Mechatronic Systems 2

Applications in Material Handling Processes and Robotics

Edited by
Leonid Polishchuk
Orken Mamyrbayev
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ROUTLEDGE

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Chapter 15

Analysis of the character of change of the profilogram of micro profile of the processed surface

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R. Iskovych-Lototsky, Z. Omiotek, O. Mamyrbaev,
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15.1 INTRODUCTION

Processing by face milling is widespread and described in reference literature (Guzeev et al., 2005; Pukhalsky & Gavrilov, 2012; Yalçın et al., 2009). In the course of face milling, various cutting parameters can be set: cutting depth t, mm; milling width B, mm; serve on the mill tooth S_z, mm/rotation; cutting speed V, m/min; rotation frequency n, minutes^{-1}. The cutting parameters are set by either the technologist from cutting mode standards (Guzeev et al., 2005) or reference books by cutting tool manufacturers, for example, of Sandvik, Pramet, Seco, and many others (Sandvik Coromant, 2019), or the machine operator a trial and error method.

The cutting parameters in standards (Guzeev et al., 2005) are given in the first case on the basis of the statistical technological transitions, collected from a large number of enterprises. These cutting parameters have to guarantee the uniformity of the carried-out size and the required roughness of the processed surface. As it is known, the wear occurs from the very beginning of processing using a tool (Loladze, 1982; Pimenov, 2103; To Simsiva et al., 2012).

In the work (Isakov, 2013), the wear intensity model of a mill is shown in processing and the geometrical model of microroughness of the processed surface, taking into account the wear of the face mill's teeth, but it does not consider the physical properties of the processed materials. Forecasting models of roughness without taking note of the wear of the tool are provided in scientific articles (Bajić et al., 2012; Grzenda & Bustillo, 2013).

In the works (Kovac et al., 2013; Rosales et al., 2010; Simunovic et al., 2013), the influence of processing parameters on the roughness of processed surfaces is investigated

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through face milling, for example, the processed surface quality arising from the milling modes or the cooling method is investigated, studies using the Taguti method, etc., are conducted. However, the abovementioned works do not consider an important component – the change in the roughness of processed flat surfaces in connection with the growth of the size of the buildup of wear on the back surface of face mill teeth. Therefore it is necessary to establish how the wear of face mills influences the roughness of the processed surface.

15.2 ANALYSIS AND PROBLEM STATEMENT

The aim is to investigate the influence of the size of the wear buildup on a back surface of face mill teeth and of the face milling parameters on the processed surface roughness during STEEL 45 (C45) processing.

This chapter (Yalçın et al., 2009) concentrates on the influence of various cooling strategies on the roughness of a surface and wear of the tool during computer milling of materials of soft preparations. The study involved a selection of milling operations in the form of dry milling, cooling with cold air, and cold liquid milling. The air cooling system was developed and manufactured for cooling of final milling tools.

The study (Pukhalsky & Gavrilov, 2012) presents a theoretical model for defining the beating of the face mill cutting edges with the mechanical fastening of the replaceable many-sided plates, considering the valid sizes and the beating of a mandrel determining the tool installation eccentricity. The interrelation of the mutual beating of step mill teeth and their wear is considered.

In the works (Guzeev et al., 2005; Polishchuk et al., 2019; Sandvik Coromant, 2019), the data necessary for defining the parameters of cutting at turning, boring, processing of openings, milling, are given for machines with numerical program control, as well as applications including data on modern CNC machine models.

In the book (Loladze, 1982), the mechanism of cutting tool destruction and wear in various processing conditions and questions of the fragility and plastic durability of a tool's cutting part are considered. The work provides durability calculation methods, as well as the theory concerning adhesive, fatigue, and diffusive wear of tools. As a result, recommendations are made on the increase in tool firmness and increase in the productivity of processing using cutting.

In the work (Kozlov et al., 2019; Pimenov, 2103), features of porosity formation are considered during the hardening of a cast high-manganic steel plate. A model for assessing the influence of this type of defect on the intensity and deformation condition of a plate resulting from strain loads of ore preparation crushers is offered. The finite element method is used for tension calculation in the DEFORM software package and the calculation of equivalent tension in characteristic sections of a plate for various parameters of the macro time of a round section.

The work (Ogorodnikov et al., 2018a; To Simsiva et al., 2012) offers a physical-probabilistic model of back surface wear of a cutting tool during high-speed turning. The authors did not consider the influence of processes of abrasive and diffusive wear.

In the work (Isakov, 2013; Ogorodnikov et al., 2018b), the geometrical model of processed flat surface face milling microroughness considering the wear of the tool is presented. The model considers the height change of microroughness of flat surfaces caused by the tops of teeth connected with the dimensional wear face mills. As a result, the operating values of microroughness height for various serves, radii of rounding, various front and back corners of mill teeth taking into account tool wear on the back surface are obtained.

The work (Grzenda & Bustillo, 2013) concentrates on the initial transformation of data and its influence on forecasting of face milling surface roughness during high torque face milling. In the experiments conducted in industrial conditions, an extensive data set was generated. The data set includes a very broad set of parameters that influence the roughness of a surface: properties of the cutting tool, processing parameters, and the cutting method. Some of these parameters can be potentially connected with the others or can slightly impact the forecasting model. Moreover, depending on the number of available records of the model, machine learning may or may not be able to model some of the primary dependences. Therefore, it is necessary to choose a suitable quantity of input signals and the appropriate configuration of the coordinated prediction model. In this article, the hybrid algorithm that unites a genetic algorithm with neural networks is offered to consider the choice of the corresponding parameters and their corresponding transformation. The algorithm was tested in a number of experiments conducted in the conditions of a master class with data sets of different sizes for research concerning the impact of the available data on the choice of the corresponding data transformations. The data set size directly impacts the accuracy of forecasting models of roughness modeling, as well as the use of individual parameters and the transformed functions. Test results show considerable improvement in the quality of forecasting models constructed using that method. These improvements become obvious when these models are compared with the standard multilayered perseptrona, which were trained with all parameters, and with data that decrease by means of the standard operation of the main components.

In works (Bajić et al., 2012; Kovac et al., 2013; Rosales et al., 2010), the influence of three cutting parameters, components of tool wear, and cutting force in face milling on surface roughness is considered in the technological process as a part of off-line control. Experiments were conducted in order to define the process planning model. The cutting speed, tooth serve, and cutting depth were accepted as influential factors. For experimentally relevant data, two methodologies of modeling were used, namely the regression analysis and neural networks. The results obtained by means of models were compared. Both models have a relative forecasting error lower than 10%. The research showed that when a set of training materials represents a small methodology of neural network modeling, they are comparable of the methodology of regression analysis and can even allow obtaining the best results, in this case with an average relative error of 3.35%. In the theory, the advantages of off-line control are explained by a process that uses process models incorporating these two methodologies of modeling.

In the works (Benardos & Vosniakos, 2002; Elhami et al., 2013; Grzenda et al., 2012), the application of the Taguti method for ANN model optimization developed by the Levenberg–Marquardt algorithm is presented. For the purpose of demonstrating the implementation of the approach, the situational research of modeling the resulting cutting force in the course of a rotation is used. The educational and architectural ANN parameters were located in the orthogonal L18 array, and the predictive productivity of the ANN model was estimated with the use of the offered equation. Using the dispersion analysis (ANOVA) and the analysis of parameters (ANOM), optimal levels of the ANN parameters are defined. The ANN model optimized across Taguti was developed and exhibited high forecasting precision. Analyses and experiments showed that optimum training and the architectural ANN parameters can be defined systematically, thereby avoiding the long procedure of tests and errors (Dragobetskii et al., 2015; Ogorodnikov et al., 2004; Vorobyov et al., 2017).

15.3 MATERIALS AND RESEARCH METHODS

The purpose of the research is to determine the degree of impact that wear of the cutting tool blade and cutting speed have on roughness Rz. The object of the research is the process of milling with a face mill equipped with T15K10 carbide plates of semi-manufacture of 45 steel.

Pilot studies are conducted to assess the roughness of surface processed using face milling in terms of different degrees of wear of the mill teeth on the back surface. For that purpose, processing of a 45 steel detail has been carried out (composition of carbonaceous qualitative structural 45 steel according to GOST 1050–88: carbon C – 0.42 … 0.5%, silicon Si – 0.17% … 0.37%, magnesium Mn – 0.5% … 0.8%, is lame Cr – no more than 0.25%, other Fe iron) (Polishchuk et al., 2019) with sizes "L = 200 mm × B = 75 mm × H = 100 mm" on an SF15 (6S12) vertical milling machine without the use of cooling, using a tool with the following parameters: cutting part material (pentahedral plate) – T5K10 (composition of solid T5K10 alloy of the titano-volframo-cobalt group as per GOST 3882-74: WC tungsten carbide – 85%, titanium carbide TiC – 6%, cobalt Co – 9%) (Loladze, 1982); mill diameter: D = 125 mm; the main angle in the plan: $\varphi = 60°$; the auxiliary angle in the plan: $\alpha_1 = 12°$; forward angle: $\gamma = 15°$; back angle: $\alpha = 8°$; quantity of mill teeth: $z = 1$; tilt angle of the main cutting edge: $\lambda = 0$. Using Brinell's TB 500403 hardness gauge the firmness of detail – HB190 is measured.

The cutting parameters were selected for different stages of processing, according to the reference book (Guzeev et al., 2005), and are given in Table 15.1.

Measurement of roughness Rz was carried out according to indications of the Profilometer Abris PM 7.0 Outline. Instrument readings were taken for basic length $L = 0.4$ mm at the beginning, the middle, and at the end of the operating course of a mill. Thus, in each experiment 3 × 5 repetitions are carried out ($k = 15$).

After each operating course, macrographs of the back surface of the face mill tooth are taken. In addition, photographs were taken of the processed surface. Pictures were processed on a personal computer and, in the mode of picture magnification, measurements of the degree of wear on the back surface of a mill tooth were conducted through

Table 15.1 The cutting modes for different face milling processing stages

No	*Milling stage*	*Milling depth t*	*Serve on tooth S_z*	*Cutting speed V*	*Rotation frequency n*
		(mm)	*(mm/tooth)*	*(m/min)*	*(min^{-1})*
1	Finishing	1	0.125	392.6	1,000
2	Finishing	1	0.16	392.6	1,000
3	Semi-finishing	1	0.25	392.6	1,000
4	Semi-finishing	1	0.25	247.3	630
5	Draft	1	0.32	196.3	500

comparison with a dimensional ruler. Thus, experimental roughness points of the processed surface for different degrees of wear and the different face milling parameters were obtained. Afterward, statistical processing of experimental data for the set statistical reliability 0.95 was carried out. Average values of the measured size were defined according to the results of five experiments. As not displaced assessment of general dispersion selective dispersion is defined. The uniformity of selective dispersions was checked by Kokhren's criteria (Kozlov et al., 2019; Yuchshenko & Wójcik, 2014).

15.4 RESEARCH RESULTS AND DISCUSSION

Figure 15.1 shows the back surface of a face mill tooth and the flat surfaces of a detail processed by the mill after the first and second pass of the tool. The first pass has an $l_z = 1.31$ mm, the second pass – $l_z = 4.6$ mm.

Wear on the back surface of the face mill tooth is shown on the left and details with the processed flat surfaces on the right with a milling depth of $t = 1.0$ mm; to serve $S_z = 0.125$ mm/tooth; cutting speed $V = 392.6$ mm/min; to the rotation frequency of the mill $n = 1000\,\mathrm{min}^{-1}$.

The experimental average roughness values of the processed surface for different degrees of wear and the different face milling parameters are provided in Figure 15. 2.

Figure 15.2 shows that roughness Rz increases from 15% to 30% with the growth of the degree of wear l_z from 0 to 3.1–4 mm. At the same time, at a constant speed of cutting $V = 392.6$ m/min, an increase in the serve S_z with 0.125 mm/tooth up to 0.16 mm/tooth leads to an increase in roughness by 7%–16%, up to 0.25 mm/by tooth – for

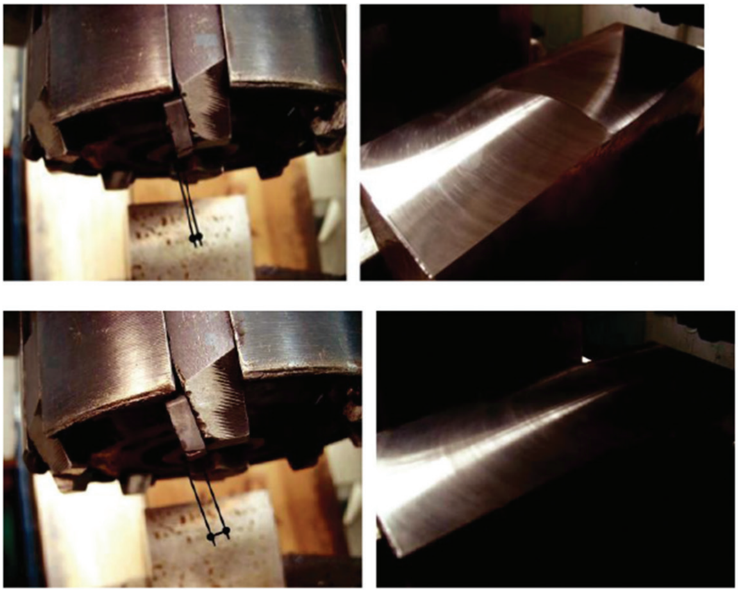

Figure 15.1 Wear on the back surface of the face mill tooth at the left and details with the processed flat surfaces on the right with a milling depth $t = 1.0$ mm; to serve $S_z = 0.125$ mm/tooth; cutting speed $V = 392.6$ mm/min.

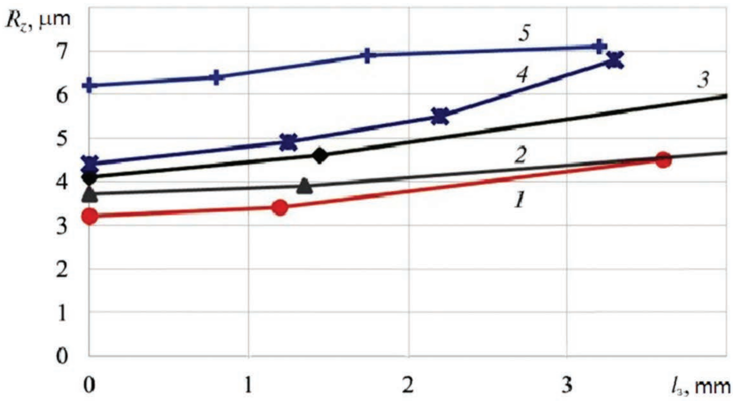

Figure 15.2 Experimental average roughness values of the processed surface Rz for different degrees of wear l_z and different face milling parameters: 1 – $S_z = 0.125$ mm/tooth, $V = 392.6$ m/min; 2 – $S_z = 0.16$ mm/tooth, $V = 392.6$ m/min; 3 – $S_z = 0.25$ mm/tooth, $V = 392.6$ m/min; 4 – $S_z = 0.25$ mm/tooth, $V = 247.6$ m/min; 5 – $S_z = 0.32$ mm/tooth, $V = 196.3$ m/min.

28%–48%, that corresponds with data (Isakov, 2013). An increase in cutting speed V from 247.3 to 392.6 m/min at invariable serve $S_z = 0.25$ mm/tooth, on the other hand, leads to a reduction of roughness by 7%–15%.

Let us show on one of the examples of face milling parameters as the profilogram of a processed surface micro profile changes in the event an increase in wear of a mill tooth on the back surface. Processing using face milling, in this case, is carried out with a depth of $t = 1.0$ mm; serve $S_z = 0.32$ mm/tooth; cutting speed $V = 196.3$ mm/min; spindle rotation frequency $n = 500\,\text{min}^{-1}$; quantity of mill teeth: $z = 4$. For evident comparison of roughness parameters of the processed planes at different degrees of wear, a detail with four steps of 1 mm high and 50 mm long each is received (Figure 15.3). Each of the steps is processed using a mill with various degrees of wear on a back surface. After processing the subsequent step, macrographs of the back surface of the face mill tooth are made. The photos were processed on a personal computer and in a photo

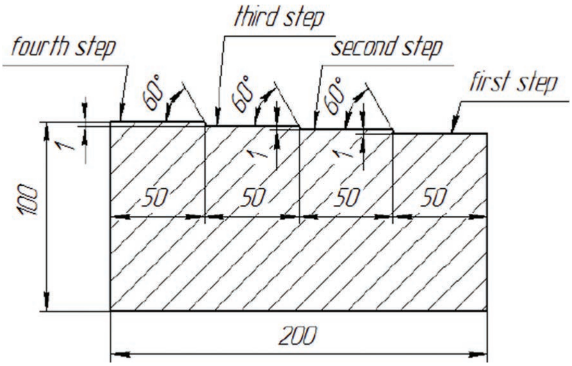

Figure 15.3 A detail with four steps.

magnification mode, and measurement of the degree of wear on the back surface of the mill tooth was carried out by comparison with a dimensional ruler.

After processing the obtained step, the detail micro profile profilogram of a processed surface with a basic length $L = 0.8$ mm is measured using a Protonmietprofilometer 130 intended for measuring parameters of a profile and roughness parameters of a surface on the average line system (GOST 2514282). For each step, a profilogram is made for five points; if the number of repetitions is $k = 5$, each time there is a change in a micro profile profilogram of the processed surface at the increase in wear of a mill tooth on a back surface, as a result, 20 profilograms are obtained. For the first step $l_z = 0$ mm, the second – the 0.18, the third – the 0.45, and the fourth – 0.88 mm. Figure 15.4 shows the profilograms for four steps at the points in the middle of the corresponding process steps.

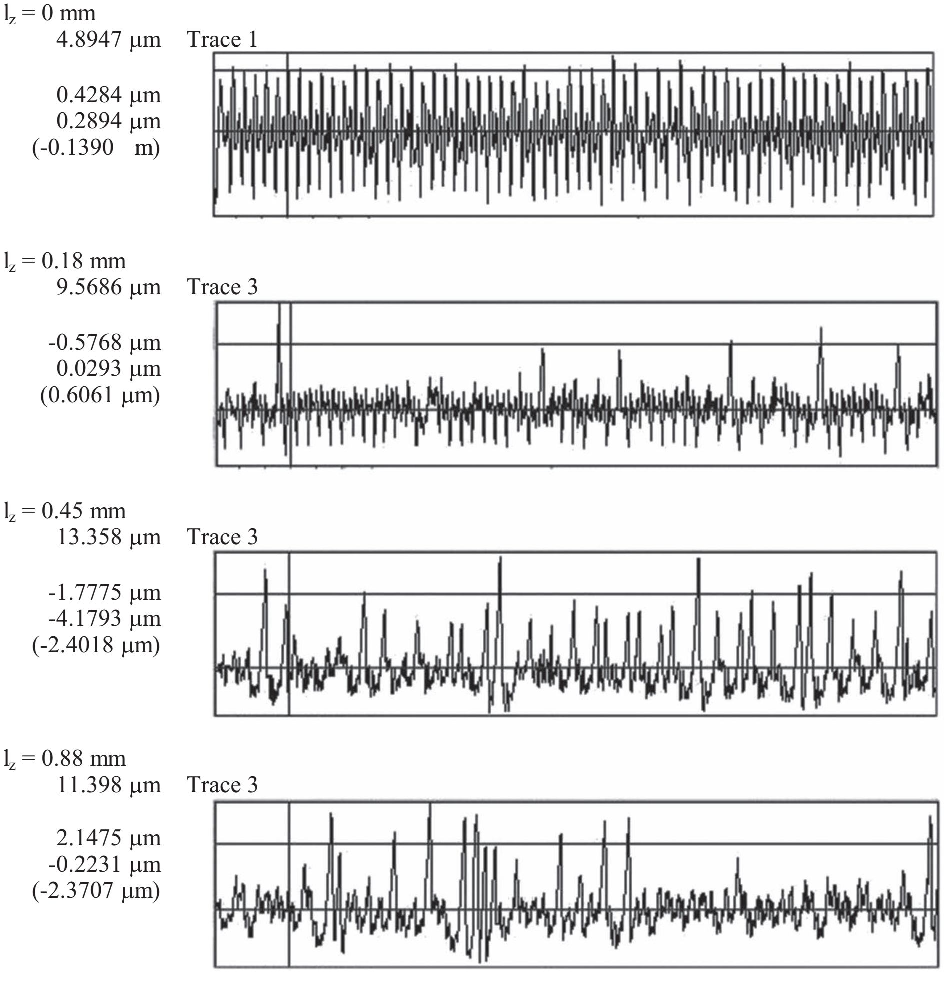

Figure 15.4 Profilograms of a processed surface micro profile at an increase in wear of mill teeth on the back surface.

From Figure 15.4 it is visible that at zero wear (the first step) the profilogram has uniform character with a high frequency and amplitude. At the same time, the sizes of the ledges $H_{imax} = 4.8947\,\mu m$ and hollows $H_{imin} = -5.2874\,\mu m$ are almost equal and the average line passes within a significant shift from the middle at $-0.1390\,\mu m$. The average value of roughness $Rz = 10.2\,\mu m$.

At wear $l_z = 0.18\,mm$ (the second step) character of a profilogram changes: sizes of ledges $H_{imax} = 9.5686\,\mu m$ prevail over the sizes of hollows $H_{imin} = -5.0386\,\mu m$, at the same time the average line is considerably displaced from the middle on $0.6016\,\mu m$. At the same time, the sizes of hollows are greater than the sizes of ledges. The average value of roughness $Rz = 10.9\,\mu m$.

At wear $l_z = 0.45\,mm$ (the third step) the same tendency remains: sizes of ledges $H_{imax} = 13.358\,\mu m$ prevail over the sizes of hollows $H_{imin} = -5.3434\,\mu m$. The average roughness value $Rz = 15.8\,\mu m$.

At wear $l_z = 0.88\,mm$ (fourth step): sizes of ledges $H_{imax} = 11.398\,\mu m$ prevail over the sizes of hollows $H_{imin} = -6.1568\,\mu m$. The average roughness value is $Rz = 16.5\,\mu m$.

In general, at the increasing degree of wear on a back surface, a reduction of frequency of ledges and hollows of a micro profile profilogram is observed. The amplitudes of ledges prevail over the amplitudes of hollows in the process of wear increase from 0 to 0.88 mm. This arises from the fact that the degree of wear on the back surface of a mill tooth smooths out the processed surface. In the process of increase in the degree of wear up to 0.88 mm, a significant increase in roughness of 15%–30% is observed.

15.5 CONCLUSION

The conducted research shows that roughness Rz increases by 15%–30% for the adopted cutting modes in the case of an increase in the degree of wear from 0 to 3.1–4 mm;

An increase in serve S_z from 0.125 up to 0.16 mm/tooth, at a constant cutting speed of $V = 392.6$ m/min, leads to an increase in roughness by 7%–16%. An increase in serve S_z up to 0.25 mm/tooth, at a constant cutting speed of $V = 392.6$ m/min, leads to an increase in roughness by 28%–48%.

An increase in cutting speed V from 247.3 m/min to 392.6 m/min at invariable serve $S_z = 0.25$ mm/tooth leads to a reduction of roughness by 7%–15%.

It is shown that the increasing degree of wear on the back surface causes a reduction in the frequency of ledges and hollows on the micro profile profilogram of the processed surface to be observed. At the same time, amplitudes of ledges prevail over the amplitudes of hollows in the process of wear increase.

During the design of face milling operations, it is necessary to consider the change of the roughness parameters, taking into account the wear of mill teeth on the back surface.

Unlike the traditional approach to the design of operations, perhaps, in processing by milling it is necessary to place more emphasis on serve, as well as the process of increasing wear of the mill teeth on the back surface, and the resulting connected increase in roughness, in order to correct the serve toward roughness reduction. This will in turn lead to an increase in productivity.

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