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Dynamical aspects in modeling long cantilevering workpieces in tool grinding

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A B S T R A C T

Tool grinding is a complex process in which temporal dynamics of workpiece and grinding wheel, and the material removal process itself, affect the quality of the workpiece. Many existing models already provide the option to study the dynamics of workpiece and grinding wheel or cutting forces and material removal processes, but mostly do not combine these aspects. Here, workpiece dynamics are studied in relation to its structural and geometrical changing properties during machining, and are used to simulate the vibrations and deformation of the workpiece during grinding. In combination with models for the grinding wheel and the material removal process, dependencies of the workpiece dynamics on the workpieces quality are studied and results from this hybrid model are in excellent agreement with empirical measurements. Furthermore, the results demonstrate the significant effects of deformations of the workpiece on its final geometry.

1. Introduction

Industrial machining requires the use of very precise tools that can withstand high wear and tear operations such as chamfering and drilling. The fabrication of these tools, in turn, is most commonly carried out by the complex process of tool grinding. The ability to predict and adjust process conditions and workpiece quality during the tool manufacturing process is imperative to being efficient in small lot sizes or the production of specific tools.

Tool grinding models offer a way to predict these process conditions accurately and a broad overview of the state of the art development is given in Brecher [1]. However, most models either focus on the dynamics of structural interaction or the local contact conditions by using simplified geometries. For example, the dynamical models by Schiefer [2], Dietrich [3], Chen [4] and Schütte [5] simplify the geometries of the workpiece and grinding wheel to generic discs while taking their relative movements into account. Schiefer [2] accounts for movements of the center of the grinding wheel to analyze chatter vibration. Dietrich [3] and Chen [4] develop similar models with added degrees of freedom to the workpiece, and Schütte distinguishes between random and chatter vibration [5,6]. Altintas and Weck summarize recent work on dynamics of grinding processes in general [7].

Alternatively, models of grain engagement and wear account for the grinding wheel topography and the local penetration accurately, but simplify or neglect dynamical effects. Kassen and Werner calculate the active number of cutting edges in their model [8,9], while Alldieck also takes the local deformation of the grinding wheel into account [10]. In recent

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times, higher computational capacity has facilitated new model approaches, as summarized in Brinksmeier [11], such as models describing a three dimensional grinding wheel topography by geometrical solids [12–16] or with the use of an inverse distribution function [17,18].

All of the models mentioned above are specialized in one aspect of grinding. However, especially in tool grinding, the interplay of temporal variation of workpiece dynamics, vibrations of the grinding wheel, cutting forces, and effects of material removal strongly influence the grinding process and the quality of the workpiece.

Thus, the presented tool grinding model describes the dynamical behavior of the workpiece by including influences due to the grinding wheel contact and cutting forces, as illustrated in Fig. 1. In particular we focus on the temporal effects of geometry changes on the workpiece dynamics and introduce therefore a mathematical model, which is validated by experiments.

This paper begins by experimentally investigating the geometry dependent workpiece dynamics as well as the influence of clamping on workpiece deformation, presented in Section 2. Based on the results from experiments, we derive a mathematical workpiece model, which is explained in Section 3. Section 4 describes results from simulations of the overall tool grinding model, which includes unsteady workpiece behavior, and compares the results with empirical measurements. Finally, the paper ends with a conclusion in Section 5.

2. Experimental investigation of the workpiece dynamics

Grinding is commonly used as a finishing process, but in tool grinding, it is used to define the geometry of the tools as well. The workpiece is clamped to the machine table and moved along its axis towards the grinding wheel, constituting one production step. Each production step, in turn, results in manufacturing of one flute with removal of several millimeters of material. For helical flutes, the longitudinal motion is retained, but the workpiece is rotated, and the grinding wheel axis is tilted to form a non-orthogonal angle with the workpiece axis resulting in a helical shaped flute.

The manufacturing takes place in three steps. In the first step, a helical flute is produced by removing up to 30 percent of the initial volume. In the second step, the shell surface of the body is removed slightly to define cutting edges and to reduce frictional contact in use. The last step involves the machining of the point angle.

The large rate and volume of material removed in the first step of the manufacturing process can be detrimental to the final product, and is the focus of this study. Large material removal leads to large cutting forces, which in turn result in significant deformations of the workpiece as described in Section 2.2. These deformations result in deficiencies in the quality of the product. In addition to the workpiece bending, there are vibrations in the workpiece caused by contact with the grinding wheel. The behavior of the entire system is then also dependent on the frequency of vibrations that are defined by the instantaneous workpiece geometry. The analysis of the eigenfrequencies of the workpiece during the different stages of production is presented in the following section. The rate and volume of material removal coupled with the eigenfrequency analysis are essential for the mathematical workpiece model explained in Section 3.

2.1. Analysis of workpiece dynamics

The analysis of eigenfrequencies and eigenmodes of the workpiece elucidate the dependency of the dynamical workpiece behavior on its momentary geometry. This section illustrates this dependency by measured eigenfrequencies of machined workpieces with helical flutes and by numerical simulation of workpieces with longitudinal flutes.

On machined drills with different lengths and numbers of helical flutes, as shown in Fig. 2(a), their first two eigenfrequencies were measured. For the measurement, the workpieces were mounted on a separate clamping support

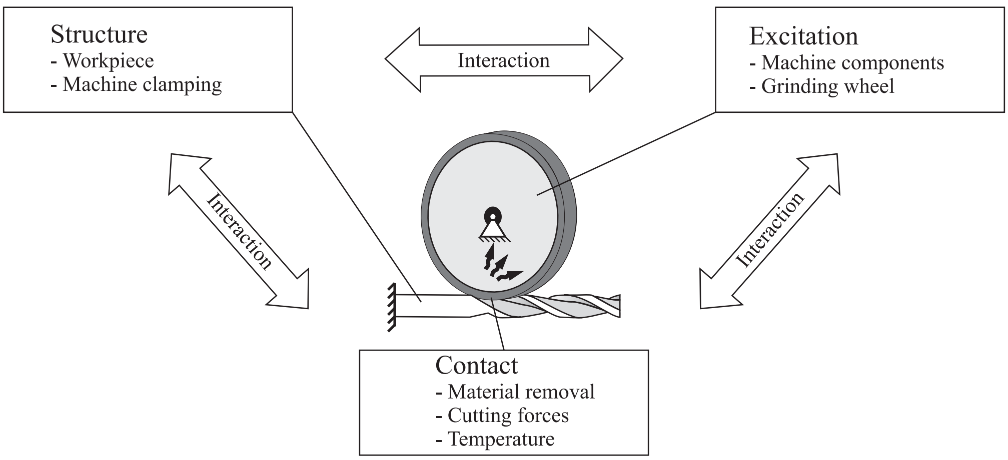

Fig. 1. Interaction between structure, contact, and excitation during tool grinding with considered influences on the hybrid tool grinding model.