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A thermal modeling to predict and control the cutting temperature. The simulation of face-milling process

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Abstract

This paper presents a new procedure to evaluate the cutting temperature milling.in HSM. The study of the thermal behavior is important because the life expectancy of a cutting tool is limited by its temperature: the higher the temperature, the shorter its life. Tests made on many uncoated tools at stand still, after milling, have shown that there is an important drop for the temperature measured values. This is due to the ventilation phenomenon which was created by the rotation of the mill, which, in turn, requires the knowledge of the global overall coefficient of heat transfer at the tool interface as a function of the cutting conditions in order to predict the cutting temperature. The performance of the model is compared to the analytically and numerically (FEM) determined performance of a cutting tool with boundary conditions or to the experimentally determined performance and the results obtained are in good agreement [12].

Keywords: milling; nonlinear equivalent resistance; cutting temperature; finite difference method; modified lamped capacitance method.

1. Introduction

During machining, heat is generated at the cutting point from three sources. Those sources cause the developments of cutting temperature:

- Primary shear zone where the major part of energy is converted into heat.

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- Secondary deformation zone at the chip–tool interface where further heat is generated due to rubbing and/or shear. At the worn out flanks due to rubbing between the tool and the finished surfaces. LOWEN and SHAW [1] have shown that the heat generated is shared by the chip, cutting tool and the workpiece.

The apportionment of sharing that heat depends upon the configuration, size and thermal conductivity of the tool-work material and the cutting condition. The maximum amount of heat is carried away by the flowing chip. From 10 to 20% of the total heat goes into the tool and some heat is absorbed in the workpiece[1]. With the increase in cutting velocity, the chip shares heat increasingly. The effect of the cutting temperature, particularly when it is high, is mostly detrimental to both the tool and the workpiece[2].The major portion of the heat is taken away by the chips. So attempts should be made such that the chip takes away more and more amount of heat leaving small amount of heat to harm the tool and the work. The possible detrimental effects of the high cutting temperature on cutting tool edge are:

- Rapid tool wear, which reduces tool life, Plastic deformation of the cutting edges of the tool material is not enough hot-hard and hot strong.
- Thermal flaking and fracturing of the cutting edges due to thermal shocks.

And the possible detrimental effects of cutting temperature on the workpiece are:

- Dimensional inaccuracy of the workpiece due to thermal distortion and expansion-contraction during and after machining.
- Surface damage by oxidation, rapid corrosion, burning etc.

Cutting temperature can be determined by three ways:

- Analytically using mathematical models for thermal field which can be developed. This method is simple, quick, inexpensive but less accurate.
- Experimentally, this method is always used because it is more accurate, precise and reliable.
- Numerically, this technique is widely used tools for thermal machining simulation and benefits the reduction of the cost and increase technical performance. Many researchers have developed models and studied, mainly experimentally, on the effects of the various parameters on cutting temperature like: work material, process parameters, cutting tool material, tool geometry and cutting fluid. A well established overall empirical equation is:

$$T = \frac{0.4U}{\rho C}\left(\frac{vt_o}{K}\right)^{0.333} \tag{1}$$

Where T = temperature-rise at tool-chip interface; U = specific energy; v = cutting speed; t_o = chip thickness before cut; ρc = volumetric specific heat of work material; K = thermal conductivity of the work material.

Recently, Lazohlu and Altintas4 [3] have applied the FDM, finite difference method, for the first time for the prediction of steady-state tool and chip temperature fields in continuous machining and transient temperature variation in interrupted cutting (milling) of different materials such as steels and aluminum alloys. A combination of grids in Cartesian coordinates for the chip and in cylindrical polar coordinates for the tool like in Refs5.[4]. The analytical approach to temperature modeling is difficult to apply to milling due to the intermittent cutting process and the varied thickness. Jaeger and Carslaw and Jaeger [5] introduced the heat source method for solving a variety of heat transfer problems for orthogonal cutting. The Jaeger moving heat source model has been modified and developed to represent the physical characteristics of peripheral milling, and has described how it can be applied in an industrial context to model workpiece temperatures due to peripheral milling. This intermittent heat is represented as a band of heat because the teeth move rapidly through the material and the time between cutting teeth is constant [6]. This model should be applicable to the milling of other materials such as titanium and carbon composites. The thermal impact to the cutting tool during heating is larger in down milling than in up milling [7].

Versions of a system equivalent circuit are commonly used in the manufacturing industry, due to its simplicity and its ability to provide reliable results,. This paper describes how it can be applied to model a tool when milling. The tool thermal model is based on the equivalent circuit. A simple RC circuit is employed to predict the cutting temperature. In the thermal model, all heat losses tool are represented by a current source injecting heat into the