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Estimation of Dynamic Grinding Wheel Wear in Plunge Grinding

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Using conventional grinding wheels, self-excited vibrations are one of the most limiting factors in terms of productivity and process stability in cylindrical plunge grinding. Depending on the dynamic behavior of the workpiece and machine, vibrations of the workpiece copy on the grinding wheel's surface, caused by uneven wear. This results in increasing waviness of the grinding wheel and by that, increasing workpiece vibration. Electromagnetic actuators are capable of influencing the dynamic process forces and therefore, the wear. The authors pursue the objective, to achieve an active control of the tool wear for low workpiece vibration and high workpiece quality. Therefore, a tool-wear-model which enables the estimation of the grinding wheel's surface is proposed. The parameterization of the model is realized carrying out a set of reference processes with subsequent identification. Aside from the dynamic tool wear, the workpiece oscillation is simulated by the model. A Kalman Filter is utilized to adjust the model onto the current process using the measured workpiece oscillation. Thus, it is possible to achieve an online estimation of the wave amplitude and phase angle on the grinding wheel's surface as well as their progression.

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1. Introduction

Finishing processes like grinding are used to achieve high surface quality or low tolerance in manufacturing. Compared to other processes like turning or milling, the material removal rate of grinding is relatively low which results in high process duration and cost-intensive processes. Thus, this costly process only is carried out, if the demands on a workpiece require it, making the economic efficiency of the grinding process an important factor. The production of a flawless workpiece may suffer from vibrations of internal or external sources. Internal disturbance is often caused by self-exited oscillations, also called chatter. Especially conventional abrasives like corundum grinding wheels tend to develop vibrations due to wheel-sided regenerative effect. Contrary to the workpiece-sided regenerative effect, where vibrations occur due to an increasingly wavy workpiece surface, the wheel-sided regenerative effect is caused by waves forming on the grinding wheel's surface. Vibrations of the workpiece copy onto the wheel due to varying contact force and tool wear. The uneven tool excites the workpiece's oscillation even more, causing an increasing waviness on the grinding wheel with every revolution. Even at low amplitudes below one micron, surface waves excite dynamic process forces and may damage the machine as well as the workpiece as they increase. The waves on the wheel have to be removed by time consuming dressing operations, limiting the economic efficiency of the grinding process.

The mechanism and development of chatter vibration has been part of various researches, many of them focusing on modeling the grinding process. In 1969 Snoeys & Brown [1] presented one of the first feedback process models relying on grinding forces, workpiece displacement and tool wear, see Figure 1. Many more recent models are based on this schematic, cf. Inasaki [2] and Weck [3]. Other approaches like Schütte [4] concentrate on the physical processes during grinding, taking geometric-kinematic, microscopic tool properties, temperatures, etc. into account, sometimes using FEM. Brinksmeyer et al. reviewed existing models and compared the complexity, usability and computational cost in [5].

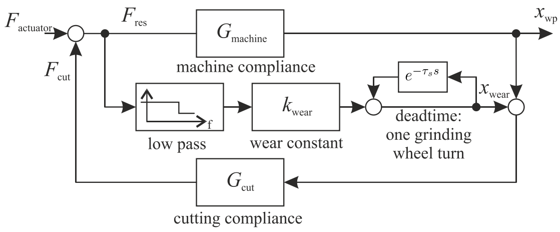

Figure 1: Simplified Grinding Process Model for Wheel-Sided Chatter Vibration in Time Domain by Snoeys & Brown, cf. [1]

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When it comes to modeling wheel-sided chatter vibration, most of the existing models suffer from the high effort of parameter setting, as the dynamic behavior of the machine as well as various process parameters are required for good model quality.
In this paper, a simplified grinding process model is presented, which targets the development of wheel sided chatter vibration and on the estimation of workpiece movement and tool wear. The authors pursue the objective, to achieve an active control of the tool wear, applying forces on the workpiece using a magnetic actuator [6]. After description of the model structure, the measurement setup is presented. An exemplary grinding process is carried out during which wheel sided chatter is deliberately induced by a magnetic actuator. This process is used for the identification of model parameters. A Kalman filter is utilized for online-estimation of the tool surface waviness during grinding processes.

2. Measurement and Actuation Setup

Figure 2 shows the measurement setup used for the experiments conducted in this paper. While the model only depends on the workpiece position measurement provided by eddy current sensors, various other sensors are implemented for validation. Besides acoustic emission, the tool position, tailstock acceleration, workpiece forces, and spindle current are measured. The magnetic actuator depicted in Figure 3 is able to apply forces onto the workpiece.

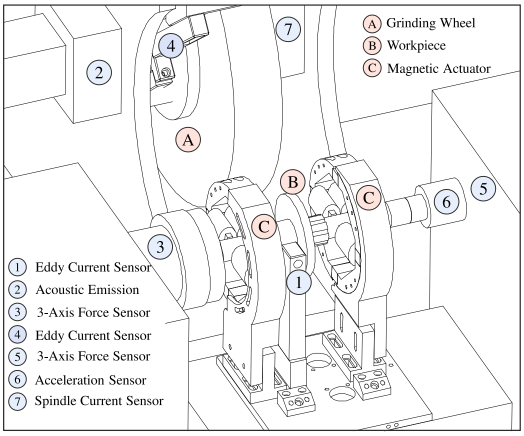

Figure 2: Measurement Setup

2.1. Grinding Machine

The experiments presented in this paper are performed on a SCHAUDT CR41 CBN, being a CNC type cylindrical plunge-grinding machine with automatic balancing system and belt driven spindle. It is equipped with hydrostatic guide ways and screw drives enhancing the damping and stiffness of the machine. To obtain comparable results, a standardized grinding process is defined. The workpiece consists of bearing steel (C100Cr6 / 1.3505 at 62HRC) in form of 10 mm wide disks with a diameter of 100 mm on a shaft of 200 mm length. The used grinding wheel is composed of white aluminum oxide at grain size F120 (FEPA) with bond hardness H and slightly porous structure. The deployed cooling fluid is mineral oil at 45 ℓ/min. Running the process at a cutting velocity of v_c =35 $\mathrm{m/s}$, a speed ratio q = 80, and a specific material removal rate Q'_w = 5 $\mathrm{mm^3/mm\ s}$ results in a slightly instable process with slow developing chatter [7].

2.2. Electromagnetic Actuator

The grinding process is influenced by the magnetic actuator depicted in Figure 3. The actuators are able to generate forces of ± 30 N at adjustable angle. The magnet's iron cores are 30 mm wide and composed of laminated soft magnetic material to reduce losses due to eddy currents and ensure high dynamics of the actuator. The current in the magnet coils is controlled by Junus servo amplifiers connected to a 160 V intermediate circuit. [8] Using a pseudo-random-bit-sequence-signal (prbs), its dynamic behavior can be identified as a $\mathrm{PT_1}$-system with corner frequency at 700 Hz and 0.2 ms delay. Thus, it is possible to reach up to 15 N at 1 kHz. The highest chatter frequencies ocouring in the presented setup are roughly at 1.1 kHz [9]. The actuator and the sensors are connected to a DSPACE ds1103 process computer system with a sample time of $t_\mathrm{s} = 10^{-4}$s.

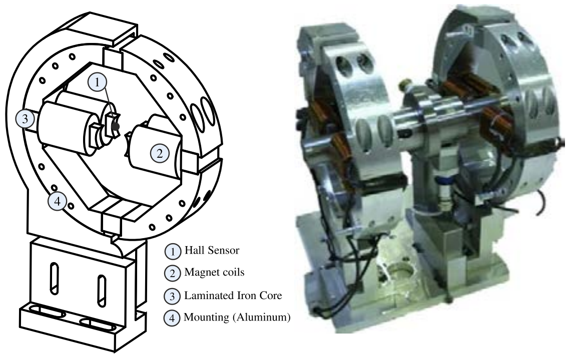

Figure 3: Electromagnetic Actuator CAD model (left) and Prototype (right)

3. Modelling of Wheel-sided Chatter Vibration

The proposed model focuses on the simulation of the development of wheel-sided chatter vibrations, i. e. the formation of waves on the grinding wheel due to tool wear. Since these waves can only form at multiples of the grinding wheels revolution frequency, the modelling can be split up in n different models, each representing a discrete frequency, covering the frequency range in which chatter vibrations may occur. Since the waves develop relatively slow, the transfer functions of the dynamic behavior of the machine as well as the dynamic cutting compliance depicted in Figure 1 simplify to a quasi-static modulation of amplitude and phase-shift of the signal. Utilizing complex numbers, the transfer functions are reduced to a multiplication with a constant complex value, cf. Figure 4.