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FINITE ELEMENT THERMAL SIMULATION OF A CNC MILLING MACHINE

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Abstract: This article concerns a thermal simulation of a 5-axis CNC milling machine by finite element method. At the early stage of a machine designing process, the analysis of thermal conditions is really important, because milling machines are exposed to heat effects. The result of it is a nonstationary temperature field, which can influence accuracy of positioning and it can generate thermal stress in the structure of machines. Besides harmful heat effects can decrease geometry accuracy of manufactured product, but making thermal analysis quality and lifecycle of products can be higher and planning time can be reduced.

Keywords: *thermal simulation, analysis, temperature field, accuracy, quality of product*

1. Introduction

Heat is appearance of energy in termodynamics, which occur between system and environment by difference of temperatures. In fact, heat sources in machine tools are energy sources which provide heat energy. Transfer of this energy can be realized by 3 different ways: conduction, convection and radiation. Conduction is vibration of molecules of material parts, convection is when atoms moves in macroscopic measure. Radiation is when electromagnetic radiation turns into heat energy.

2. Description of temperature fields

In this section we detail the theory of temperature fields. Based on it, we can get information about distribution of temperature in machines. Generally temperature is a physical quantity as function of location coordinates as well as time coordinate

$$t = t(x, y, z, \tau). \tag{1}$$

Using this function, we can get temperature distribution over the domain realized by the investigated machine. As the result of time dependency, heat is treated as a transient problem. In that case when the time is fixed, the temperature field is stationary, hence the following functions are available

$$\begin{gathered} t = t(x, y, z) \\ \frac{\partial t}{\partial \tau} = 0. \end{gathered} \tag{2}$$

2.1. Specific transient curves of machine tools

At starting the machines heat generation begins from different heat sources on machines. During the process, the units continue heating and form a constantly changing temperature field. By examining the equilibrium of heat quantities, it is possible to determine the warming curve, a temperature vs. time diagram that shows the way that the particular machine parts reach the constant temperature eventually. Practical warming curves may differ from the ideal, such as the starting grease-lubricated spindles shown in *Figure 1*.

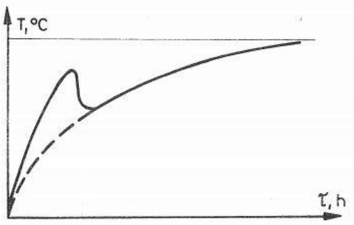

Figure 1. Ideal and practical warming curves [1]

3. SOLVING THERMAL PROBLEMS USING FEM (FINITE ELEMENT METHOD)

From a mathematical approach, the finite element method work with partial differential equations to solve engineering problems. We can use static, dynamic, vibration, thermal analysis and so on, and, besides, we can evaluate the simulation results and, moreover, product optimization is also possible. You can get information about faults during manufacturing process, and it is possible to draw up development directions. FEM is a complex way to analyse and solve thermal problems for example.

3.1. Thermal analysis of DMU40 milling machine

In this section the thermal analysis of a 5-axis CNC milling machine is presented. The investigation of the behaviour of a machine tool during milling process is performed. The 3D model of the machine tool is created first of all, then the influence of the milling tool, the workpiece, and several mechanical and thermal boundary conditions, like working temperature of bearing, cutting forces and temperatures, effect of cooling lubricant have been considered. Figure 2 shows the 3D model of analysed machine tool.

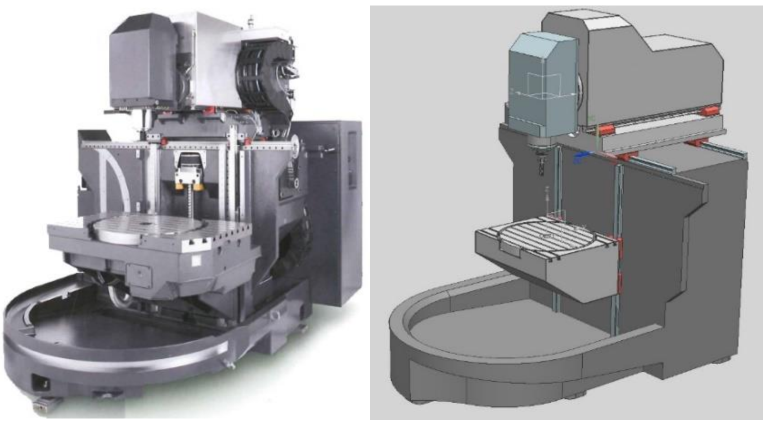

Figure 2. Result of the geometry modelling process – milling machine 3D model [2]

The analysed process is a primitive milling process using WIDIA Warimill 4777 tool with the following technological parameters. Diameter of tool is $D_1 = 20\ mm$, cutting speed is $v_c = 150 \frac{m}{\min}$ and the depths of milling are $a_p = 2\ mm; a_e = 10\ mm$. *Figure 3* shows the milling tool and sketch of the milling process.

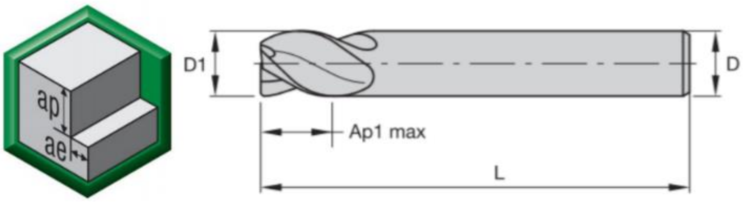

Figure 3. Sketch of milling process and used milling tool [3]

4. Simulation results of the thermal model

In this chapter a finite element model of DMU40 milling machine using ANSYS software is created. The previously defined boundary conditions, loads, material types, etc. have been assigned tot he model. Then the meshing of the model was generated, then the finite element methods is applied to determine the temperature distributions and to analyse thermal stresses and deformations caused and coupled by thermal and mechanical loads.

It is observed that the maximum temperature appears nearby the contact zones of the milling tool and workpiece. The spindle and further precision units have also loaded by the heat significantly. *Figure 4* shows the effect of cutting temperature during process and temperature field around headstock.

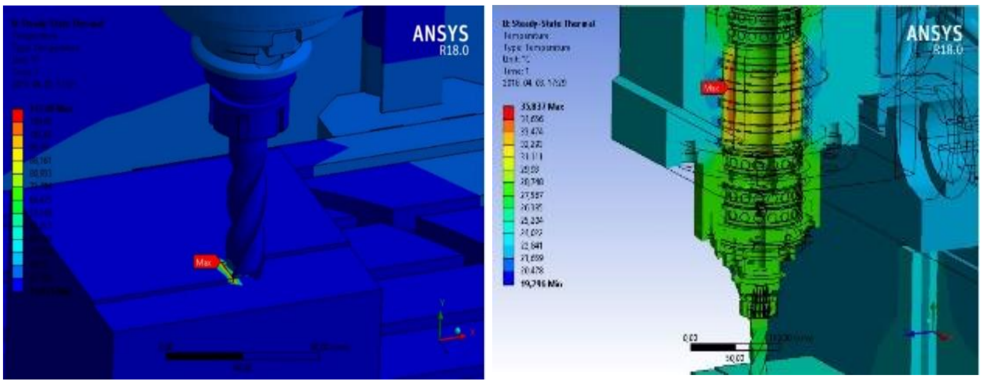

Figure 4. Temperature fields during milling process

Besides, the thermal stress during the milling process was also investigated by the finite element software. We can see that significant stress values can occur around milling tool and workpiece. These effects can dicrease lifecycle of tool and they can reduce quality of product.

Figure 5 shows stress field during process. The deformations in several directions and displacement magnitude were analysed, too. Around milling tool and workpiece there is almost homogeneous deformation field with approximately $60 \mu m$ displacement magnitudes. This kind of displacements distribution is advantageous, because we can reduce errors from heat and mechanical effects with easy direct- or indirect compensation algorithms.

Using direct compensation we measure thermal deformations directly with sensors and compensate this errors by modify NC codes of milling process. With indirect compensation algorithms first we create a mathematical thermal model of machine. Combine this model with compensation algorithms we can modify NC codes in real-time during process. Using these methods thermal errors can reduce and accuracy of product can be higher. We can see on *Figure 5* stress field and deformation field during process on machine tool.

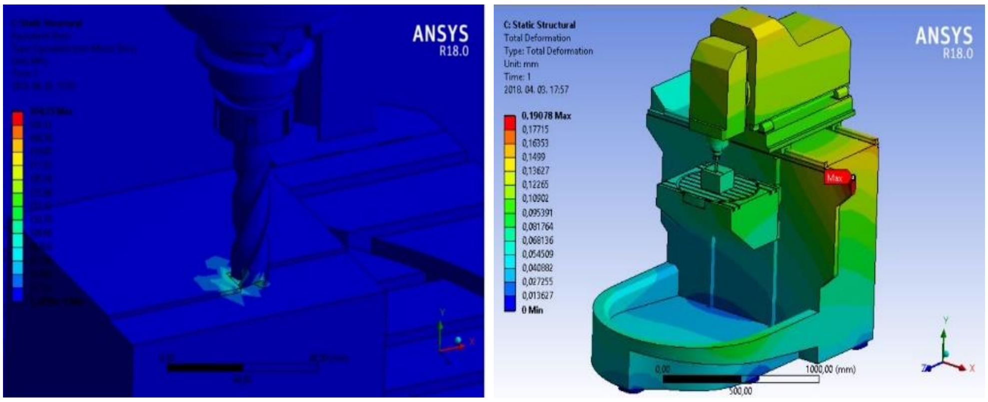

Figure 5. Stress-and deformation fields during milling process

In these figures it is seen that the geometrical 3D model of the machine tool was created as much accuracy as it was necessary, because we wanted to analyse the milling process with real working conditions. A really detailed model however, will increase the calculation time of simulation, and it can be much higher, but the most important is to get a valid simulation first of all.

In this chapter the TCP (Tool Center Point) thermal deformation is also analysed at any working conditions. We used a spindle rotational speed – time function as input parameter. Using ANSYS finite element software we created TCP temperature curve in time and after that I made a simulation series with these parameters. Finally a thermal deformation curve in radial-, and axial directions in time has been obtained. This mathematical model can give a lot of information about milling machine during processes. We can get idea about heat sources, heat conditions, critical structure elements, etc. and it is also possible to draw up some develop directions in machine plannig process.

Figure 6 shows the mentioned mathematical model for TCP thermal deformation.

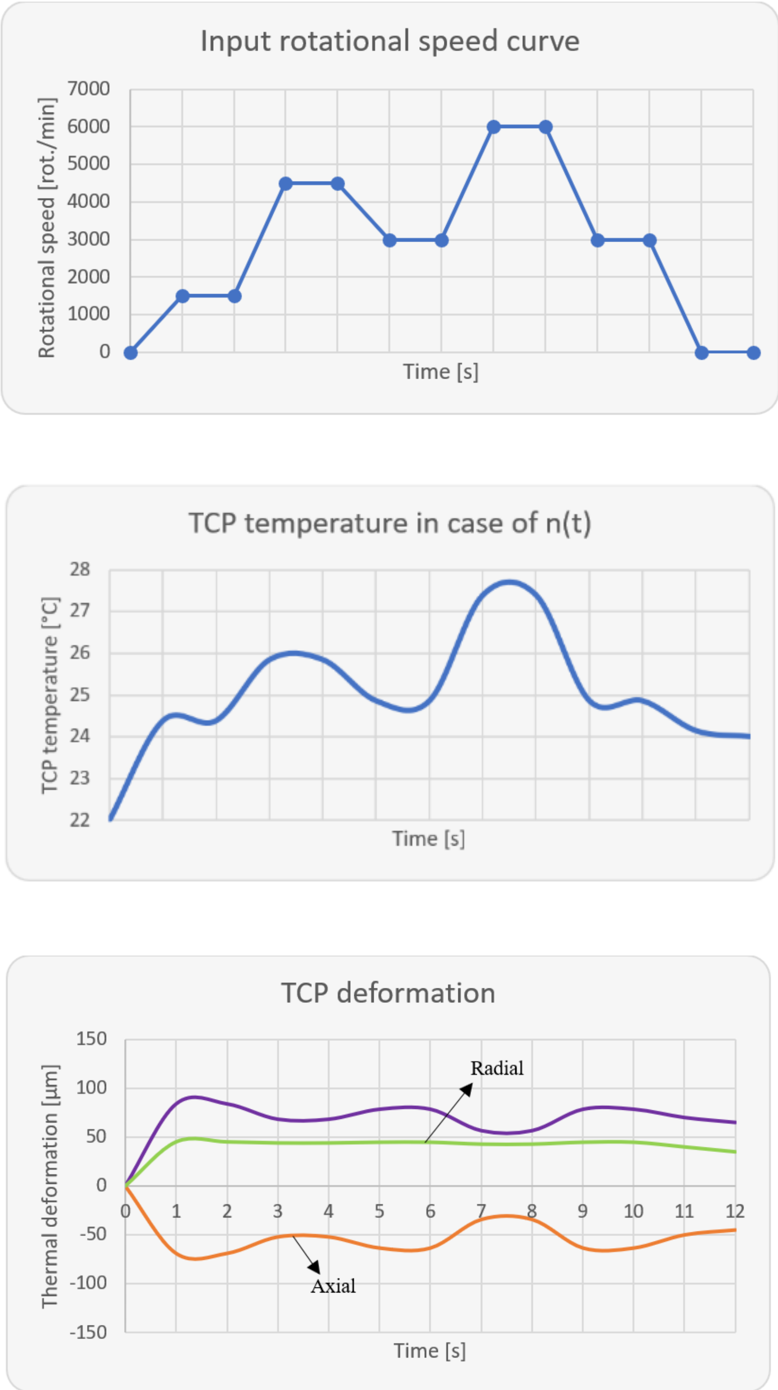

Figure 6. TCP thermal deformation curves used simulation model

5. SUMMARY

In this article an FEM analysis of a 5-axis CNC milling machine during process was performed. First we presented description of temperature fields and warming curves of machine tool units, too. After that we showed a finite element method to solve thermal engineering problems. We created the 3D model of analysed machine tool and we run a complex simulation in ANSYS finite element software. Then the temperature-and stress fields around milling tool and workpiece is presented, besides we also examined displacement fields. and created a mathematical model for TCP thermal deformation in axial and radial directions.

Using these thermal-mechanical analyses we can increase quality of product and reduce thermal errors which can cause geometry inaccuracy in manufactured products. Finite element methods and analysis of machines can also dicrease costs and construction time, so they are really important means at early stage of a designing process.

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