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Heat flux and temperature distribution in gear hobbing operations

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Abstract

Thermal deviations in gear hobbing are one of the main reasons for wet machining. To reduce lubricant, especially for dry machining of large modulus, it is necessary to compensate these thermal deviations.
Gear hobbing is a very complex technology, where chip geometries are changing continuously. To measure cutting forces during machining a simplified fly cutting test is commonly used. Within this study a modification of the fly cutting test was necessary to enable the measurement of temperature and temperature distribution in the gear during the process.
For a better understanding, in addition numerical simulations are performed to calculate the heat flow and thermal distribution. Thereby, a two step simulation procedure was applied. The generated heat during chip formation was evaluated in the first step. The second step is a heat flow simulation, where the generated heat from the first step was used. In this simulation part, the heat flow and thermal deviations are calculated, and also chip removal is taken into account. Thereby, different simulation strategies are used to reduce the calculation time, which will be described within this paper.
The results are showing a good agreement between the measured and calculated temperature fields in chip formation and heat flow.

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Keywords: gear hobbing; thermal deviation; FEA; temperature measurement

1. Introduction

Following the demand for ecological manufacturing more and more cutting processes reduce the use of coolant. But this can lead to different cutting conditions and negative effects. Thermal loading in dry cutting processes leads to geometrical deviations in dimension and form. Hobbing is a complex manufacturing process with simultaneous tooth contact. Thereby different chip formations represent temporally and locally independent heat sources. Especially for gears, such thermally caused deviations cannot be refinished and lead to failure in flank and profile line, pitch errors and position deviations. Within a Priority Program, the different heat sources and quantities and their effect on the workpiece are investigated. Consequentially different compensation methods are going to be developed. Therefore, the knowledge of thermal deviations and temperature distribution is necessary.

2. Fundamentals

2.1. A brief introduction in gear hobbing

Gear hobbing is one of the most common used techniques to produce external spur gears [1], [2]. For a scientific approach, gear hobbing is too complex to measure at real process condition, because of the multiple tooth engagement with the workpiece. Therefore, the fly-cutting test [3], [4] was developed to separate the tool engages, which allows to measure forces for each chip.

The fly-cutting test is a commonly used test for investigations of tool wear and cutting forces, [5], [6] and can be realised using an industrial gear hobbing machine tool. The continuous rotation of tool and workpiece,

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equal to real gear hobbing process, limits the measurement possibilities, especially for the tactile ones. To get better access especially for temperature measurement equipment, the fly cutting test was modified by IFQ.

2.2. Modified fly-cutting test for temp. measurement

To measure the thermally caused geometrical deviations it is necessary to calculate and validate the temperature field in the workpiece. Within the project two measurement strategies are used:

- by a self-developed high-speed-thermal camera to measure the chip temperatures at every tooth contact, and
- by thermal resistant thermometer to measure the temperatures impact in the environment of the tooth gap.

To realise the measurement setup and to avoid the rotation of the workpiece, the process was transferred to a five-axis-milling-machine by changing the cutting sequences [7]. Within the modified fly cutting test, all chips of one gear position are cut in axial feed direction along the workpiece width, before the next gear position is adjusted and cutting kinematic starts in the same way. Although there is an influence on chip geometry, it is a smart possibility to investigate the thermal distribution caused by the gear process.

The changed sequence according to common fly-cutting test and real gear hobbing is taken into account within numerical simulations. This guarantees the transferability of the results into common fly-cutting tests and real gear hobbing processes.

3. Experimental

3.1. Experimental set-up

The experimental investigations were performed using a five-axis-milling machine type FT2000 of company Heller. The applied cutting kinematic is shown in Fig. 1.

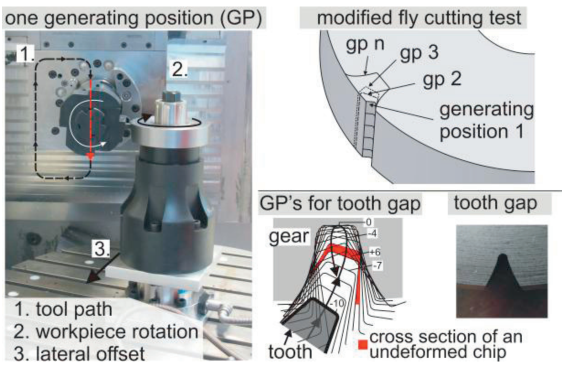

Fig. 1. Kinematic of modified fly-cutting test

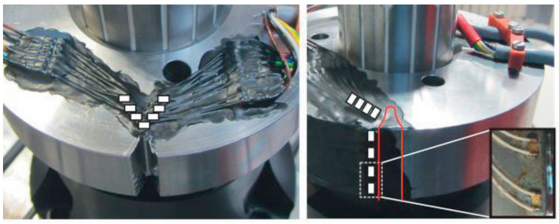

Fig. 2. Thermal distribution measurement, resistance thermometer

In the modified fly-cutting test, one single tooth gap is produced by each single sequence, Fig. 1 (b). After cutting one generating position (GP) over the whole width, sequence (1.) in Fig. 1 (a), the workpiece is adjusted by rotation (2.) and translation (3.) into the next generating position and the kinematic starts again at sequence 1 with next GP. The workpiece rotates only by small angular steps. There is no revolution of the workpiece. This set-up allows the measurement of the temperature distribution using resistance thermometer type Pt100.

Due to the measurement capabilities, the limit of a simultaneous measurement of the thermal distribution had to be compensated using several measuring set-ups, Fig. 2 (a) and (b). The resistance thermometers (Pt100) are fixed with thermal adhesive. Afterwards they were connected by silver platted wires. The cutting forces were measured using a multi-component force plate. To measure the temperature of every single chip of the tooth contact it was necessary to self-develop a thermography camera, which allows a precise measurement of high temperatures during high-speed processes [5].

3.2. Experimental results

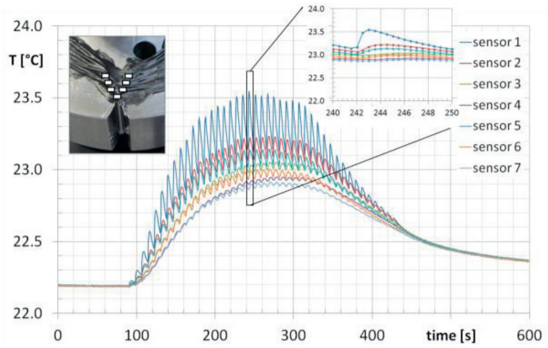

Fig. 3. Thermal distribution measurement, temperature vs. time diagrams

For the different measuring set-ups the temperature vs. time curves were measured for all generating positions, Fig. 3 and 4. Each temperature peak is caused by generated heat during chip formation for one single generating position (GP). The zoomed plot in Fig. 3 shows the effect more detailed.