexact [5, 6]:

$$R_{max} = (3\ldots6)R_a. \tag{2}$$

For this reason the author of this paper demonstrated another mathematical model that appraises directly R_a roughness:

$$R_a = 32 \cdot \frac{s^2}{r} \cdot c_2, \tag{3}$$

where: c_2-correction coefficient that depends on the cutting speed and that will be further determined through an experimental research.

The present paper tries to determine the cost of the cutting process on the basis of R_a roughness.

2. Mathematical Model of Economical Efficiency Expressed through Costs of Cutting Process

As the costs of cutting process represent a very important indicator of economical efficiency, this part of the paper presents a mathematical model regarding the influence of some cutting parameters, especially the cutting feed upon the costs. For this, it is considered the case of a longitudinal turning using a nose ray cutting tool.

The part of the processing cost that depends on the cutting regime can be expressed through:

$$\Delta C = C_{tb} + C_{us}, \tag{4}$$

where: ΔC-part of the processing cost that depends on the cutting parameters [m.u./part], C_{tb}-cost of the basic time [m.u./part], C_{us}-cost of using the tool [m.u./part].

Developing the terms from the formula from above, it results:

$$C_{tb} = t_b \cdot C_{as}, \tag{5}$$

where: C_{as}-costs regarding the machine-tool absorption and salary costs [m.u./part].

$$C_{as} = C_a + C_s, \tag{6}$$

where: C_a-cost of machine-tool absorption [m.u./part], C_s-salary cost [m.u./part].

The cost of machine-tool absorption can be expressed through the following formula, considering a linear absorption [7, 8]:

$$C_a = \frac{P_{mu}}{n_a \cdot n_z \cdot n_s \cdot n_h \cdot 60}, \tag{7}$$

where: P_{mu}-purchasing price of the machine-tool, n_a-number of years for machine-tool absorption, n_z-number of working days from a year for machine-tool absorption, n_s-number of shifts, n_h-number of hours from a shift.

$$C_{us} = \frac{t_b}{T} \cdot C_{es}, \tag{8}$$

where: C_{es}-cost of tool exploitation [m.u./sharpening], T-tool life [min].

$$C_{es} = t_{sr} \cdot C_{as} + t_{asc} \cdot C_{asc} + \frac{P_s}{N_{asc}}, \tag{9}$$

where: t_{sr}-time of tool exchanging-adjusting [min], C_{asc}-cost of a sharpening [m.u./min], t_{asc}-time of tool sharpening [min], P_s-purchasing price of the cutting tool [m.u.], N_{asc}-number of sharpening born by the tool; in case of using metal carbide cutting plates, t_{asc}= 0 and N_{asc} represents the number of cutting edges of the plate.

Having in mind the formulas from above and the variable part of the cutting process cost that depends on the cutting parameters becomes:

$$\Delta C = \frac{L}{n \cdot s} \cdot \left(C_{as} + \frac{C_{es}}{T} \right). \tag{10}$$

Developing the tool life in accordance with Taylor formula [9], it results:

$$\Delta C = \frac{L}{n \cdot s} \cdot C_{as} \cdot \left(1 + \frac{C_{es} \cdot v^{\frac{1}{m}} \cdot t^{\frac{xv}{m}} \cdot s^{\frac{yv}{m}}}{C_v^{\frac{1}{m}} \cdot C_{as}} \right), \tag{11}$$

where: m-tool life exponent that depends on the cutting conditions, t-cutting depth [mm], C_v,x_v,y_v-coefficient, respective exponents that depend on the type of the processed material and cutting tool and other cutting conditions, L-cutting tool stroke [mm], n-turning [rot/min].

Using the following notations:

$$k_4 = \frac{L}{n} \cdot C_{as}, k_5 = \frac{C_{es} \cdot v^{\frac{1}{m}} \cdot t^{\frac{xv}{m}}}{C_v^{\frac{1}{m}} \cdot C_{as}}, k_6 = \frac{yv}{m} \tag{12}$$

the mathematical model of processing cost appraisal immediately results:

$$\Delta C = \frac{k_4}{s} \cdot \left(1 + k_5 \cdot s^{k6} \right). \tag{13}$$

3. Application

This application has the role to show the impact of the mathematical models (3) upon the economical efficiency of the cutting process expresses through the costs of the cutting process taking into consideration the cutting parameters and then the surface roughness, R_a.

3.1. Function of Cost Variation in Accordance with the Cutting Feed

For watching the evolution of the part of the processing costs that depend on cutting parameters it is considered the same case of a longitudinal turning with a nose ray cutting tool and the following data:

- purchasing price of a CNC machine-tool: 280000 m.u.;
- salary cost: 1500 m.u./month, meaning 0.142 m.u./min;
- cutting tool purchasing price: 30 m.u.;
- time of machine-tool absorption: 10 years;
- time of tool exchanging-adjusting: 1 min;
- number of uses for the cutting plate: 8;
- number of shifts: 2.

On the basis on the data and formulas from above it results:

- C_a = 0.122 [m.u./min];
- C_{as} = 0.264 [m.u./min];
- C_{es} = 4.014 [m.u./cutting edge];
- m = 0.15;
- x_v = 0.22;
- for $s \le 0.3$: C_v = 126, y_v = 0.40;
- for $s > 0.3$: C_v = 112, y_v = 0.50.

The values of the coefficient C_v and exponents m,x_v,y_v are in accordance with paper [10]. For analysing the variation $\Delta C = f(s)$, it is considered the data series regarding different values for the cutting feed and for every value the cost function is calculated.

Table 1. Values of Function $\Delta C = f(s)$

Crt. no.	s [mm/rot]	ΔC	k_1, k_2, k_3
1.	0.02	2.76	$k_1 = 0.21$ $k_2 = 3.19$ $k_3 = 2.67$
2.	0.04	1.39	
3.	0.06	0.94	
6.	0.08	0.72	
5.	0.10	0.60	
6.	0.12	0.54	
7.	0.14	0.50	
8.	0.16	0.47	
9.	0.18	0.46	
10.	0.20	0.459	
11.	0.22	0.465	
12.	0.24	0.478	
13.	0.26	0.496	
16.	0.28	0.52	
15.	0.30	0.54	
16.	0.32	0.58	$k_1 = 0.21$ $k_2 = 7.01$ $k_3 = 3.33$
17.	0.34	0.63	
18.	0.36	0.69	
19.	0.38	0.76	
20.	0.40	0.83	
21.	0.42	0.91	
22.	0.44	0.99	
23.	0.46	1.08	
26.	0.48	1.18	
25.	0.50	1.28	
26.	0.52	1.39	
27.	0.54	1.50	
28.	0.56	1.62	
29.	0.58	1.75	
30.	0.60	1.88	
31.	0.62	2.02	
32.	0.64	2.17	
33.	0.66	2.32	
36.	0.68	2.48	
35.	0.70	2.65	

The graphic from figure 1 shows that the cutting feed has a great influence upon the processing cost and thus upon the economical efficiency of the cutting process. As it can be seen, the increase of the cutting feed leads to the decrease of the cost till one point (till $s = 0.2$ mm/rot). For values of the cutting feed greater than 0.2, the cost significantly increases. This aspect can be explained through the influence of the cutting speed upon the tool life. The increase of the feed determines the decrease of the tool life and thus, the cost of tool exploitation increases.

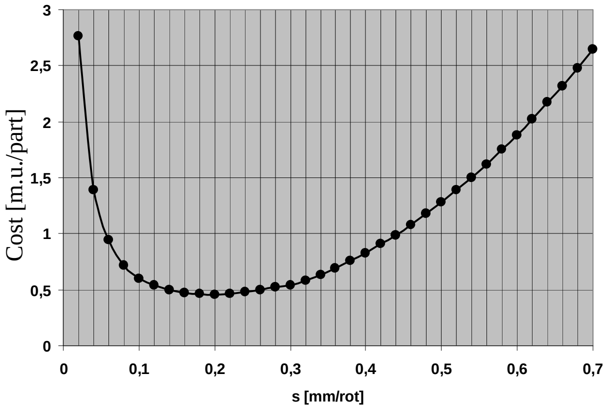

Figure 1. Variation of the Cutting Cost in Accordance with the Cutting Feed

The data from table 1 were mathematically processed, using Modeller software program [11], with a view to obtaining a new mathematical functions:

$$\Delta C = 0.1876 s^{-0.599401}, \quad (14)$$

for $s \in [0.02; 0.3]$

and

$$\Delta C = 7.768 s^2 - 2.492157 s + 0.582729 \quad (15)$$

for $s \in (0.3; 0.70]$.

3.2. Cost of Cutting in Accordance with the Roughness

For showing the importance of the mathematical models (3) determined by the author of this paper in some previous papers, it is useful to express the cost of the cutting process taking into consideration the roughness. For this reason it is made a comparison between using the roughness models met within specialized literature and the model demonstrated by the author.

Specialized literature presents a model of expressing $R_{\max}$ or R_z roughness, as specified before, through formula (1). Because on the working drawings it is specified R_a roughness, the passing from $R_{\max}$ or R_z roughness to R_a roughness must be made. Specialized literature presents again formula (2) in this way, resulting:

$$R_a = \frac{R_{\max}}{(3 \ldots 6)}. \quad (16)$$

Taking into consideration formulas (1) and (16) it results that the cutting feed varies within the following interval:

$$\left(0.15 \cdot \sqrt{r \cdot R_a}, \quad 0.22 \cdot \sqrt{r \cdot R_a} \right). \quad (17)$$

This interval generates uncertainty and subjectivism in choosing the optimal value for the cutting feed in order to achieve the desired roughness. For eliminating this aspect, by using the formula (3), determined by the author, the value of the working feed is precisely determined:

$$s = 0.18 \cdot \sqrt{r \cdot R_a}\ . \qquad (18)$$

Formula (18) does not take into consideration the correction coefficient.

Taking into consideration formulas (3), (14) and (15) the cost of the cutting process, that depends on the cutting parameters and thus on the roughness R_a can be expressed in the following way:

$$\Delta C = 0.033 \cdot (r \cdot R_a)^{-0.01}, \qquad (19)$$

$$\text{for } 0.18 \cdot \sqrt{R_a \cdot r} \in [0.02\,;0.3]$$

and

$$\Delta C = 0.24 \cdot r \cdot R_a - 0.44 \cdot \sqrt{r \cdot R_a} + 0.582729 \qquad (20)$$

$$\text{for } 0.18 \cdot \sqrt{R_a \cdot r} \in (0.3\,;0.7]$$

4. Conclusions

The present paper, beside other papers tries to demonstrate the importance of the mathematical model (3) determined by the author. This importance refers to the fact that this mathematical model eliminates the uncertainty of choosing the optimal value of the cutting feed and also, through this model some indicators regarding the economical efficiency of the cutting process can be precisely determined. In this way, this paper presents some mathematical functions representing the variation of the cost of the cutting process in accordance with an important parameter of the cutting regime, which is cutting feed, expressed through formulas (13), (14) and (15):

$$\Delta C = \frac{k_4}{s} \cdot \left(1 + k_5 \cdot s^{k6}\right),$$

$$\Delta C = 0{,}1876 \cdot s^{-0.599401},$$

$$\text{for } s \in [0.02;\ 0.3],$$

$$\Delta C = 7.768 \cdot s^2 - 2.492157 \cdot s + 0.582729,$$

$$\text{for } s \in (0.3;\ 0.70].$$

The two limits for the cutting feed generate two limits for the cost of the cutting process, for example for values of the feed greater than 0.3 mm/rot:

$$\Delta C_1 = 0.175 r R_a - 0.374\sqrt{r R_a} + 0.582729, \qquad (21)$$

$$\Delta C_2 = 0.376 r R_a - 0.548\sqrt{r R_a} + 0.582729 \qquad (22)$$

Taking into consideration these limits, it results some additional costs of:

$$\Delta(\Delta C) = 0.201 \cdot r \cdot R_a - 0.174 \cdot \sqrt{r \cdot R_a}\ . \qquad (23)$$

If it is considered a value for roughness R_a of 6.3 μm, than the additional costs are 1.161 m.u./part, representing an increase of the cutting costs of 38%.

References

1. Ivan-Gavrus, C., Ivan, N.V., Ivan, M.C.: *Roughness Appraisal of Surface Processed through Turning Using Wide Cutting Tools.* Proceedings of International Conference on Manufacturing Systems, Romanian Academy, p. 395-398, ISSN 1842-3183, Bucharest, Romania, October 2006
2. Ivan, N.V., Ivan, C.: *More Accurate Assessments of the Roughness of the Processed Surface*. Academic Journal on Manufacturing Engineering, Vol. 3, No. 4, 2005, p. 39-43, ISSN 1583-7904, Timisoara, Romania
3. Ivan-Gavrus, C.: *Technical-Economical Efficiency of Using the Computer in Product Engineering.* Scientific Research Grant, Transilvania University of Brasov, October 2005 (in Romanian)
4. Picos, C.: *Machine Manufacturing Technology*. “Didactică şi Pedagogică” Publishing House, Bucharest, Romania, 1974 (in Romanian)
5. Enache, S.: *Processed Surface Quality*. Dunod, Paris, France, 1972 (in French)
6. Chang, T.C., Wisk, R., Wang, H.P.: *Computer Aided Manufacturing*. ISBN (10) 0131429191, ISBN (13) 9780131429192, Prentice Hall, England, 2006
7. Abrudan, I., Candea, D.: *Production System Engineering*. Dacia Publishing House, ISBN 973-35-1588-4, Cluj-Napoca, Romania, 2002 (in Romanian)
8. Stroe, C.: *Company Management*. University of Pitesti Publishing House, ISBN 973-8212-94-4, Pitesti, Romania, 2001 (in Romanian)
9. Deliu, M., Fota, A., Chivu, C.: *Bases of Mechanical Processing*. “Transilvania” University Press, ISBN 973-635-011-8, Brasov, Romania, 2002 (in Romanian)
10. Picos, C.: *Design of Design of Mechanical Processing by Cutting*. Vol. 1. Universitas Publishing House, ISBN ISBN 5-362-00971-0, Chisinau, Moldavia, 1992, (in Romanian)
11. Ivan, N.: *Modeller Program-mathematical Data Processing*. Transilvania University of Brasov, Romania, 1992