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Modeling of thermal processes arising during shaping gears with internal non-involute teeth

N V Kanatnikov, P A Kanatnikova, V V Vlasov, A S Pashmentova

Orel State University, 95, Komsomoliska St., Orel, 302026, Russian Federation

E-mail: NKanatnikov@ya.ru

Abstract. The paper presents a model for predicting the thermal processes arising during shaping gears with internal non-involute teeth. The kinematics of cutting is modeled due to the analytical model. Chipping is modeled using the finite element method. The experiment is based on the method of infrared photography of the cutting process. The simulation results showed that the maximum temperatures and heat flows in the tool vary by more than 10% when the rake and clearance angels of the cutting are changed.

1. Introduction

Machines and mechanisms consist of parts that require complex machining, for example gears with internal non-involute teeth. Such details are used in torque transmitting mechanisms and connections: planetary gears, gear pumps, ratchet mechanisms, etc. Such details are used in construction and mining machines, agricultural machinery, aircraft industry, handling equipment, railway transport and other industries [1].

The geometry of the profile of the teeth of the internal non-involute gears is optimized to achieve the required performance properties. To processing of non-involute gears, a special cutting tool must be used. To reduce the negative influence of heat on the formation of the properties of parts and the tool's stability, it is necessary to understand the heat generation in the tool, workpiece and chips [2-5]. Of particular importance is the problem of rational selection of adjustable design and technological parameters of the system to ensure the required accuracy of processing and maximum tool life [6, 7].

This paper presents a model that allows virtual studies of the effect of design parameters of special gear cutters on the thermal phenomena that arise during processing. In the course of experimental studies, thermal phenomena in the cutting zone were estimated by infrared radiation.

2. Modeling

The input data for modeling are the geometry of the cutting edge of the tool, the geometry of the cut chip, the behavior of the material during deformation, and the conditions of contact between the workpiece and the tool.

Figure 1 shows the calculation schemes for determining the geometry of the cross section of the chips and the geometry of the tool. The resulted geometry of chips and the tool is typical at the conditions of shaping gears with internal non-involute teeth.

The geometry of the cut-off chips is given by an array of chips thickness values [a1, a2, ..., ai] in given sections, the values of the rake and clearance cutting angles are given taking into account their kinematic variation. The value of the chips thickness in a given section and the kinematic changes in the angles are determined by the method of the spatial mapping of the cutting scheme [8].

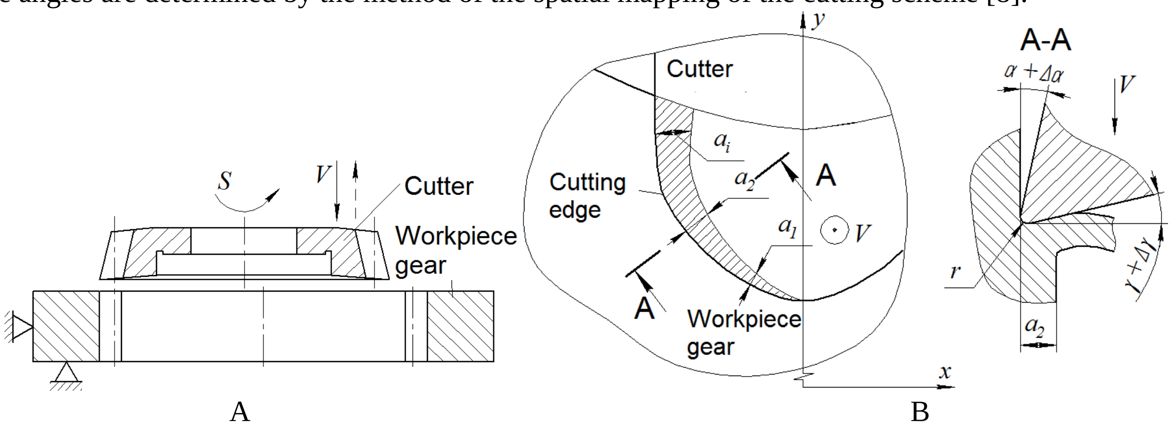

Figure 1. Calculation schemes for determining the parameters of the simulated process (A - scheme of the process of gear cutting, B - scheme for determining the geometry of the cut-off chips and the kinematic change of the cutting angles).

The modeling assumes the following assumptions: the workpiece is stationary, all the movement that necessary for shaping are made by the tool; the tool is absolutely homogeneous and absolutely solid; the surface of the tool has a homogeneous structure; the processed material has a geometrically and physically nonlinear structure. The deformation of the workpiece is described by the Johnson-Cook method using the von Mises yield criterion; the rolling takes place along the pitch circle of the wheel without sliding.

To simulate the cutting process numerically, the software package Deform3D is used. It allows to realize finite element analysis of cutting processes on the basis of an implicit Lagrange approach with continuous new mesh generation. In order to increase the accuracy of calculations in areas where the workpiece is subjected to an increased local load, a smaller grid that is continuously changing during the simulation is used. For friction definition the shear friction model is used [9]. The Johnson-Cook model is used to describe the deformation of the workpiece's material [10]. This model allows us to provide a fairly accurate description of the behavior of the material under conditions of large deformations in combination with high temperatures.

Modeling shaping gears with internal non-involute teeth was performed using the example of processing a gear with internal teeth of triangular profile, tooth height h = 2.2 mm, width of processed gear crown b = 2.5 mm, cutting speed V = 20 m / min. The material of the workpiece is 16MnCr5; the tool material is tungsten carbide.

In the process of carrying out a numerical experiment, options for changing the geometric parameters of the cutting part of the tool, namely the rake and clearance angels of the cutting, were considered. The change in the rake angle occurred in the range of 2 to 8 degrees in increments of 3. The change in the clearance angle occurred in the range of 5 to 15 degrees in increments of 5. The choice of these ranges is based on practical recommendations for selecting cutting angles for gear cutters.

3. Modeling results

Figure 2 shows the temperature field in the part of chips, which is cut off from the workpiece, at time t = 1.0 ms. The maximum temperature is observed at the chips root along the cutting edges. The temperature increases from the zone of the side surface through the radius of the rounding to the surface of the cavity. The highest temperature is observed in the intersection of the radius of the rounding and the surface of the cavity. However, there is no significant peak in the temperature distribution.

In the modeling conditions, the cutting edges of the tool are not subjected to an increased thermal load caused by complex chips formation since the temperature of the chips, which is cut off from different cutting edges, is not significantly different.

Figure 3 shows the temperature distribution on the front surface of the tool, at the moment of cutting t = 1.0 ms. The maximum temperature is observed in the radial rounding zone of the tool edge, the further cutting process shows that in this area the tool has the worst heat dissipation inside the tool, in comparison with the side and vertex cutting edges.

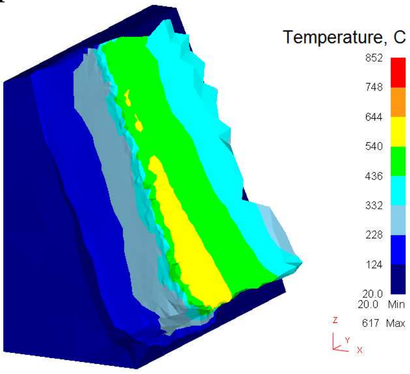

Figure 2. Field of temperature distribution in the chips at the moment of cutting t= 1.0 ms.

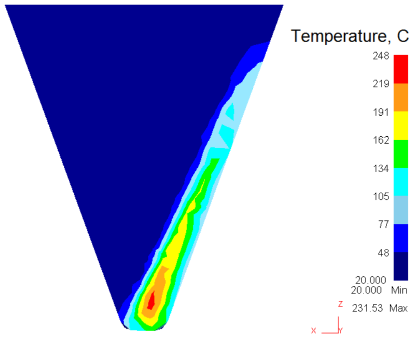

Figure 3. Field of temperature distribution on the front surface of the tool at moment t=1.0 ms.

4. Experimental research

For experimental studies, the authors used a special cutting tool, Figure 4. The cutting tool consists of a body (1) in which the cutters (7, 8, 9) and spacers (2, 3) are fixed. The accuracy of the position of the cutting blades relative to the axis of the tool is achieved by moving the cutters with screws (5, 6) in the desired direction. Fastening of cutters in the body is done with screws (4).

The relative positioning of the cutting blades of the tool tooth during cutting is reproduced with the help of cutters 7, 8, 9. Cutter 7 limits the lengths of the cutting blades of the tool. Cutter 8 is designed to guarantee a certain geometry of the cut metal layer by cutter 9.

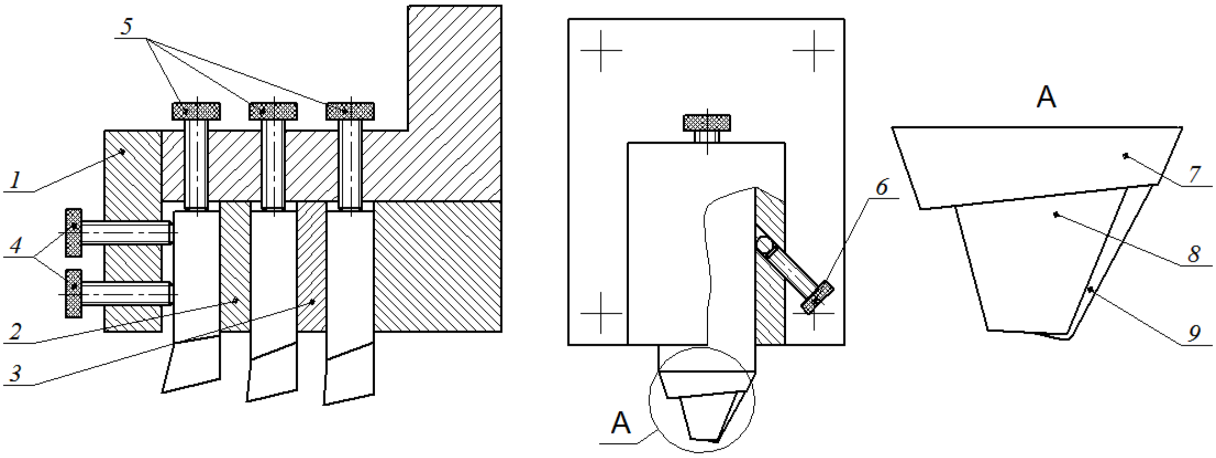

Figure 4. A scheme of the special cutting tool.

Nine different experiments were carried out with different combinations of rake and clearance cutting angels. The rake angel took the values: 2, 5 and 8 degrees, the clearance angle: 5, 10 and 15 degrees. Each experiment was carried out three times, the result was the arithmetic mean value. Table 1 compares the results of the numerical and real experiment. Differences in results do not exceed 10%.

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Table 1. Results of researching the maximum tool's temperature

Rake Angle γ, degree	Clearance Angle α, degree	The maximum tool's temperature, ºC	
		Modeling	Experimental
2	5	231	215
2	10	232	225
2	15	235	230
5	5	241	230
5	10	245	235
5	15	249	240
8	5	251	245
8	10	255	245
8	15	260	250

Figure 5 shows a comparison of the measured and simulated temperatures in the workpiece. The nature of the distribution of the temperature fields and the values of the maximum temperatures in the workpiece and the tool are corresponding. It should be noted that the measured temperature values in the chips are lower than the calculated values, and the temperatures and distribution of the temperature fields on the front surface of the tool cannot be accurately determined.

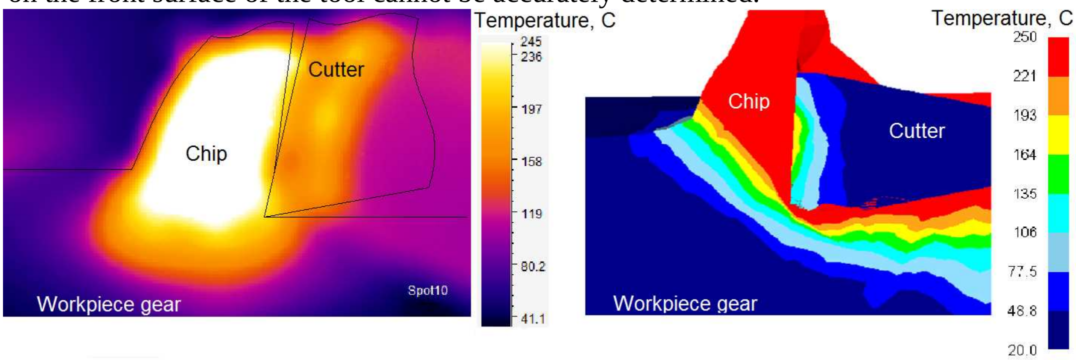

Figure 5. Measured and modeled temperature fields.

The graph of changing the maximum temperature in the tool, depending on the rake and clearance angles, is shown in Figure 6. The graph of the change in the value of the heat flow, depending on the rake and clearance angels, is shown in Figure 7.

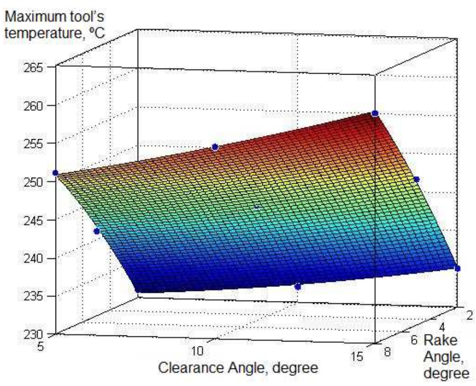

Figure 6. Graph of changing the maximum temperature in the tool, depending on the angle of inclination of the cutting edges.

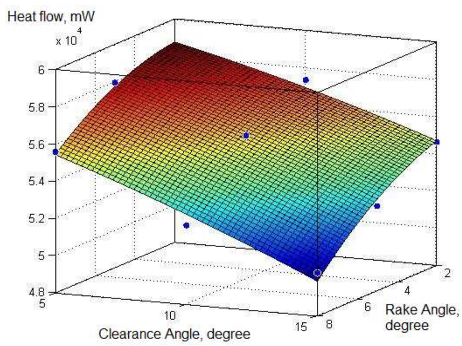

Figure 7. Graph of changing heat flow in the tool, depending on the angle of inclination of the cutting edges.

5. Conclusion

Thermal phenomena arising in the process of shaping gears with internal non-involute teeth have a significant effect on the quality of processing and the durability of a special cutting tool. It is necessary to predict the nature of thermal phenomena and take into account their influence on the process, as well as develop recommendations that reduce the negative influence of temperatures on the processing. The article presents a model of the process of shaping gears with internal non-involute teeth, based on the synthesis of analytical and numerical approaches to cutting research. Experimental studies carried out made it possible to verify the model of the process proposed by the authors.

Researches of the influence of adjustable design parameters (rake and clearance cutting angles) have shown that the maximum tool temperature and the distribution of temperature fields depend on their values. The values of the sharpening angles in the range recommended in the reference literature were studied. The maximum heating temperature of the tool changes by 12% in the specified range.

6. Acknowledgments

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