Open Access

Factors Analysis Affecting the Roughness at Side Milling

Ladislav Mišík, Katarína Monková and Sergej Hloch*

Faculty of Manufacturing Technologies of Košice with a seat in Prešov, Slovak Republic

Abstract: The study deals with evaluation of side milling factors, which influence the surface roughness parameter Rz. Four 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 factorial analysis. The surface roughness has been evaluated by static quality characteristic from 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. The main effect of different factors and their interaction significance has been found, which generated surface profile under defined conditions by side milling.

INTRODUCTION

Milling belongs to the material removal processes where geometry is generated by changing the mass of the incoming material in a controlled and well-defined manner. This manufacturing process is a universal method in the field of machining technologies in consequence of rising miscellaneousness of machining tools, control systems, cutting tools [1,2]. 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 [3]. Nowadays milling is still in development in the 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 aim 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 what has been observed to weigh possibilities of modern machining [4,5].

LITERATURE REVIEW

Milling is a versatile, efficient process for metal removal. It is used to generate planar and contour surfaces through the action of rotating multiple-tooth cutters. Surfaces having almost any orientation can be machined because both the workpiece and cutter can move in more than one direction at the same time. Cutters with multiple cutting edges rotate in a spindle. The machining process is interrupted as the teeth of the milling cutter alternately engage and disengage from the workpiece. Milling speed varies greatly depending on workpiece material composition, speed, feed, tool material, tool design, and cutting fluid. For highest efficiency in removing metal, while minimizing chatter conditions, the feed per tooth should be as high as possible. The optimum feed rate is influenced by a number of factors type of cutter, number of teeth on the cutter, cutter material, workpiece machinability, depth of cut, width of cut, speed, rigidity of the setup, and machine power [6,7]. Knowledge of the factors and then optimization lead to better fulfilment of rising requests of quality of machined surface. Whenever two machined surfaces come in contact with one another the quality of the mating parts plays an important role in the performance and wear of the mating parts. Most scientific papers concerning the evaluation of microgeometrical features of side milling are available [8-10]. The objective is to determine the final shape of the surface quality, which is a function of the geometric characteristics of the tool [11]. The roughness of the machined surface can be seen through micro-geometrical irregularities of the surface. The result of this technological process depends on a large number of process factors such 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 the surface profile parameter to get the average roughness *Ra*. From the previous experiments and from available literature [12-16] the average roughness parameter is not enough for adequate evaluation of any process because average roughness is sensible on extreme values as is shown on Fig. (**1**).

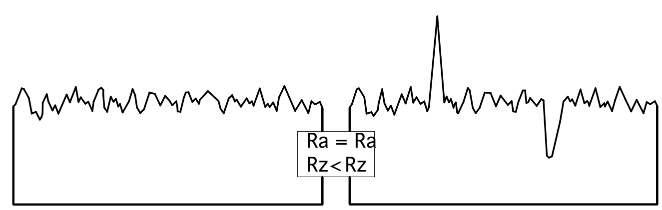

Fig. (1). Two surfaces equal from the point of view of *Ra* and different from the view of *Rz*.

EXPERIMENTAL SET UP

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,

*Address correspondence to this author at the Faculty of Manufacturing Technologies of Košice with a seat in Prešov, Slovak Republic;
E-mail: hloch.sergej@gmail.com

whereas a real roughness appears as the result of theoretical roughness though with bigger or lesser occasional roughness provoked 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], cutting depth a_p [mm]. 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 [7,11]. The explicitly defined function is shown in 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 Factor on Surface Roughness

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

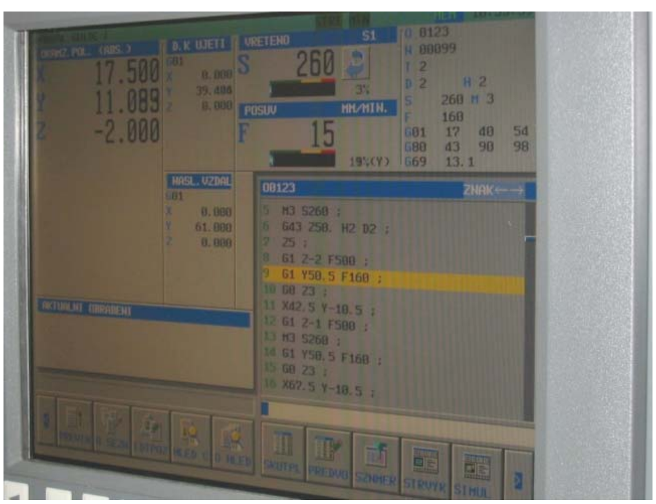

Fig. (2). Screen with the program of the CNC vertical machining centre Pinnacle PK-VMC 650S.

A three dimensional (Fig. **2**) side milling CNC vertical machining centre Pinnacle PK-VMC 650S, was used in this work with following specification: size of the table 850x510 mm, with maximum table load of 600 kg, spindle speed 60 - 80000 rpm. As a cutting fluid Emulkat UNI 101 P has been used.

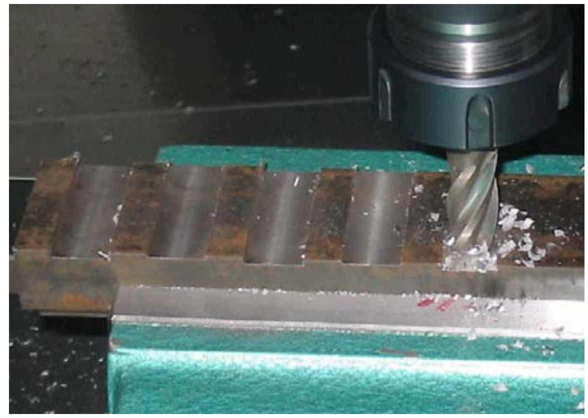

Fig. (3). Experimental samples production at CNC vertical machining centre Pinnacle PK-VMC 650S.

The experiments (Fig. **3**) 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*. has been used High-Grade Steel E295 has been used on a target material. A digital surftest Mitutoyo 301 has been used to calculate the peat 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 a total of 192 measurements.

RESULTS AND DISCUSSION

The quantitative description of the conditions effects on peat to valley was performed. Response surface methodology is an empirical modeling 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 to 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 $\alpha = 0.05$, 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 has been rejected for the further evaluation. The regression equation obtained after analysis of variance gives the level of peak to valley as a function of independent variables (Table **1**). All terms regarding their significance are included in the following equation 2:

$$Rz = -0{,}655 f_z - 0{,}57 a_p + 0{,}137 \tag{2}$$

These results can be further interpreted in the Pareto Chart, which graphically displays the magnitudes of the effects from the results obtained. Fig. (**3**) 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 is 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 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 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 shows the factors significance in percent expression. As can be seen, the most important factors affecting surface parameter is feed per tooth f_z and cutting depth a_p.

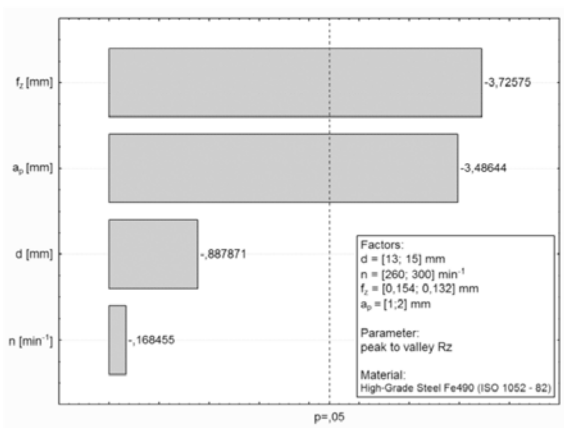

Fig. (4). Pareto chart shows that feed per toot was found to be the most sufficient factor that affects the surface profile roughness parameter Rz at side milling.

As we can see on (Fig. **4** and **5**), the significant influence on surface profile parameter *Rz* has feed per tooth, its percentage is 45 %. Further significant factor is the 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 and that we consider the factors as statistically non significant. On the following Fig. (**6**) is shown the influence of free factors; feed per tooth f_z = 0,132 mm, depth of cut and diameter of the milling on surface profile parameter *Rz*.

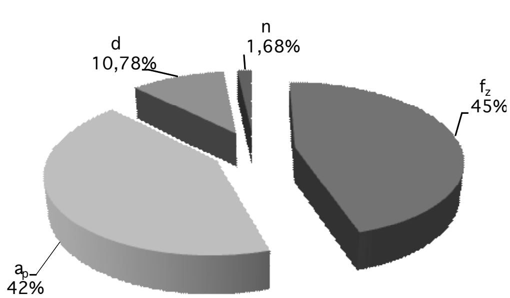

Fig. (5). Significance of evaluated side milling factors in the percentage expression.

One can see on the Fig. (**5**) 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, comparing to feed per tooth 0,154 mm. During side milling with feed per tooth 0,154 mm is a tendency to decrease the real profile of surface roughness much smaller.

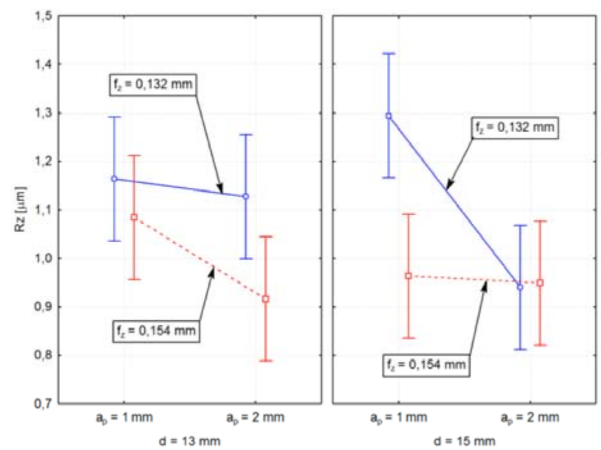

Fig. (6). Plots of marginal means for independent variables: milling cutter diameter *d*, depth of cut a_p, and feed per tooth f_z affecting the surface profile parameter *Rz* after side milling.

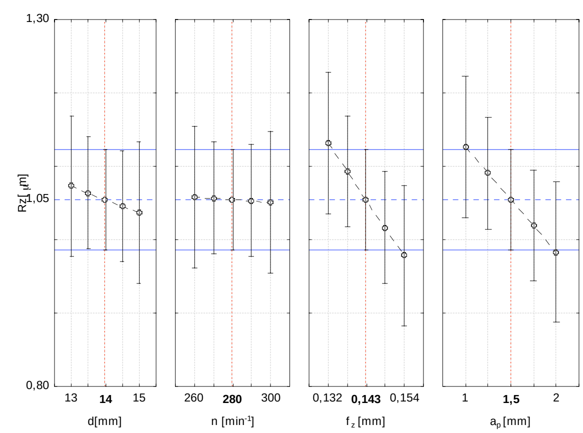

Fig. (7). Profiles for predicted surface profile parameter *Rz.*

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

CONCLUSIONS

The lack of full understanding of side milling 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 only affected by one factor, but by the set of the factors, which must be taken into account when predicting surface roughness profile parameter *Rz*. This analysis has pointed out that variable independent factors influence the morphology of the cutting surface in terms of micro cutting quality. It has been found that influences of selected factors are variable related under different conditions. Obtained regression equation after analysis of variance gives the level quality as a function of the evaluated process factors. In presented 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 factor (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 of 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 the tendency of machines high stiffness and with high precision. All investigated factors cause decrease of maximal height of real profile of surface roughness *Rz*, which was shown in the Fig. (**7**). Experimentally was confirmed different of significance of investigated factors affecting the values of the surface profile parameter *Rz*. Machining with aimed configuration leads to the need of orthogonal cutting because its condition causes less intensive plastic deformation of surface and therefore occurs improvement of all characteristics of surface (roughness, hardening, and residual stresses). From performed analyses results, that smooth cut allows the achievement of maximum cutting depth in given target machined material. Achievement of high cut depth and smooth cut is possibly reached by optimal dimension of side milling technological factors with a significant impact on final workpiece quality, and also on economy work.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the support of Scientific Grant Agency of the Ministry of Education of Slovak Republic, Commission of mechanical engineering, metallurgy and material engineering, for their contribution to project 1/4157/07.

REFERENCES

[1] Andonov, and J. Békés, "Analysis and synthesis of engineering objects and processes," *Bratislava, ALFA*, p. 376, 1986.

[2] P. Blahuš, "Factor analysis", *STNL, Praha*, p. 354, 1985.

[3] P. Franco, M. Estrems, and F. Faura, "A study of back cutting surface finish from tool errors and machine tool deviations during face milling," *International Journal of Machine Tools and Manufacture*, vol. 48 (1), pp. 112-123, 2008.

[4] M. Gombár, "Statistical model of surface roughness" *Electrotechnics in practise*, vol. 16, no. 11-12, pp. 26-28, 2006.

[5] M. Gombár, "Surface morphology relationship analysis and the cutting time," *Fine Mechanics and Optics*, vol. 51, pp. 323-325, 2006.

[6] D. Kozak, J. Vojvodica, N. Gubeljak, and D. Semenski, "Factors influencing the yielding constraint by cracked welded components" Program and book of abstracts of 12th Conference on Materials and Technology / Jenko, Monika, Ed. Ljubljana: Institut za kovinske materiale in tehnologije, 2004, pp. 79-79.

[7] R. L. Mason, R. F. Gunst, and J. L. Hess, "Statistical design and analysis of experiments" 2nd ed. Wiley-Iterscience. A John Willey & Sons Publication, New Jersey, 2003, p. 760.

[8] P. Monka, and K. Monková, "Intensification of cutting parameters contra surface roughness" In: *New ways on manufacturing technologies*, 5th International conference: Prešov, 2000, pp. 271-274.

[9] K. Monková, "Creating of 3D model with difficult shapes without the parameters and dimensions of real part" In: GCG 2007: Geometry and Computer Graphics 2007, 27th The International conference: Nedvědice. Brno: VUT, 2007, pp. 145-150.

[10] K. Monková, "The methods of NC program creating", *Scientific Bulletin*, vol. 19, pp. 499-504, 2005.

[11] D. C. Montgomery, "Design and analysis of experiments" 5th. ed. Hamilton Printing Company, 2001, p. 660.

[12] A. Šalak, K. Vasiko, M. Selecka, and H. Danninger, "New short time face turning method for testing the machine ability of PM steels", *Journal of Materials Processing Technology*, vol. 176, pp. 62-69, 2006.

[13] S. Seguy, G. Dessein, and L. Arnaud, "Surface roughness variation of thin wall milling, related to modal interactions". *International Journal of Machine Tools and Manufacture*, vol. 48 (3), pp. 261-274, 2008.

[14] K. Vasilko, "A new classification of mechanical engineering processes.," Transactions of the Technical University of Košice. Cambridge: Riecansky Science Publ. Co, 1995, pp. 80-88.

[15] K. Vasilko, and A. Macurová, "New mathematical description of the dependence T=T(vc)", Science Report: Measuring technology in advanced machine manufacturing systems: Kielce, 2004. Kielce: Kielce University of technology, 2004, pp. 174-177.

[16] K. Vasilko, and D. Vasilková, D. "Methods of improving of the surfaces morphology", Technical University of Košice, 2000, p. 120.

Received: February 25, 2008 Revised: July 22, 2008 Accepted: October 13, 2008