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Simulation of error-prone continuous generating production processes of helical gears and the influence on the vibration excitation in gear mesh

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Abstract

A very important feature of high quality gears is a low noise emission in all operating conditions. Micro-geometry of the gear is of relevance for the vibration excitation in the tooth contact and significantly affected by the manufacturing process, especially the finishing operations. Besides known process related effects, uncontrolled variations such as inaccuracies in the speed synchronization of different axes or vibrations influence the surface structure of the tooth flanks. In this paper a detailed simulation of the production process is presented, providing crucial information about characteristic process properties and enabling investigations on the impact of manufacturing process on gear mesh acoustics.

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Keywords: simulation of gear machining; defective cutting process; acoustic relevant vibrations

1. Introduction and state of the art

An essential feature of high quality gears is low vibration excitation in all operating conditions. Therefore, especially in the automotive industry, the tooth design phase focusses on optimized micro-geometry [1]. The aim is, to reduce transmission errors and thereby vibration excitation. This micro-geometry is influenced by the gear manufacturing processes, especially the finishing operations [2].

On one hand, during the creation of modifications further process related effects may occur. For example producing a crowning with continuous gear grinding will lead to twist. On the other hand, uncontrolled variations such as inaccuracies in the speed synchronization of different axes influence the surface structure of the tooth flanks. There is also the fact that sometimes structures from soft machining still occur on the finished flank surface, as the tactile measured tooth flank in Fig. 1 shows. These influences are, unlike classical flank modifications, usually not minded by the engineers during the design phase. But they have provably significant influence on the excitation behavior of a toothing.

However, some production related effects are just noticed empirically, but have not been examined causative. In order to design further transmissions acoustically inconspicuous, taking into account the manufacturing process, a more detailed simulation of the production process is essential. Besides that, a thorough process model provides a wide range of valuable information about process characteristics, enabling an optimal layout of all available setup parameters.

As a foundation for a general and flexible consideration of cutting process influence on the workpiece surface and also on process characteristics which might lead to increased wear of the tool or unfavorable process forces, a simulation-based analysis on geometric penetration is necessary. Therefore many different approaches are known [3], but not all of them are suitable for gear production processes. For the workpiece here dexel-based models are introduced [4] as well as so-called contour line models [5]. A dexel (artificial word for "depth pixel") is a nodal value of a scalar or vector field on a meshed surface. For generation grinding piecewise analytical approaches for representation of the worm´s surface have been implemented [5] as well as usage of meshed enveloping surface [4]. In few cases deviations in the process have already been viewed [6, 7], but especially for e.g. the influence of vibrations during the grinding process further work is necessary.

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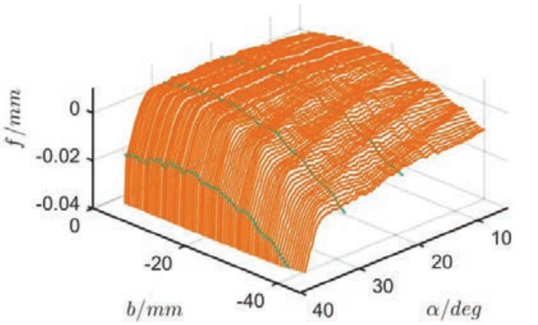

Fig. 1. Tactile measured tooth flank of a finished wheel with acoustically effective structures from the soft machining process.

2. Modelling of gear wheel production processes

The production process of a gear wheel includes typically multiple machining steps. The common steps for high-quality gears as demanded in most automotive applications are soft machining, hardening and finishing. Within these steps a wide range of production technologies are established and combinable. Below the processes skiving and generation grinding are discussed concerning the key issues of a process simulation, the kinematics and the cutting model.

Gear skiving is a rapidly emerging gear cutting process with defined cutting edge. It is mainly utilized for internal gears or applications with interfering geometry features, such as shaft shoulders close to the gear to be machined. Thus it mainly competes with established processes like gear shaping or broaching. In opposition to gear shaping, skiving technology is characterized by the crossed-axes angle between workpiece and tool. Depending whether or not the gear has a significant helix angle, the tool's rake faces are aligned straight to each other or cascaded like a stairway.

Continuous gear grinding is a widespread finishing operation applied subsequently to the heat treatment in order to achieve a well-defined surface for durability and efficiency as well as acoustic aspects. Therefore the quality of the tooth flank is subjected to high demands.

2.1 Kinematic chain

The essential requirement for the mathematical model for every production process is to be capable of describing all possible motions relevant for production. To include rotatory as well as translational transformations in one mathematical operation, homogeneous coordinates can be used [8]. Aim of all transformations is to have workpiece and tool in one coordinate system for the calculation of the penetration and thus the removal.

The main reason why gear skiving is considered to be significantly more productive than competing processes is its continuous kinematics. Due to the crossed-axis angle the tool rotation motion from the perspective of the workpiece coordinate system can be described as a combination of a tangential and an axial vector component (Fig. 2). Only the latter motion leads to the actual chip removal [9, 10].

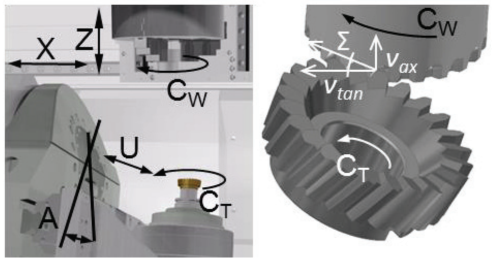

Fig. 2. Gear skiving kinematics.

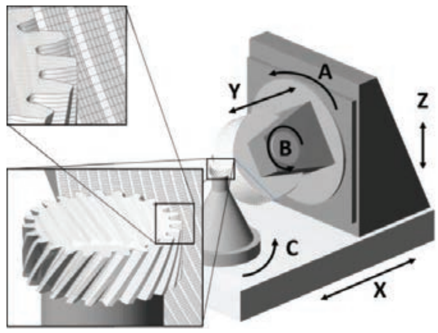

Fig. 3. Kinematics and discretization of continuous generation grinding.

Unlike similar gear cutting processes, skiving tool geometry cannot be easily described by using straight (gear hobbing or generating grinding) or involute profiles (gear shaping, rolling). Furthermore the derivation of a cutting edge profile out of a given - mostly involute - workpiece tooth profile in combination with a rather complex process kinematics makes it necessary to employ a software tool.

The creation principle of involute spur gears with generation grinding comes close to the model of a cylindrical worm drive. The main kinematic relation is the coupling between the rotational axes of tool and workpiece (B- and C-axis in Fig. 3). For helical gears an additional rotation coupled to the feed in the workpiece axis is utilized depending on module and helix angle [11]. In case of modifications additional movements along the tooth trace or shifting will be required.

2.2 Cutting model

In case of gear skiving a multi-dexel-solution is chosen. Both left hand and right hand tooth flanks are described by a dexel matrix with variable grid size. The placement of the dexel entity is described by its index in axial and radial direction, while the dexel itself is characterized by a single angle value, which describes its length starting from the center of the workpiece tooth. That means that the elements have the shape of an arc. An additional radial dexel system ensures, that undercuts, which occur in gear skiving especially in the tooth root region, can be represented in the model, as well. For cutting simulation purposes, the tool is basically