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A process model for force-controlled honing simulations

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Abstract

The selection of process parameter values for honing operations is challenging since their effect on the resulting surface characteristics is difficult to predict. With the right settings, the finishing operations can reduce surface roughness values, enhance the shape accuracy of bores and shafts, and create surface topographies with improved functional properties.
In this paper, a model for honing operations based on microscopic scans of tool topographies is presented. The model allows the simulation of material removal during the process by taking force-controlled honing operations into account.

Keywords: Modelling; Simulation; Honing; Finishing; Force-Controlled; Machining

1. Introduction

Highly resistible surfaces can be manufactured by using finishing operations. These can reduce dimensional errors and affect the micro-topography of the surface. A typical application of long-stroke honing processes is the manufactur of cylinder liners where cylindricity can be improved and surfaces should contain deep grooves [1]. Short-stroke honing (finishing) operations reduce the surface roughness in order to enhance the functional properties of the workpiece [2]. Determining process parameter values that create a predetermined topography is difficult since the material removal process is complicated and the interrelation of the parameters is complex. Because of this, experimental investigations of finishing operations are necessary, and modelling the process is beneficial. First, a better understanding of the functional dependencies between the input parameter values and the result they produce helps to reduce the amount of time that is needed for process parameterization. Second, model-based simulation approaches allow for a virtual optimization process in order to avoid costly experimental investigations.

Models for the simulation of honing operations have been studied with very different key aspects. Numerical models for rotating tools have been used to simulate the dynamic tool behavior responsible for surface formation on the macroscopic scale [3]. Reizer et al. simulate the material removal process by applying filters and transformations to the measured data in order to predicted 2D profiles and 3D surfaces [4]. On the macroscopic scale, honing processes have been investigated in [5]. Another mathematical approach that takes many effects of the process into account is described in [6]. By using a numerical algorithm to simulate surface generation, tool dynamic and regenerative effects of the operation are accounted for.

A common problem of many modelling approaches is the abstraction of the honing operations either by mathematical transitions or by substituting the surface topography with their characteristic values, e. g. roughness. The potential for an increase in process knowledge and simulative prediction afforded by the availability of a honing process model motivates the research presented in this paper. The model developed is capable of describing material removal on a microscopic scale and computing process forces. This allows the transient simulation of force-controlled honing operations.

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2. Process Model

The basic requirements for a process model describing honing operations are a model for the tool, a model for the workpiece, and a method for computing the material removal process. In the following, both models are described and a material removal algorithm is presented that contains a model for the process forces.

2.1. Tool and Workpiece Models

Honing processes are surface preparation operations, and planar parts of a workpiece can be accurately represented by height values. Heightfields are grid-like structures with equidistantly arrayed entries representing the surface topography in a simple and compact manner. The surface is discretized and each parcel is associated with a floating-point number representing an exact height, neglecting an inherent limited computational precision in computer hardware. All entries contain relative values that are to be set in relation to some reference height. In contrast to the honing simulation presented in [7], the heightfield is mapped onto the cylindrical outer surface of the workpiece to avoid distortions.

A heightfield modelling the wall of a cylinder is shown in Fig. 1(a). Only a small area of the workpiece has been captured with confocal white light microscopy, yielding a local model in high detail with a very high resolution of 0.31 µm (Fig. 1(b)). This degree of precision is necessary because of the low roughness values that are to be expected in finishing operations. At this resolution, a model for a cylinder with diameter $r_{\text{workpiece}}$ = 25 mm and height h = 55 mm would require a memory size for values of type *float* of more than 330 GB. This size cannot be handled by current computer workstations and the use of the simulation would be questionable.

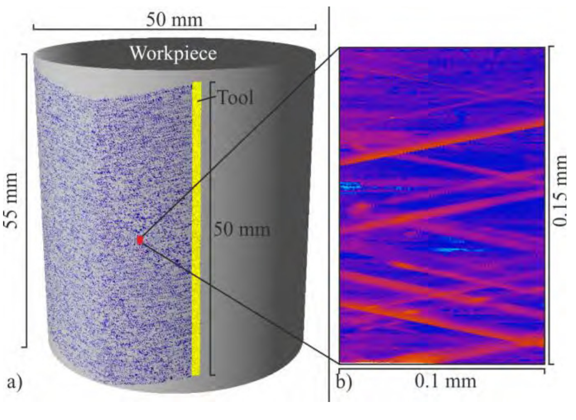

Fig. 1. (a) Complete workpiece model for a shaft and the current contact area of a finishing belt (yellow); (b) Model of a small area of the workpiece with higher precision.

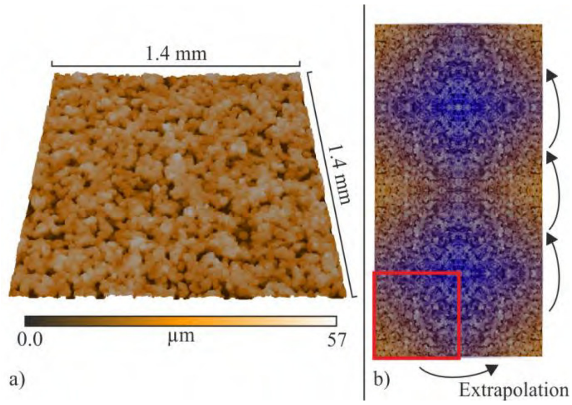

Fig. 2. (a) Captured height values of a finishing belt; (b) Complete model of the tool. The red marked area is extrapolated by mirroring to ensure continuity of the model. The color gradient visualizes the extrapolation algorithm using mirroring.

The tool model is based on three-dimensional scans of finishing belts for which heightfields are also created. Since scanning the tool is very time consuming, the tool model is enlarged and the height values are copied by consecutively mirroring them (cf. Fig. 2) over its surface. The tool model is limited to the contact zone of the finishing belt with the workpiece. In the contact zone, the tool is pressed onto the surface of the workpiece by a polymer roller and assumes the shape of the shaft. To simulate this, the height values of the tool are mapped onto a cylinder wall. A common problem associated with confocal white light microscopy is the introduction of measuring artifacts by reflecting surfaces and steep flanks, resulting in gaps and spikes in the heightfield data. While the former can be compensated for via interpolation, filter algorithms are required to repair the latter. For the simulation results described here the height values of the tool model have been clipped to a value that was determined by comparing the model with raster-electron images of the tool.

2.2. Time-Discrete Process Simulation

In the honing process, the workpiece rotates and the finishing belt oscillates axially. The combination of both movements results in the actual cutting speed. In the process simulation the cutting speed is emulated completely by the tool in order to avoid multiple moving objects in the visualization. Since no model for tool wear has yet been realized, the feed of the belt is neglected so that the whole operation is performed with a static tool model. The process simulation performs time-discrete simulation steps and calculates for each point in time the relative position of the tool. On top of the ongoing rotational and oscillatory movement of the tool, the reference radius r_{tool} can be modulated in order to take force-controlled honing into account. For each