CIRP Annals - Manufacturing Technology 64 (2015) 321–324

Contents lists available at ScienceDirect

CIRP Annals - Manufacturing Technology

journal homepage: http://ees.elsevier.com/cirp/default.asp

Modeling and simulative analysis of the micro-finishing process

Petra Kersting [a,b,*], Raffael Joliet [a], Michael Kansteiner [a]

[a] Institute of Machining Technology, TU Dortmund University, Baroper Straße 303, 44227 Dortmund, Germany
[b] Institute of Manufacturing Technology and Quality Management, Universitätsplatz 2, 39106 Magdeburg, Germany
Submitted by Klaus Weinert (1), Dortmund, Germany.

ARTICLE INFO

Keywords:
Honing
Modeling
Surface

ABSTRACT

Honing operations are primarily applied to enhance tribologically loaded surfaces. In order to reduce the experimental effort during process design and optimization, a prediction of the specific surface topography resulting from a particular honing operation is necessary. Therefore, a high-resolution geometric process model for force-controlled honing operations was developed, which utilizes numerical data of tools and workpieces from topographic scans. In this paper, the modeling approach is presented and applied to a micro-finishing process with different process parameter values. The simulation results are also compared to surface topographies generated in experiments in order to validate the simulation model.

1. Introduction

Honing operations are used to reduce form and dimensional errors and to influence frictional properties of tribologically loaded surfaces. A typical application of short-stroke honing processes, so called micro-finishing, is the manufacturing of crankshaft bearings [1]. Due to the complexity of the material removal mechanisms [2] and the strong effects and interactions of the process parameter values on the topography of the resulting workpieces, the manufacturing of surfaces with the desired characteristics is a great challenge. Often a great deal of process expertise and many experiments are necessary to achieve the required properties [3].

In order to gain deeper process knowledge and to reduce the number of experiments, simulation systems can be used, which allow a virtual analysis and optimization of processes. An extensive overview of recent developments in the simulation of machining and grinding processes [4,5] is given by Brinksmeier et al. [6] and Altintas et al. [7]. For the simulation of honing operations, different models focusing on specific aspects of the process are known in literature [8–14]. Voronov et al. [9,10] used numerical models to simulate the dynamic tool behavior of a bore-honing process on the macroscopic level. Reizer and Pawlus [11] developed a method for computer-generated topographies of plateau-honed cylinder surfaces based on measured data. A macroscopic simulation of the honing process was developed by Goeldel et al. [12], which takes the cylinder and tool geometry as well as the initial roughness values into account. Covington et al. [13] presented a macroscopic simulation using FEM, while statistical models were investigated by Buj-Corral et al. [14].

In contrast to these approaches which are based on characteristic values (e.g., roughness), the system proposed in this paper allows the prediction of the resulting surface characteristics based on original topographic data. A high resolution geometrical representation combined with a force-control model allows for an accurate prediction of the resulting surface characteristics. This simulation system, the experimental setup for the validation experiments, and a comparison of simulated and machined results will be presented in this paper.

2. Modeling of the micro-finishing process

The simulation of honing processes requires a geometric modeling of the tool and the workpiece and of their engagement situation [7]. In this article, a simulation system is presented which represents the workpiece and the finishing belt by height fields [15]. By geometrically intersecting the tool and the workpiece model, the uncut chip shape can be described and analyzed in order to predict the cutting forces. These forces are used in an additional control model in order to simulate force-controlled operations.

2.1. Geometric models of the tool and the workpiece

For a detailed modeling of the resulting surfaces which are free of undercuts, both the workpiece and the tool are geometrically represented by height fields (Fig. 1a). The basic idea of this efficient modeling technique is to discretize an object by parallel line segments of variable length which are arranged on a grid-like structure over a defined domain (Fig. 1b) [7]. In order to analyze the micro-finishing process, this domain is curved so as to model the finishing belt and the geometry of the workpiece. In order to be able to analyze the resulting honing structures on the workpiece surface, a high resolution of the grid is necessary.

The values of the height fields are initialized utilizing measured data of the tool and the workpiece. For this purpose, topography

---

[*] Corresponding author.
E-mail address: pkersting@isf.de (P. Kersting).

http://dx.doi.org/10.1016/j.cirp.2015.04.014
0007-8506/© 2015 CIRP.

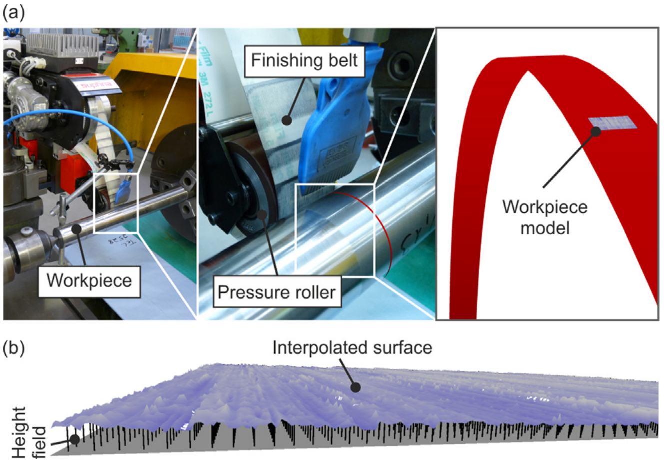

Fig. 1. (a) Experimental setup and simulated workpiece surface. For the simulation of the process, only a very small area of 0.4 mm × 0.4 mm is taken into account. (b) The height values are defined with respect to a two-dimensional reference area.

scans had to be made using, e.g., a confocal white light microscope. The model of the finishing belt is limited to the contact area and is assumed to be representative for the whole belt. Since the model does not take tool wear into account, the belt feed is neglected in the simulation model.

2.2. *Modeling of the material removal process*

The approach developed here is based on a time-domain simulation system [15]. For each discrete time step, the relative position of the tool and the workpiece is updated and the intersection between the two models has to be computed in order to calculate the current material removal.

Since the finishing belt, which is pressed against the workpiece by an elastic roller, adapts to the shape of the workpiece in the contact area and, thus, the radii of the finishing belt and the outer shaft are equal, the engagement can be limited to this two-dimensional region (Fig. 2a).

For each height value of the workpiece model, the nearest height value of the tool model in surface normal direction is determined and this value is used to clip the height value of the workpiece (Fig. 2b). As a result, the intersected and removed parts define a model of the uncut chip, which is used for the force calculation.

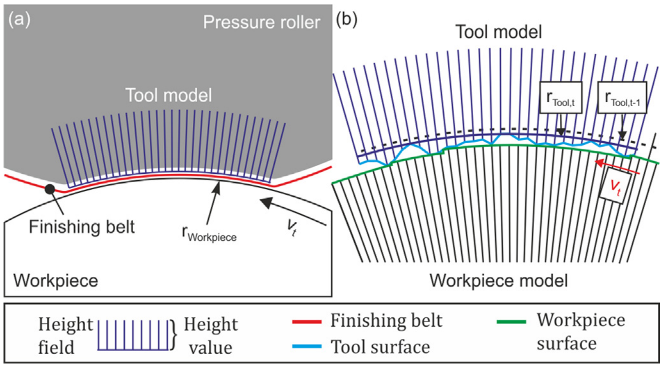

Fig. 2. (a) The outer shell of a cylinder was used to model both the shaft perimeter and the finishing belt during the contact situation. (b) For each time step, the relative position of the tool and the workpiece is calculated by intersecting each height value with the nearest value of the tool model.

2.3. *Force calculation and control feedback*

In order to model the force-controlled operation, the normal forces and the pressure on the workpiece surface have to be calculated. The forces are determined in each simulation step using an empirical model according to [15]. For this purpose, the uncut chip thickness h is necessary, which can be determined using the model of the removed material (Section 2.2). For each row of the height values the uncut chip thickness h is determined (Fig. 3). These values are used to calculate local force values, which are then combined to compute the normal force. By dividing this value by the contact area, the surface pressure is obtained [15].

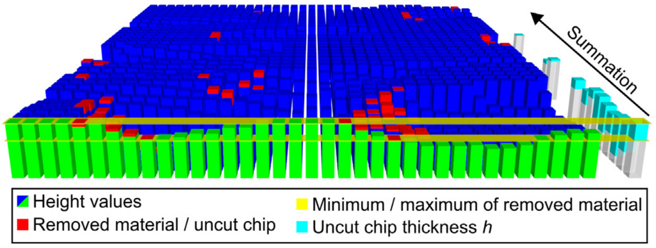

Fig. 3. Calculation of the uncut chip thickness h for each row of the removed material in order to calculate the normal force on the tool. In the cutting direction, the uncut chip thickness is determined by using the maximum and the minimum values. All force values are summed up perpendicular to the cutting direction.

The calculated pressure value is used in the control model to adapt the radial infeed r_{inf} of the tool. For each time step t, the radial infeed $r_{\mathrm{inf},t}$ is updated, based on the smoothed pressure difference $\Delta p_{\mathrm{smooth},t}$, which is a weighted sum of currently and previously calculated pressure values:

$$r_{\mathrm{inf},t} = r_{\mathrm{inf},t-1} + f_{\mathrm{correction}} \cdot (\Delta p_{\mathrm{smooth},t}), \quad f_{\mathrm{correction}} > 0 \tag{1}$$

$$\Delta p_{\mathrm{smooth},t} = \Delta p_{\mathrm{smooth},t-1} \cdot (1-\alpha) + (p_{\mathrm{sim},t} - p_{\mathrm{target}}) \cdot \alpha, \quad 0 \le \alpha \le 1. \tag{2}$$

The parameters $f_{\mathrm{correction}}$ and α characterize the behavior of the control mechanism, and p_{target} defines the pressure value used in the real experiments. This value was calculated by assuming a constant contact area. If the simulated pressure value $p_{\mathrm{sim},t}$ is too high, the radius of the tool model is increased, which leads to a lower engagement of the grains. By applying this approach, the simulation of the force-controlled process becomes possible.

The influence of the parameter α is presented in Fig. 4. Using both parameter values, $\alpha = 0.25$ and $\alpha = 0.5$, the simulation is able to match the predefined force of 400 N. With $\alpha = 0.25$, the control tends to overshoot the predefined force value. Higher values for α resulted in an unstable control behavior.

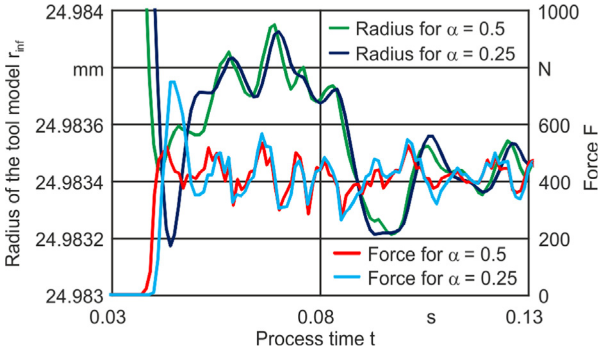

Fig. 4. Parameterization of the infeed control model and its effect on the process kinematics. The model corrects the radial infeed of the tool model in order to reach a predefined contact force.

3. Experimental setup

To validate the simulation model, experiments with different values for the parameters process time, tangential velocity, feed of the finishing belt, and contact force were conducted. The