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Procedia CIRP 58 (2017) 97 – 103

www.elsevier.com/locate/procedia

16th CIRP Conference on Modelling of Machining Operations

Heat sources and fluxes in milling: Comparison of numerical, analytical and experimental results

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Abstract

The paper describes the comparison of numerical solution, analytical approach and experimental results calculating heat sources and heat fluxes in a milling process with the aim of the calculation of the temperature distribution. Analytical solutions for standard geometries are superposed in order to represent the tool best possible. Exposed with the heat sources calculated by finite element simulation of the interrupted chip formation process the solution of these analytical representation is compared with numerical ones. These have been investigated in previous research on a consistent numerical simulation method for calculation of heat sources and fluxes in milling. Both models are fitted and verified by cutting experiments.

Keywords: Finite element Method; Simulation; Analytical solution; Experimentation

1. Introduction

Nowadays dry machining operations play an increasing role in manufacturing due to environment, health care and economical requirements. These exigencies stand in contradiction to minimization of tool wear caused by high process temperatures and tool deformations caused by these high temperatures.

In precise machining operations controlling the introduced heat is important to keep the tool center point (TCP) displacements constant and exactly known [1,2]. For the estimation of these thermal deformations in tool and clamping devices heat generation, partitioning and temperature distribution in machining has to be well known.

On this question a lot of scientific works have been realized about generated heat (Shaw [3] among others), heat fluxes and their partitioning in tool, workpiece and chips (Takeuchi et al. [4] and Blok [5], among others).

Because the direct measurement of the cutting temperature is complicated and improper and of heat fluxes is even less exact [6] in this publication a semi-analytical/numerical approach has been chosen which has been adjusted to measured values.

For this the authors their selves used relevant investigation summaries in their work to a purely numeric approach of heat distribution and resulting deformations in milling operations as an interrupted cutting process [7]. In this investigation the numeric outcomes are complemented by an analytical approach based on simplified assumptions. The FEA approach itself has, in comparison to the analytical solution, no principal limitations in geometry but requires about material behavior as well as contact and boundary conditions. Herein heat transfer coefficients (HTC) between tool and workpiece and to the surrounding play a key role.

doi:10.1016/j.procir.2017.03.200

2. Experimental Study

Regarding experiments in publication [8] (dry down-milling operation on S235 steel with three uncoated WC inserts) the temperatures in the tool are investigated. Based on the chosen parameters for v_c=100 m/min and v_c=200 m/min the results are used for comparison with the numerical and analytical model. So far, only the temperatures in the workpiece with locally placed thermosensors could be considered and used for a comparison. For the temperatures in the tool, data from a thermal image are now evaluated. This is accomplished in three central steps.

1. Definition of a search field with which the front side local values in the temperature field can be identified
2. Locate and counting the maximum values for each time step
3. Transfer of the measured values into a function equation by regression analysis

While the tool is moving along the workpiece, at the same time, real images and thermographic data are recorded at defined time intervals (see Fig. 1).

Fig. 1: Experimental setup and thermal image.

In the following an algorithm for evaluating the measured temperatures at the tool is applied (see Fig. 2). First, all temperature values of the thermographic shot are read in at each time step. Subsequently, local search fields are defined which represent the range of the temperatures acting on the front side (see Fig. 1). These are defined in each case, so that the three cutting edges of the tool and the workpiece can be mapped. In Fig. 2, at the top left, all accumulated data is shown for the respective search field. The maximum values for each time step are then detected (see Fig. 2, bottom left) and are documented in tabular form for the tool as well as the workpiece. With plausibility conditions, an error analysis such as the finding of chips flying in the image area can be carried out.

By means of regression analysis, it is possible to transfer the faulty values into a functional correlation. The regression is based on the function:

$$f(t) = a \tanh(bt + c) + d \quad (1)$$

Consequently, the optimization problem can be solved for the smallest error squares.

$$\min_{a,b,c,d} F(a,b,c,d) = \frac{1}{2}\sum_{i=1}^{n}(a \tanh(bt_i + c) + d - y_i)^2 \quad (2)$$

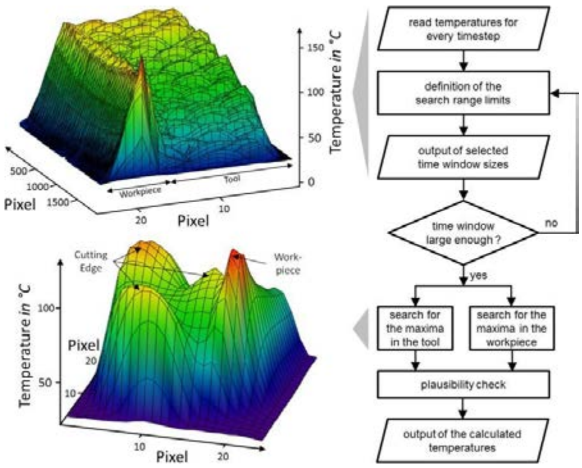

Fig. 2: Temperatures and flow chart of the experimental investigations.

The solution of the analysis requires estimated start values, which are listed in Table 1.

Table 1: Estimated and calculated values for the basic function.

v_c	Values	a	b	c	d
100	Estimated	95	0,04	0	50
m/min	Calculated	$2{,}03 \cdot 10^7$	0,02	6,45	$-2{,}03 \cdot 10^7$
200	Estimated	100	0,05	0	50
m/min	Calculated	$1{,}69 \cdot 10^7$	0,03	6,40	$-1{,}68 \cdot 10^7$

A function can be described with the calculated values and the temperatures at the cutting edge can be described very well over the measured time range (see Fig. 3). The Pearson's correlation coefficient for this is 0.99 and shows a very good agreement. The temperature in the workpiece was also carried out in the thermographic image with subsequent regression analysis. The Pearson's correlation coefficient is only 0.75 for this. The image area for the workpiece was too small respectively the resolution of the camera is too low. Therefore, it was decided to forgo any description.

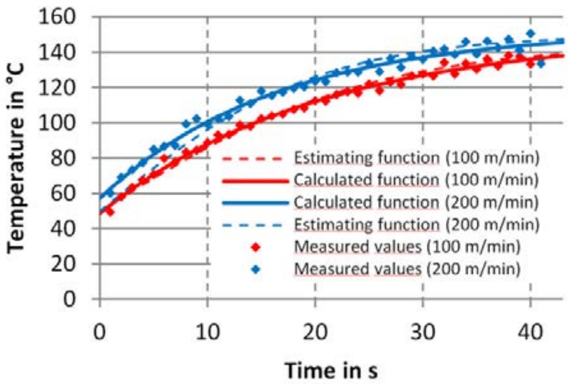

Fig. 3: Temperature curves for the tool.