Research of thermal fields in the tools under end milling of titanium alloy BT6 with cooling

Dmitry Viktorovich Evdokimov, Dmitry Leonidovich Skuratov, Dmitry Gennadievich Federov

Samara State Aerospace University named for academician S.P.Korolev (national research university) (SSAU)
Moskovskoe chaussee, 34, Samara, 443123, Russian Federation

Abstract. The procedure of thermal field calculation in the end mill with considering of cooling lubricant supply to the cutting zone, based on CAE technology, which can be used to calculate the thermal fields in almost any edging cutting tools. An example of calculation of the thermal field in the end mill is given when processing of constructive titanium alloy BT6.

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Introduction

The tendency of current technology development, and in particular aviation-related, aims to increase the resource of the parts and products in general at reducing the part weight and labor input for their production. This set goal can be achieved only on the basement of joint solutions of engineering and process tasks. Herewith nowadays the design idea is significantly ahead of the ability of production, and this means that the production technology requires a substantial improvement, use of the new processing methods, new techniques and approaches to the development of the processes.

Area of concern in the field of production is relatively low research of physics of the cutting process and formation of the surface layer. At the same time, in-depth research of physics of force and thermal phenomena in the edge cutting and abrasive machining of workpieces [1-7] is able to give the necessary information for development of measures aimed for reducing of the operation cost and improving of the quality of machining.

The self-cost of the operation is influenced by two main factors, which depend upon the cutting conditions: these are processing performance and costs associated with the operation of the cutting tool. On the one hand, the more intensive is the cutting mode, the higher is the processing performance, and, on the other hand, the higher is the processing performance, the higher is the temperature in the cutting zone, more intensive wear rate of the tool and thus higher operating costs of the cutting tool. So you can select a cutting mode, at which the self-cost of machining will be minimal.

Resource of the parts is strongly influenced by the residual stresses generated under influence of force and temperature field impacts. In this case the dominant influence on formation of residual stress is made by the force factor [7], if structural and phase transformations have not taken places in the surface layer.

In connection with the abovementioned provisions, the objective was set, which consists of development of the procedure that makes possible to calculate the temperature distribution by the volume of the cutting tool with high accuracy and minimal labour intensity for the cutting process conditions and including on the contact surfaces. Awareness of the temperature distribution on the contact surfaces is necessary firstly to assess the operating conditions of the cutting tool and secondly, to determine the change of thermophysical properties of the workpiece material which are necessary, for example, to calculate the residual stresses.

Procedure of calculation of thermal fields in the tool

The end milling process was chosen as a subject of research. To achieve this goal it was decided to develop the previously mentioned procedure based on CAE technology. CAE acronym determines for Computer-aided engineering and usually the programs, supposed under this name, are intended for analysis of the stress and thermal conditions of the parts as well as calculation of the flow processes properties. The last listed function of CAE programs is included in the chapter of continuum mechanics and is referred to as" computational dynamics of fluid" or «Computational fluid dynamics» (CFD - calculation).

The thermal calculation of the tools and workpieces for conditions of end milling in the work [4] was carried out in ANSYS program in module Thermal, taking into account supply of the cooling lubricant (coolant) in the cutting zone, but without simulating of its movement. However, it is very crucial to analyze the sizes of the cutting tools and the workpieces, which receive coolant. This action makes possible to increase the accuracy of the calculation of thermal fields in the cutting zone due to integration of coolant parameters in system ANSYS. To solve this problem just been involved CFD – calculation was involved just for solving this present problem.

Implementation of simulation of the cooling process at the end milling and numeric calculations of thermal fields in the tool was preceded by creation of virtual computer model both for the mill itself and the supply system of cooling lubricant (coolant) in the cutting zone, but also of the working zone of the machine filled with coolant and ambient air. The size of air zone was defined so that when splitting of the zone into finite elements, the effect of the border does not give an impact on it.

Development of the virtual model of the system, consisting of a mill, device for coolant supply and directly coolant and ambient air in the zone of consideration, was performed in the software package of automation design system SolidWorks. The result of structure of this model is shown in Fig. 1.

The structure of this model is the first step in the developed procedure of calculation of the thermal field in the cutting tool and, accordingly, on its contact surfaces.

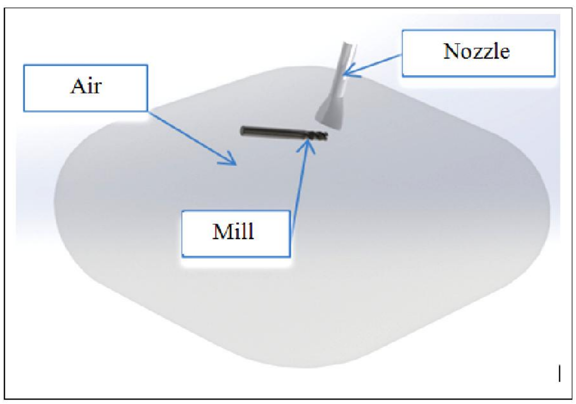

Fig.1. Model of the system: mill, device for coolant supply and working zone of the machine with coolant and ambient air

In the second stage of the mentioned before procedure, import of this virtual model in the program ANSYS is performed. At this stage, certain difficulties were faced which lies in the fact that when the model of the system is loaded into module «ANSYS Geometry» data loss occurred, which led to errors. To eliminate these difficulties it was proposed to replace the tool complex surface geometries, such as spiral grooves of mills and similar to them surfaces on more simple. This measure somehow made worse the mill geometry, but it is allowed to import the geometric model of the mill into ANSYS environment without loss of information.

Research of thermal fields in the tool under end milling, for example, by using CFD - ANSYS module or on the basement of usage of the other methods is possible only with awareness of density of heat flows coming into the tool. As it is known the heat flows come into the tool through the contact surfaces that occur during cutting in the front and rear surfaces of the mill teeth. The teeth of the end mills are arranged on the cylindrical part and at the end. As the heat flow density is defined as the ratio of the heat flow capacity to the contact area, so, accordingly to determine the heat flow density in the front and rear surfaces of the mill teeth it is necessary to know corresponding heat flow capacity and the area of contact of the tool with cuttings and the tool with the workpiece.

Capacities of heat flows on the front and rear surfaces of the mill teeth were determined on the base of using of the calculated dependences presented in the work of Professor A.N Reznikov [1-3]. On the basis of these dependences the algorithm and the program of calculation to determine the capacity of heat flows on the front and rear surfaces of the teeth of the examining tool. The calculation was carried out in software MathCad.

To determine the contact area of the front tooth surface with the cuttings and rear surface of the mill tooth with the workpiece, it is necessary to know the respective lengths of the contact. [8] It was therefore decided to determine these parameters basing on the simulation of the cutting process. Module «Explicit Dynamic» of the software package ANSYS was used to simulate the cutting process. The moment of simulation of the workpiece processing with the mill is shown in Fig. 2.

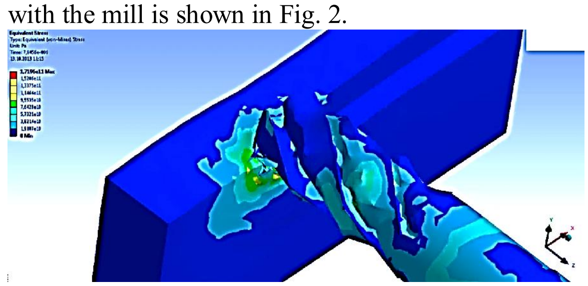

Fig. 2. Moment of processing simulation created in the software package ANSYS

Structuring of the virtual model shown in Fig.1 to the finite elements was produced in module «MESH» of program ANSYS [9, 10]. Thereby due to that the virtual model represents two separate bodies which are in contact with each other at a very complex surface, some difficulties appear with creation of finite element mesh. Mesh for the system must be applied such a way that these bodies were conjugated. Otherwise, the calculation of thermal fields becomes impossible.

In the present procedure these mentioned problems were solved complexly with using different approaches. One of such approaches was using of the module «Finite Element Modeler», which is a part of the program ANSYS. Taken into consideration of the previously stated, airspace instead of the spherical form acquired elliptical form. Part of the finite element model of the virtual system is shown in Fig. 3.

A key stage in the developed procedure of calculation of thermal fields in the tool is work in the module «CFX», which is part of the program «ANSYS» [11, 12].

Virtual model of the system consisting of a mill, coolant and ambient air is essentially a multiphase. That is, it comprises three components, that is: air and emulsion at 20 degree Celsius that corresponds to the temperature of industrial premises and tool material from which the mill is made, also taken at an initial temperature of 20 degrees Celsius [4].

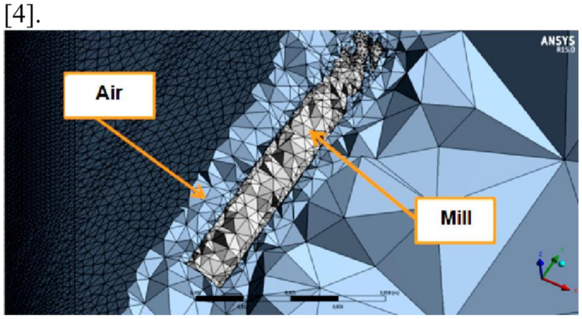

Fig.3 Part of the finite element model of the virtual system

The initial values of the temperatures and also the values of the working pressure of the pump and the atmospheric pressure in the module «CFX» were taken as boundary conditions (boundary condition).

Preliminary, in module «Geometry» the traces, limiting surfaces which are identical to contact zones of the mill with cutters and a workpiece during the cutting process, were generated on the shank of the mill by means of three-dimensional figures (cylinder, cone, cube, etc.). Fig. 4 the zone of contact of the front surface of the mill tooth with cuttings is indicated with the full line.

The final view of the system virtual model with completely defined boundary conditions is shown in Fig. 5, and the final view of the mill being a part of the virtual system, is shown in Fig.6. Arrows in Fig. 5 represent the specified boundary conditions for a particular flat surface and the arrow on the mill (see Fig. 6) represent the contact of the air and coolant with the mill surface.

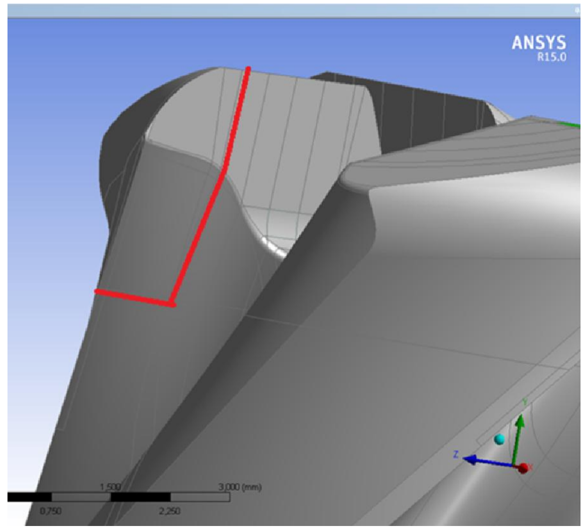

Fig.4. The contact zone of the mill tooth front surface with the cuttings

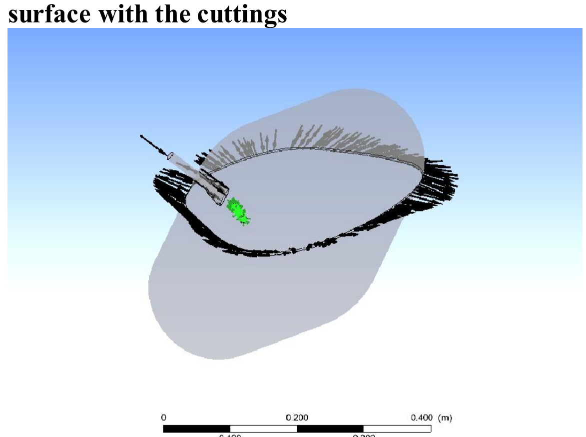

Fig.5. Final view of the virtual model of the system with fully defined boundary conditions

The gravity was determined in addition to these boundary conditions for the system. That is, for modeling of heat transfer between the coolant mill and air cutter the function of heat transfer (heat transfer) was included - thermal energy (thermal energy).

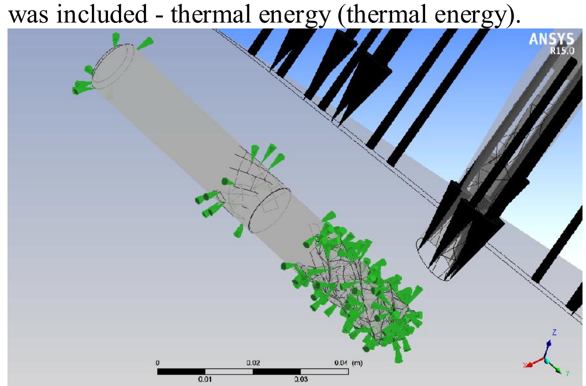

Fig. 6. Final view of the mill being a part of the virtual system

The main part

In accordance with the developed procedure the calculation of the thermal field in the hard-face end mill was made when processing structural titanium alloy BT 6 on the mode: cutting speed − υ = 30 m/min, feed per mill tooth − S_z = 0.08 mm/tooth, depth of cut − t - 3 = mm, milling width − B = 5 mm. The calculations were made with taking into consideration of cooling lubricant supply to the cutting zone. The results of the calculation of the temperature distribution on the surface of the tool is shown in Fig. 7, and the coolant temperature and the ambient air in the zone of the virtual model is shown in Fig. 8. The temperature value is given in Kelvin degree in these figures.

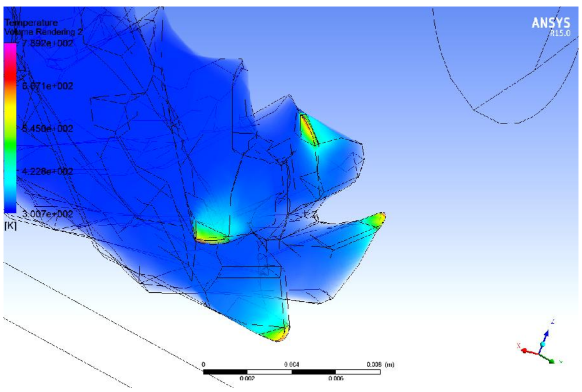

Fig. 7. Temperature distribution on the surface of the tool with taking into consideration of the coolant supply to the cutting zone

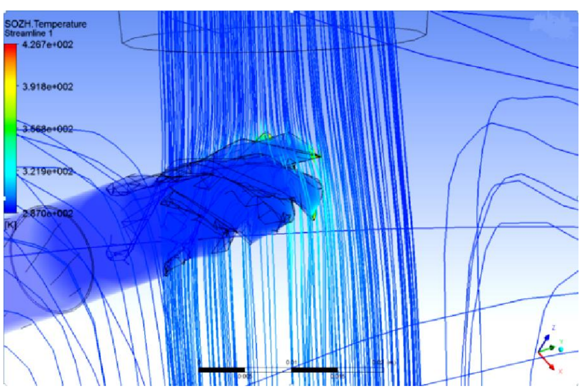

Fig. 8. Coolant temperature and ambient air in the zone of the virtual model

As can be seen from Fig. 7, the highest temperature values, equal to 789 K (516), take place in the zones which are adjoined to the cutting edges of the mill. It should be noted that the received results of the temperature are in very good correspondence with the values calculated from the empirical dependence, given in the work [13], and which is intended to determine the temperature in the cutting zone for conditions of the end milling of the titanium alloy BT 6. The calculation results obtained with using of the module CFX of software package ANSYS [14], and the calculation results obtained on the basement of using of an empirical dependence (517) differ only by one degree.

If necessary, the distribution of the temperature values may be obtained for any section of the end mill.

As seen in Figure 8, the coolant in some zones of the virtual system is converted into superheated steam with maximum temperature of 426 K (153 ^oC). Thus the temperature of the coolant will have a value of approximately 320 K (47) under the conditions of a steady state process.

Conclusion

The produced procedure for calculating of the thermal fields in the end mills at cutting of the materials with considering of coolant supply into the processing zone, which is based on CAE technology can also be used to calculate the thermal fields practically in any edge cutting tools. At that, the time spent on the calculation of thermal fields in the tool is much less than the time required to prepare and perform a full-scale experiment and calculation accuracy is more than sufficient in comparison with that required one for engineering calculations.

Resume

The procedure of calculation of thermal fields in cutting tools based on CAE technology is developed, which provides high convergence of the results of numerical and full-scale experiments.

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Corresponding Author:
Dr.Evdokimov Dmitry Viktorovich
Samara State Aerospace University named for academician S.P.Korolev
(national research university) (SSAU)
Moskovskoe chaussee, 34, Samara, 443123, Russian Federation

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