Analysis of the Face Milling Process Based on the Imitation Modelling

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Abstract. The results of simulation modeling of the face milling process allowed to analyze the surface finish dependence on cutting conditions. It is noted that the surface irregularity in the form of unevenness appears in face milling. Besides, the ratio of feed rate to spindle revolutions speed influences dimensions of surface roughness. The data received are experimentally confirmed.

1. Introduction

Engineering support of the parts of required quality along with a simultaneous costs reduction of machining processes is one of the most important problems of mechanical engineering. Geometrics of milled surface quality, in particular, surface roughness, influence almost all part performances. To measure surface roughness, the parameters of height, step and shape are used. If all the aspects of the industrial process system are taken into consideration, cutting conditions and structural-geometric parameters of cutting tools are the main factors in making topography of the milled surface.

Simulation modeling is the most effective research method in such complex process as shaping by face milling. Simulated model allows to characterize the development of a prototype process in time, and this makes possible to carry out computational experiments. Computational experiments allow analyzing surface roughness dependence on different milling process parameters; moreover, unlike real experiments there is no demand in a large amount of financial and time spending [1-9].

Consequently, a conceptual foresight of the surface finish by using simulation modeling in face milling is actual. Design technique of face milling operations can be based on it.

2. Materials and research methods

For carrying out numerical experiments we have created a simulated model of the face milling process. The model structure is shown in Figure 1.

The model consists of the following models: the model of the milled surface; the models of the cutting edges; the model of the mill; the model of the milling kinematics; the model of the cutting process; the model of the plastic deformations; the model of the cutting forces; the model of the vibrations; the model of the teeth wear. All these models are connected with each other by information streams and interrelate at every step of iterative computation in time.

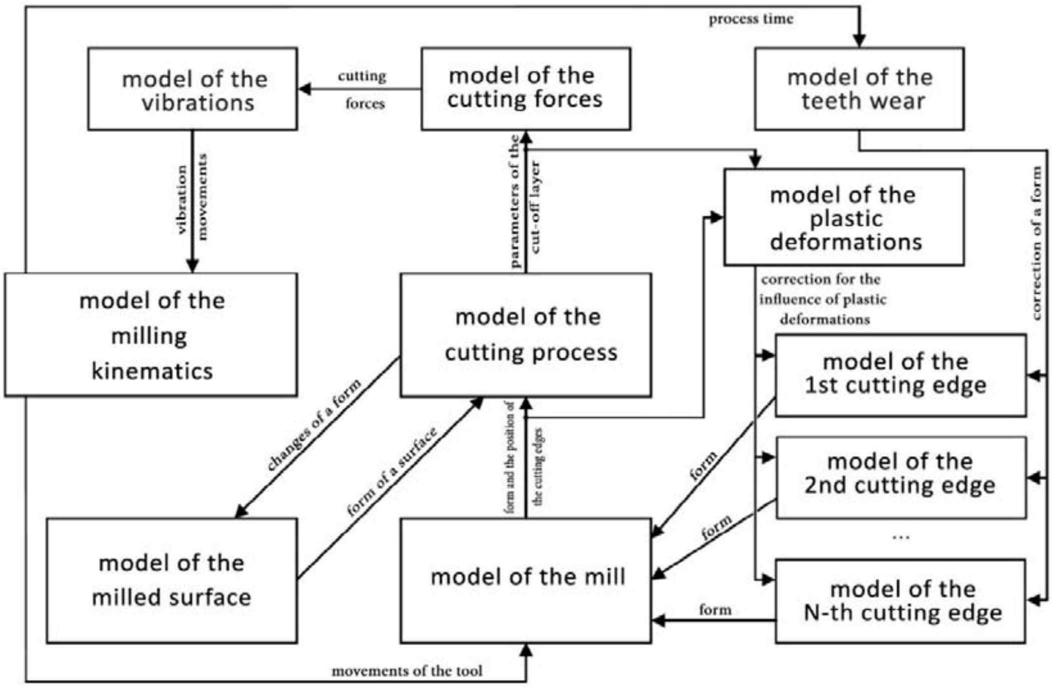

Fig. 1 - Simulated model structure

The modeling result can be illustrated as a topographic scheme of micro irregularities. This scheme demonstrates all the information about geometric parameters of the surface finish.

On the basis of the model, numerical experiments were carried out aimed at studying the connection between geometric parameters of the surface finish and structural-geometric parameters of cutting tools and cutting conditions in face milling.

The results have shown that the general principles of formation of the micro relief on the milled surface stay the same for various cutting conditions, milling cutters constructions and machined materials. The following are the results received by modeling the milling process of steel 1045 (AISI) with a face milling cutter having the diameter 50 mm, 4 teeth, SCEA=23°, γr=5°, γa=5°, ε=108°, r=0.8 mm, the cutting head material is T15C6 (a titanium-tungsten alloy), feed per minute equals 1600 mm/min, spindle speed is 400 revolutions per minute, cutting depth is 1 mm. The cutting conditions are chosen for efficient analyzing of the principles and demonstrating research results.

In topogram of the machined surface (Figure 2) ordinate axis is in line with feed directions, the range on the abscise axis illustrates milling width. The values of micro irregularities are coloured.

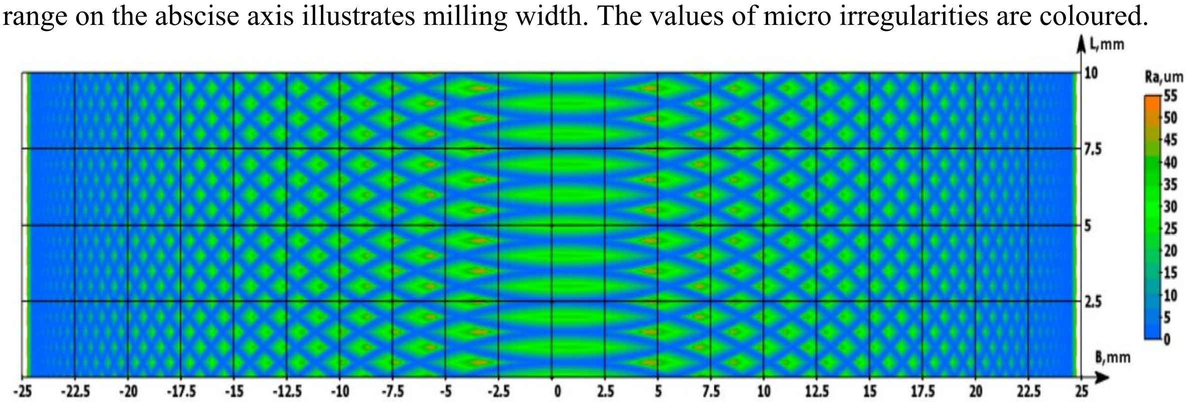

Fig. 2 – Topogram of the machined surface

Analysis of this topogram lets us conclude that different values will be obtained for different positions of roughness measure lines. This is illustrated in Figire 3, which demonstrates the relation between height parameters (ordinate axis) measured along the lines of parallel feeds and the position of the cross-section towards the full milling width (abscise axis).

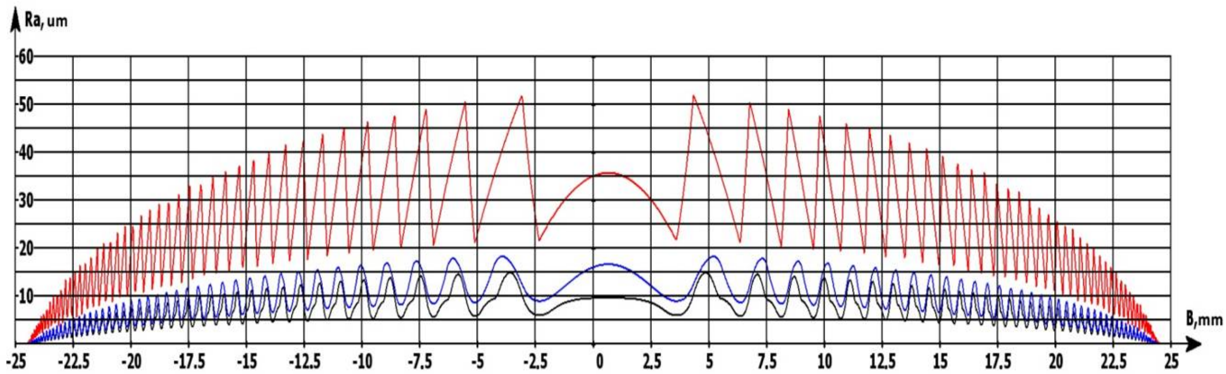

Fig. 3 – Height parameters of surface roughness (vertically down: Rmax, m, Ra)

Analysis of the figure shows that the surface receives a form deviation which is determined by the character of face milling. This deviation is an unevenness which can be calculated as the difference between the ordinate of the cross-cup the envelop curve and cutting width border line and the maximum value of the envelop curve. Another characteristic of the topography produced by face milling process is improving the surface finish in the peripheral area; it can be explained with the influence of the cutting kinematic and better conditions while milling if the layer cut off peripherally is thinner.

One more important parameter of surface finish is a relative carrying length of the profile at some level. The scheme of setting up the values of the relative carrying length of the profile in dependence to the cross-sectional position and level p (Figure 4) illustrates significant changes of this parameter for relatively close set up cross-sections.

Arithmetic average roughness height depends on both the position of profile line and its direction (Figure 5). The maximum values of the arithmetic deviation have the edge positions of the central area (if measured parallel to feed motion).

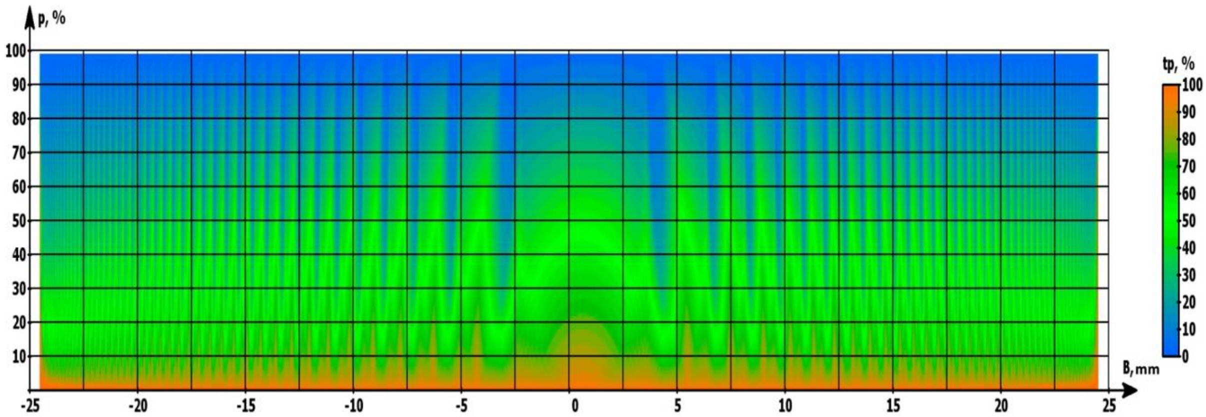

Fig. 4 – Setting up the relative carrying length of the profile

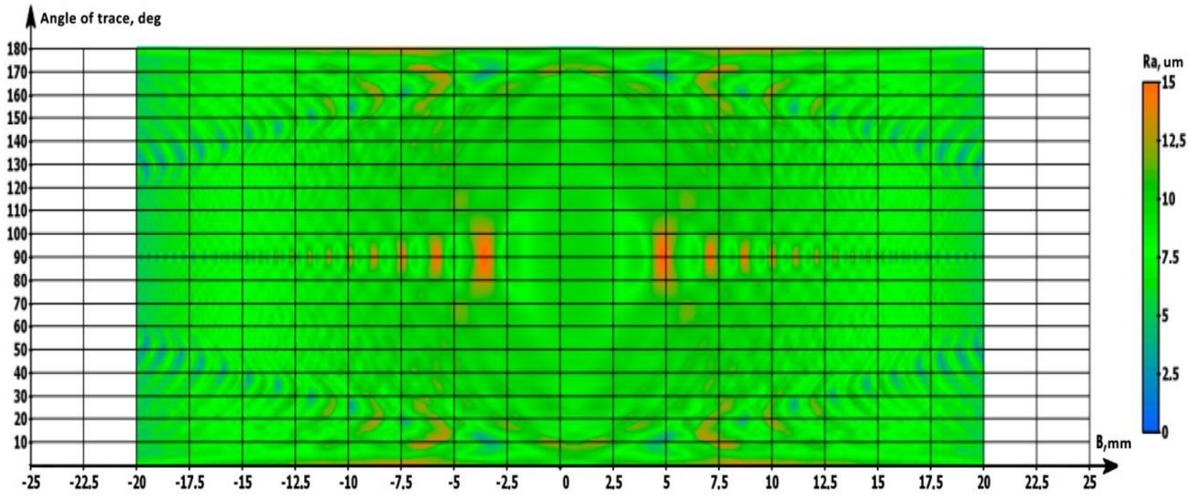

Fig. 5- Setting up the arithmetic average roughness height

The central area of the surface produced by face milling is likely to have rather different roughness with a relatively slightly varying value of feed to spindle revolutions per minute ratio (Figure 6).

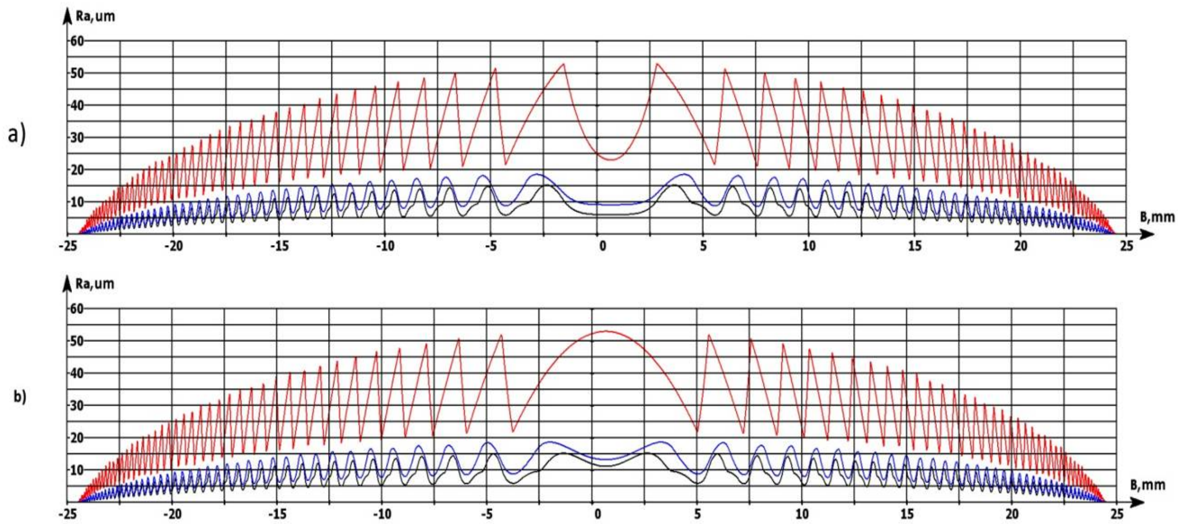

Fig. 6 – Height parameters with n=400 rpm for different feed values: a) S=1612 mm/min; b) S=1619 mm/min

Dependency graph of arithmetic average roughness height from feed per minute for cross-sectional position with B=0 mm shows that periodic coincidences of teeth motion trajectory in case of “backward” motion and previously made machining signs influence the character of the obtained dependence, it is expressed by local maximum height parameters (Figure 7). The local minimums correspond with a teeth pass in case of “backward” motion through the rest of micro irregularities.

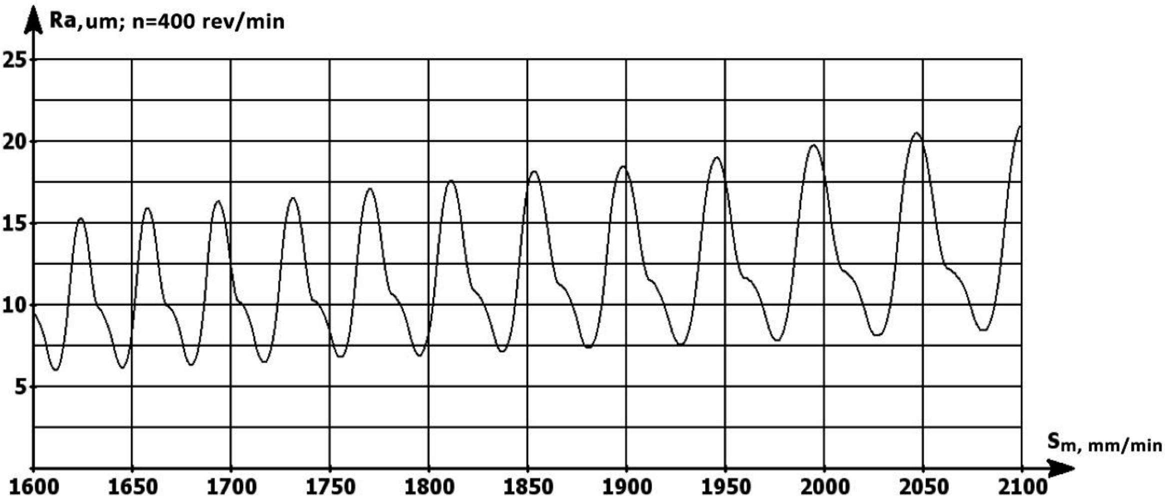

Fig. 7 – Dependency Ra in the central area from feed per minute value

Dependency of the maximum value Ra from feed per tooth which is shown in Figure 8, attracts a technologist in practical terms most of all.

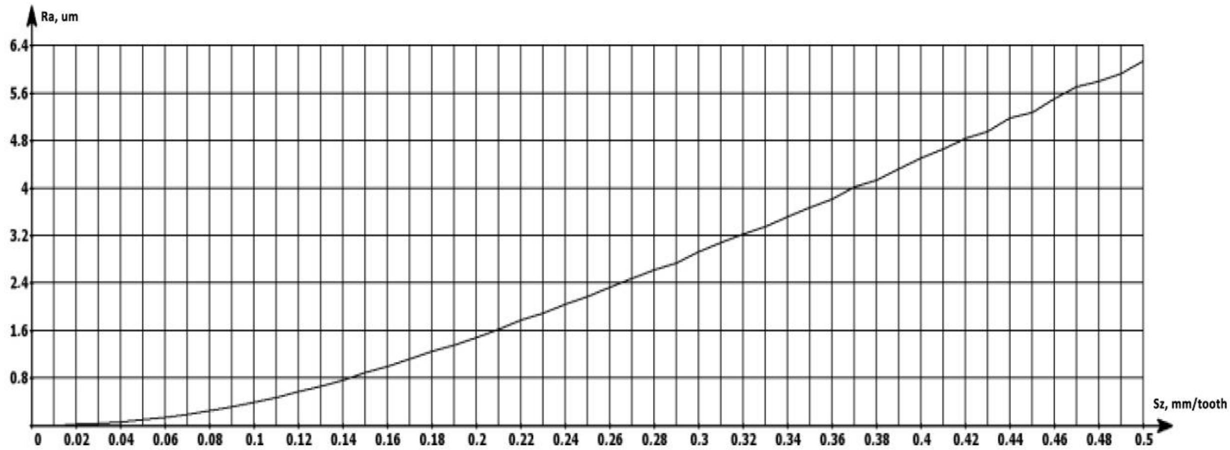

Fig. 8 – Dependency of the maximum value Ra from feed per tooth

This dependency is received due to mathematical analysis of the results of numerous numerical experiments conducted with the use of the developed model.

3. Experimental technique

To prove the possibility of practical using the results received while the work with the simulation model, a series of experiments was conducted under different cutting conditions with the cutters of different construction. The experiment was conducted on the milling machine GF2171 equipped with CNC FMS 3200, 24 pieces made of steel 1045 (AISI) were milled with cutting depth 1 mm. Roughness measurements were made with roughness measuring station Hommel Tester W55.

Table 1 – Experiment conditions and results

Cutting tool	Feedrate (mm/min)	RPM (min^{-1})	Ra (um)				tp (%)			
			Measured	Average	Calculated	Deviation (%)	Measured	Average	Calculated	Deviation (%)
Mill Ø50, 4 teeth, SCEA=23°, T15C6	F=630	S=800	1.39				33.8			
			1.47	1.44	1.46	1.4	32.9	33.4	31.4	5.9
			1.45				33.4			
		S=1600	0.45				29.9			
			0.43	0.42	0.38	9.5	30.5	30.3	29.0	4.3
			0.39				30.8			
	F=1000	S=800	2.97				36.2			
			3.03	3.01	3.09	2.7	36.9	36.1	33.6	6.9
			3.01				35.2			
		S=1600	0.90				30.7			
			0.89	0.90	0.96	6.7	30.9	31.0	29.6	4.5
			0.92				31.4			
Mill Ø100, 8 teeth, SCEA=23°, T15C6	F=630	S=400	1.36				31.4			
			1.42	1.39	1.45	4.3	31.9	31.2	30.4	2.5
			1.40				30.2			
		S=800	0.39				29.6			
			0.33	0.36	0.38	5.5	29.9	30.1	28.9	3.9
			0.37				30.9			
	F=1000	S=400	3.24				37.3			
			3.18	3.22	3.10	3.7	36.4	36.8	35.2	4.3
			3.25				36.8			
		S=800	0.94				29.8			
			0.99	0.95	0.96	1.1	31.2	30.6	29.6	3.3
			0.92				30.8			

The data received were mathematically analyzed and as a result the values of the arithmetic average roughness height and the relative carrying length of the profile were obtained. The data analysis showed that the differences of experimental and calculated by the model parameters are less than or equal 10 %, and the average value of deviations makes up about 5 %. Thus, the developed model fully affords the imitation of milling cutters operation.

4. Conclusion

1. Topogram analysis reveals that different positions of profile lines depend on far different values of roughness parameters.
2. Mathematical model provides the calculation of the surface roughness parameters rather accurate. The model has revealed the principles which illustrate as sufficient as possible the process of the surface topography formation in face milling according to a strict technological system.
3. Geometrical parameters dependencies of a part surface finish from milling input parameters received in the result of the numerical experiments can be used in design of milling operations by machining various parts.

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