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Simulation of the plain milling process

A Yu Nikolaev

Irkutsk National Research Technical University, 83, Lermontov str., Irkutsk, 664074, Russia

E-mail: AndrNikolajev@gmail.ru

Abstract. The article considers the dynamics of the plain milling process. The model takes into account the time-lag effect due to the algorithm of new surface formation during material cutting-off. A reduced model based on the results of a modal analysis of the milling cutter is applied to describe the dynamics of the tool. The results of the work are presented in the comparison of the microprofiles obtained as a result of processing and simulation of surfaces.

1. Introduction

Metal milling is a significant part of the production process. The study of the machining process aims to increase productivity and quality of processing [1-7]. The authors use different methods for research of metal processing. In paper [3], it is proposed to evaluate residual stresses in the surface layers of steels by x-ray diffraction and Barkhausen noise. One of the research methods is simulation. Development of the model of a correct machining process is the issue of the day. The authors of many publications present the simulation as an effective method for optimization of cutting conditions [8-10]. The works [9, 10] propose the method based on the study of vibrations that occur during metal processing.

When selecting simulation as the main research method, it is primarily required to create an adequate model, which clearly reflects the dynamics of the object. To obtain this model, it is necessary to describe the processing surface, workpiece, tool and laws, according to which the cutting force will change. These are basic, but not always sufficient blocks that should be present in the model. This model will not be accurate, and, therefore, it is not suitable for determining the optimal cutting conditions and correction of the NC machine tool control program. The problem of accuracy is solved by the complexity of the model, adding to it such additional part as the deviations correction. Further refinement of the model is possible when we introduce additional extra factors obtained by correlation with experimental data or derived ab initio. The creation of model that will do for simulating of regenerative vibration during cutting is basic object of research. The model may enable us to receive a clear picture of the machining process.

2. Materials and methods

In the case of plain milling simulation, a mathematical model depending on its complexity can take into account a number of mechanisms of vibration excitation which occurs during the cutting process [11-13]. For example:

- 1. Resonance of the chip breaking-off;
- 2. Self-oscillations due to the joint action of the cutting and friction forces;

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3. Self-oscillations due to a nonlinear descending character of the cutting forces depending on the cutting speed;

4. Self-oscillations due to the differences in the cutting forces at the entrance and exit of the cutter;

- 5. A mechanism of coordinate relation;
- 6. Self-oscillation during cutting the machined surface a time-lag mechanism.

In the work, we applied the approach of 'Simulation modeling' [14-15]. It consists in the numerical integration of equations of the system motion. For this purpose, the algorithm of geometric modelling with the determination of the instantaneous values of the chip thickness is given as the time-lag. It may be possible owing to retaining of the surface formation history. The time-lag mechanism underlies the developed model. The system time-lag is formed because of regeneration of the surface. Figure 1 is a schematic diagram of cutting process dynamics.



Figure 1. The scheme of cutting process dynamics.

To exclude errors during formation of the machined surface, it is necessary to consider the moments when the tool is entering and exiting the workpiece. For this purpose, in the algorithm, before the calculation of the chip thickness and cutting forces, we should take into consideration the relative position of cutting edges and the workpiece surface, thereby checking whether milling cutter teeth are in the metal or not.

During passage of the milling cutter tooth, the elastic movements of the tool are calculated (with allowance for specified parameters of damping, rigidness and mass) and formed by the machined surface. The next tooth passes on the newly formed surface. This approach allows one to take into account the variable chip thickness, and consequently to simulate regenerative vibration during the machining process. Later, that allows us to get an adequate picture of the machining process. The structure of the mathematical model is presented in figure 2.

Designations of the equation: M, C, K - matrices that define the dynamic model of the milling cutter; F[P, H, G, V(t), V(t-T)] – cutting forces; P – parameters of the processed material; H – parameters of the processing conditions; G – parameters of the milling cutter geometry; V(t) - dynamic movements of the milling cutter; V(t-T) - dynamic movements of the milling cutter with time-lag. To obtain tool dynamic characteristics used in the simulation, a modal analysis is performed.

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Figure 2. The structure of the mathematical model.

3. An experimental part. Modal analysis

The tool setup clamped in the spindle is presented in the form of a combined body which has mass, elasticity, resiliency and the ability to change the shape for a short time (Figure 3, a). Vibration of the setup, which has all these characteristics, can be divided into three main categories: free, forced and self-excitation.

Forced vibrations arise as a result of continuous external influences on the system. While the free vibrations are often represented in the time domain, the forced vibrations, as a rule, are analyzed in the frequency domain. This emphasizes the amplitude and phase dependence on frequency and permits to determine the natural frequencies. Vibrations with a relatively high amplitude occur when frequency of forced vibrations are close to the natural frequency.

The result of modal analysis is the stable cutting depth dependence on the spindle speed (Stability lobes). Cutting conditions, which reach within the area above the blue line, are unstable and accompanied by vibrations, modes located below the line theoretically should be stable by reducing the vibration component of the cutting forces.

According to the results of the performed modal analysis of finishing milling cutter AZ-3D16R6L65, made of hard alloy, the diagram of stability is built (figure 3, b). Modal analysis has been performed in the system 'Cutpro'.



a)

b)

Figure 3. Modal analysis of cutter AZ-3D16R6L65: a - studied instrumental setup; b - stability diagram.

Table 1 presents the machining process parameters, which are selected in accordance with the stability diagram.

Table 1. Machining process parameters				
Tool	Cutting depth, a _p ,	Cutting width,	Spindle	Feed, f _z ,
	mm	a _e , mm	speed, s, \min^{-1}	mm/tooth
AZ-3D16R6L65	20	0.5	15000	0.08



The machined surface has been measured on contact profilometer Taylor Hobson Form TalySurf i200. The results are presented in figure 4.

Figure 4. The surface obtained after the machining process.

As we can see from figure 4:

 $R_{max}{=}1.4 \ \mu\text{m}, \ R_{a}{=}0.24 \ \mu\text{m}, \ R_{z}{=}1.33 \ \mu\text{m}.$

Figure 5 shows the simulation result of the profile of the machined surface.



Figure 5. The surface obtained during simulation

In the program, the height of the workpiece was set to be equal to 50 mm; taking into account $a_p=20$ mm, we obtain the surface profile with:

 $R_{max} = |(30.0012-30)| + |(29.9998-30)| = 0.0014 \text{ mm} = 1.4 \mu \text{m}.$

That correlates with the experimental data.

4. Conclusion

The convergence of calculation and experiment is evidence of the correct reaction of the math model to the changing machining process parameters. The time-lag mechanism underlying the developed model allows us to obtain the surface with set-up parameters of the machining process quite accurately. That gives us the opportunity to adjust the machining process conditions to obtain the best

quality. The use of 'Simulation modeling' allows us to simulate regenerative vibration during cutting that gives the opportunity to receive a clear picture of the machining process.

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