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SIDE MILLING FACTORS ANALYSIS AFFECTING THE SURFACE IRREGULARITIES OF HIGH-GRADE STEEL E295

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Original scientific paper

The paper deals with experimental research and evaluation of side milling by evaluation of technology factors, which influence the surface profile parameter peak to valley of high-grade steel E295 by means of design of experiments. Four selected technological factors (diameter of milling cutter, spindle speed, feed per tooth and depth of cut) which enter into technological process of side milling of slots have been evaluated by means of full factories analysis. The surface quality has been evaluated by static quality characteristic the peak to valley *Rz* parameter. The multiple linear regression equation obtained after analysis of variance gives the level quality *Rz* as a function of the significant factors. Different factors main effect and their interaction significance have been found, which generated surface profile under defined conditions by side milling.

Keywords: *side milling, factor analysis, Rz*

Analiza čimbenika bočnog glodanja koji utječu na nepravilnost površine visokokvalitetnog čelika E295

Izvorni znanstveni članak

U radu je prikazano eksperimentalno istraživanje i procjena bočnog glodanja pomoću procjene tehnoloških čimbenika koji utječu na parametar profila površine visokokvalitetnog čelika E295 pomoću pokusa. Četiri odabrana tehnološka čimbenika (promjer glodala, brzina osovine, sadržaj po zubu, dubina rezanja) koji spadaju u tehnološki proces bočnog glodanja utora ispitana su pomoću potpune analize čimbenika. Kvaliteta površine je ispitana pomoću *Rz* parametra. Višestruka jednadžba linearne regresije dobivena nakon analize varijance daje razinu kvalitete *Rz* kao funkciju važnih čimbenika. Uočen je glavni utjecaj raznih čimbenika i važnost njihova međudjelovanja, koji su dali profil površine u zadanim uvjetima pomoću bočnog glodanja.

Ključne riječi: *bočno glodanje, analiza čimbenika, Rz*

1 Introduction
Uvod

Milling becomes a universal method in field of machining technologies in consequence of rising miscellaneousness of machining tools, control systems, cutting tools. Machining tools with a great variety are used for milling stating with older single-purpose machining tools till contemporary modern more-axis CNC machining tools [4, 7, 9]. Nowadays milling is still in development in field of machining tools, milling cutters so as conditions of milling. Result parameters of milling are caused by composite action of condition of a machining tool and properties characteristic of work piece and that is why we focus our attention to several significant factors in milling. It is necessary to point out that in most of cases it is possible to reduce time for milling or adjust conditions for better technical application. It is important in advance to analyze machining and in respect of observed to weigh possibilities of modern machining.

2 Related Works
Srodni radovi

Milled surface is developed by scribing shape of cutting the edge of milling cutter on the machined surface by its relative movement to the workpiece. The result depends on the geometrical shape of the cutting edge and on kinematics of movements of the cutting edge. Mechanical properties of the machined material and tribological relations between the cutting tool and the workpiece have a significant effect [5]. Knowledge of the factors and its optimization leads to better fulfilment of rising requests of the quality of machined surface. Whenever two machined surfaces come in contact with each other the quality of the mating parts plays an important role in the performance and wear of the mating parts. Most scientific papers dealing with the evaluation of microgeometrical features of side milling are available [4, 8, 11, 12, 13, 16, 17, 18]. The objective is to determine the final shape of the surface quality, which is a function of the geometric characteristics of the tool. The roughness of the machined surface is seen through micro-geometrical irregularities of the surface. The result of this technological process depends on a large number of process factors such as: cutter d, mm; running speed n, min^{-1}; feed per tooth f_z, mm; cutting depth a_p, mm. But most of the papers for the evaluation of the technological process used as the surface profile parameter the average roughness *Ra*. From the previous experiments and from available literature [7, 14, 18] the average roughness parameter is not enough for adequate evaluation of any process because average roughness is sensible with extreme values as shown in Fig. 1.

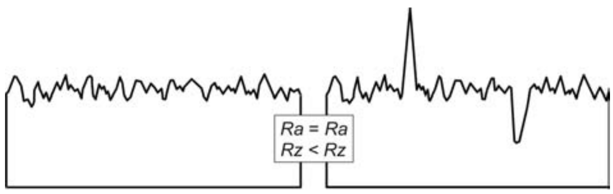

Fig. 1 Two surfaces equal from the point of view of Ra and different from the view of Rz [18]
Slika 1. Dvije površine jednake s motrišta Ra i različite s motrišta Rz [18]

3
Experimental Set Up
Organizacija ispitivanja

The evaluation of the quality of machined surface in our experiment is based on the judgment of its surface roughness profile parameter *Rz*. Theoretical roughness depends exclusively on tools geometry and applied process of machining whereas real roughness appears as the result of theoretical roughness though with bigger or lesser occasional roughness caused by many factors. The surface roughness is influenced by the most important factors such as: diameter of milling cutter *d*, mm; spindle speed *n*, min^{-1}; feed per tooth f_z, mm and cutting depth a_p, mm - Fig. 2.

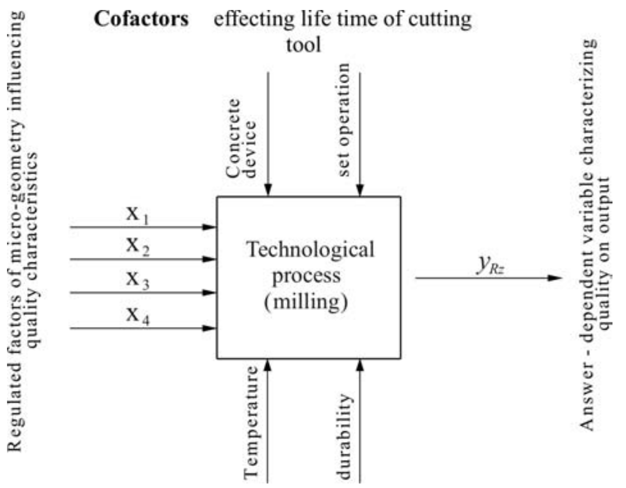

Fig. 2 Process model of influence of independent factors on dependent variable
Slika 2. Model procesa utjecaja nezavisnih faktora na zavisnu varijablu

In order to investigate the influence of side milling factors on surface roughness profile parameter *Rz*, full factorial design for four independent variables at two levels was adopted to obtain the combination of values that can optimize the response, which allows one to design a minimal number of experimental runs [5, 6]. The explicitly defined function is shown in the following Eq. 1:

$$Rz = f\left(d, n, f_z, a_p\right) \tag{1}$$

Four factors submitted for the analysis in the factorial design of each constituent at levels [1; +1] are listed in the Table 1.

Table 1 Influential factors on surface roughness
Tablica 1. Utjecajni faktori na hrapavost površine

Factors		Level	
Var.	Terminology and dimension	-1	+1
x_1	milling cutter diameter *d*, mm	13	15
x_2	spindle speed *n*, rpm	260	300
x_3	feed per tooth f_z, mm	0,154	0,132
x_4	depth of cut a_p, mm	1	2

The experiments were carried out based on the analysis using Statistica 7.0 and Matlab to estimate the responses of the surface profile parameter roughness peak to valley *Rz*. A three dimensional side milling CNC vertical machining centre Pinnacle PK-VMC 650S was used in this work with the following specification: size of the table 850x510 mm, with maximum table load of 6 kN, spindle speed 60 - 80000 rpm. As a cutting fluid Emulkat UNI 101 P has been used. High-Grade Steel E295 has been used as a target material. A digital surftest Mitutoyo 301 has been used to calculate the peak to valley roughness with 0,01 μm precision of measurement. The measurement procedure consisted of measure variable dependent *Rz* with replicates of 12-times yielding total of 192 measurements.

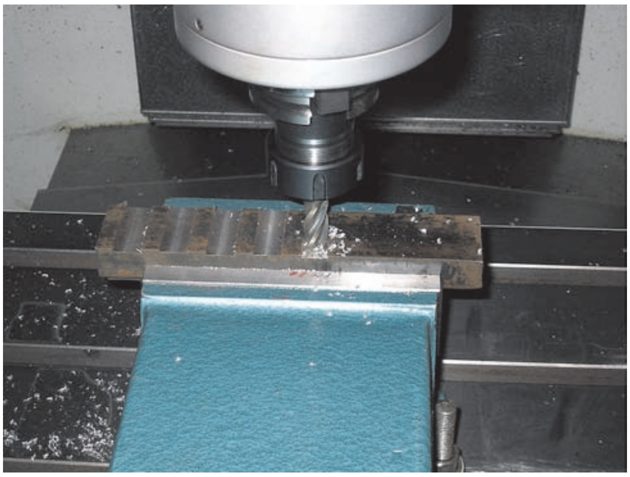

Fig. 3 Three dimensional side milling CNC vertical machining centre Pinnacle PK-VMC 650S
Slika 3. Trodimenzijsko bočno glodanje na CNC vertikalnom obradnom centru Pinnacle PK-VMC 650S

4
Results and discussion
Rezultati i diskusija

The quantitative description of the conditions effects on peak to valley was performed. Response surface methodology is an empirical modelling technique used to evaluate the relationship between a set of controllable experimental submitted factors and observed results. The results were analyzed using the analysis of variance as appropriate for the experimental design used. The normality of experimental measured data has been tested according to Shapiro-Wilkson test criteria for its good power properties as compared to a wide range of alternative tests. Shapiro-Wilkson test proved that all repeated measurements are not greater than critical value W n = 12 and α = 0,05, respectively value of probability p is out of range, as preferred significance level α, we can accept the null hypothesis about normal distribution measurements repeatability. The regression coefficients and equations obtained after analysis of variance gives the level of significance of variable parameters tested according to Student's t-test. Obtained regression coefficients that show no statistical significance have been excluded from the further evaluation. The regression equation obtained after analysis of variance gives the level of peak to valley as a function of independent variables (Tab. 1). All terms regarding their significance are included in the following equation 2:

$$y = -0{,}655 \cdot x_3 - 0{,}57 \cdot x_4 + 0{,}137 \quad (2)$$

These results can be further interpreted in the Pareto Chart, which graphically displays the magnitudes of the effects from the results obtained. Fig. 4 graphically displays the influence of magnitudes of the effects, which are sorted from largest to smallest, from obtained results. The most important factors affecting the *Rz* parameter are feed per tooth and cutting depth. The fit of the model (2) has been expressed by the coefficient of determination $R^2 = 0{,}8423$ which was found to be for equation indicating 84,23 % for the model of the variability in the response which can be explained by the models. The value also indicates that only 15,77 % of the total variation is not explained by the model. This shows that equation is a suitable model for describing to the response of the peak to valley *Rz*. The value of adjusted determination coefficient $R_{adj} = 0{,}71$ is good to advocate for a high significance of the model. A higher value of the correlation coefficient $R = 85{,}32$ % justifies a good correlation among the independent variables. This indicates good agreement between the experimental and predicted values of surface profile parameter. The significance of independent variables is interpreted in Fig. 4 and 5 that show the factors significance in percent expression. As can be seen the most important factors affecting surface parameter are feed per tooth f_z and cutting depth a_p.

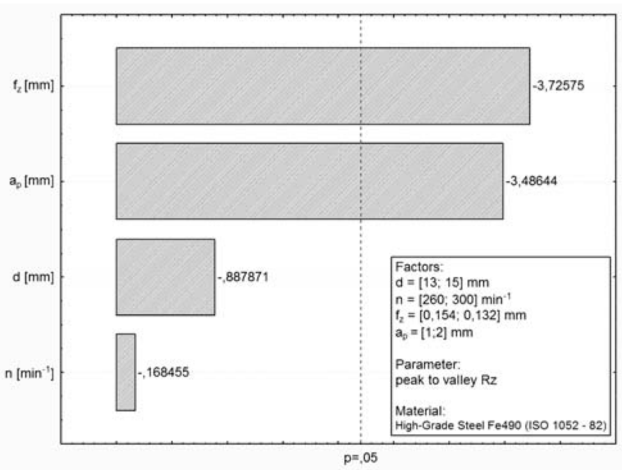

Fig. 4 Factors significance affecting the real surface profile parameter Rz after side milling
Slika 4. Čimbenici značaja koji utječu na stvarni parametar profila površine Rz nakon bočnog glodanja

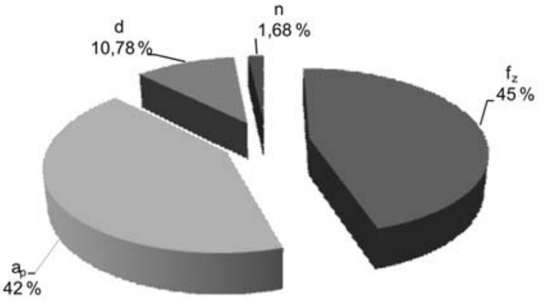

Fig. 5 Factors significance in percent expression
Slika 5. Čimbenici značaja u postotnom prikazu

As we can see in Fig. 4 and 5 the significant influence on surface profile parameter *Rz* has feed per tooth, its percentage is 45 %. Further significant factor is depth of cut 42 %. Diameter of milling cutter is the third significant factor. Spindle speed has only 1,68 % influence on the real profile of surface roughness after the side milling. We consider those factors as statistically insignificant. The influence of free factors is shown in the following Figure 6 ; feed per tooth $f_z = 0{,}132$ mm, depth of cut and diameter of the milling on surface profile parameter *Rz*. One can see in the Figure 5 a great decrease of real profile of surface roughness after the side milling by diameter of milling cutter Ø 15 mm for feed per tooth 0,132 mm compared to feed per tooth 0,154 mm. During side milling with feed per tooth 0,154 mm a tendency of decrease of real profile of surface roughness is much smaller.

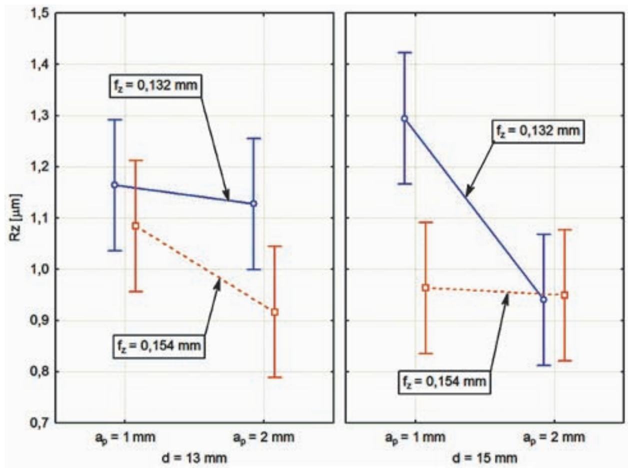

Fig. 6 Plots of marginal means for independent variables: milling cutter diameter d, depth of cut a_p, and feed per tooth f_z affecting the surface profile parameter Rz after side milling
Slika 6. Dijagrami marginalnih srdnjih vrijednosti za neovisne varijable: promjer glodala d, dubina rezanja a_p i sadržaj po zubu f_z koji utječu na parametar profila površine Rz nakon bočnog glodanja

Figure 6 shows the influence of factors with mutual interaction on surface profile parameter *Rz* after the side milling, Fig. 6 is describing the influence of feed per tooth as a statistically significant factor. Rising value of feed per tooth f_z causes decrease of the investigated surface profile parameter *Rz* after the side milling. Similar influence have also cutting depth and diameter of the milling cutter. On the plot of profiles for predicted surface profile parameter *Rz* means (Fig. 7) we can see the same trend also in case of running speed.

5 Conclusions
Zaključci

Undoubtedly, machining of metal materials by side milling is very useful. The lack of full understanding of the technological process is still a frequent problem. The surface finish of mechanical components produced by side milling is given by factors such as cutting conditions, workpiece material, cutting geometry, tool errors and machine tool deviations. The surface profile of milled parts is not affected only by one factor, but by many factors, which must be taken into account when predicting surface roughness profile parameter *Rz*. This analysis has pointed

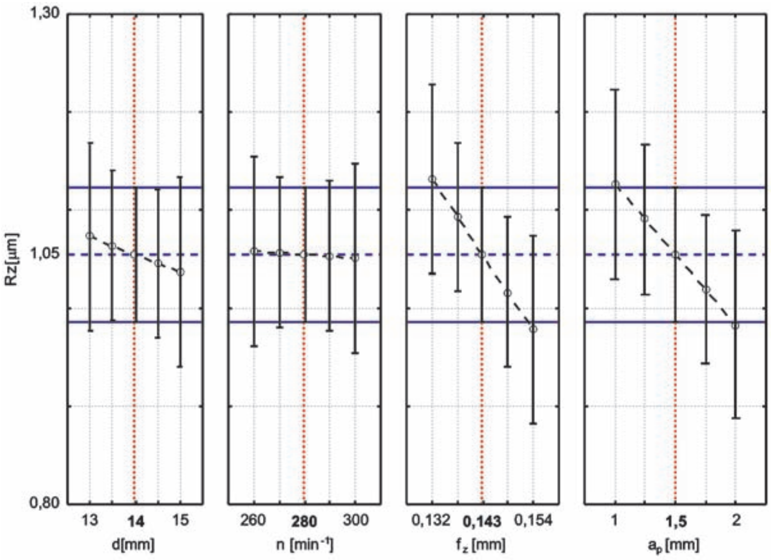

Fig. 7 Profiles for predicted surface profile parameter Rz
Slika 7. Profili za predviđeni parametar profila površine Rz

out that variable independent factors influence the morphology of the cutting surface in terms of micro cutting quality. It has been found that influence of selected factors is variable under different conditions. Obtained regression equation after analysis of variance gives the level quality as a function of the evaluated process factors. In this paper, the influence of the four selected factors: milling cutter diameter d, spindle speed n, feed per tooth f_z and depth of cut a_p on surface finish were studied. Significance of four process factors (diameter of milling cutter, running speed, feed per tooth and cutting depth) were analyzed by means of factor analysis. The experimental design of using the full factorial analysis is employed to create the mathematical model by means of regression analysis. The analysis using full factorial design reveals that higher number values of surface profile parameter are caused with decreasing of feed per tooth, cutting depth, spindle speed and diameter of milling cutter. Nowadays one can observe a tendency to machines with high stiffness and with high precision. All investigated factors cause a decrease of maximal height of real profile of surface roughness *Rz*, what is shown in the Figure 7. Experimentally was confirmed a difference of significance of investigated factors affecting the values of the surface profile parameter *Rz*. Machining with aimed configuration leads to need of orthogonal cutting because its conditions cause less intensive plastic deformation of surface and so improvement of all characteristics of surface (roughness, hardening, and residual stresses). From it can be observed analyses results, that smooth cut allows achievement of maximum cutting depth in given target machined material. Achievement of high cut depth and smooth cut is possible by optimal dimension of side milling technological factors with significant impact on the final workpiece quality, but also on economy work.

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