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FEM-supported simulation of chip formation and flow in gear hobbing of spur and helical gears

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ABSTRACT

An integrated procedure for simulating the complicated chip formation and flow in gear hobbing is presented. The mathematical description of this manufacturing method is based on the calculation of penetrations between cutting teeth and gear gap, a solid modeling process and finally an implementation into a FEM code. Additionally, hobbing of spur gears and the four possible variations for manufacturing helical gears are investigated. A comparison of the calculated chips with the cut ones was conducted and revealed a sufficient similarity. Finally, visualization of phenomena such as of the chip collision with gear flanks during the chip flow in individual generating positions is provided.

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1. Introduction

Gear hobbing is an efficient method for manufacturing high quality gears, with complicated process kinematics, chip formation and tool wear mechanisms. FEM-supported calculations of the chip removal mechanisms are pivotal in optimizing the hobbing process. A FEM-based analysis provides insights into the material deformation under the complicated interaction among a multitude of phenomena, i.e. rate-dependent plasticity, heat generation and flow, tool-chip boundary conditions, material fracture, etc. Prediction of stress, strain, strain rate, temperature gradients and additional parameters during chip formation is of primary concern, since they affect the tool loads and wear, the expected gear accuracy, etc.

Simulations of machining processes based on FEM-modeling in conjunction with the rapid advancement of computing engineering have led to an entirely challenging field of scientific research. Gear hobbing process involves complicated kinematics due to the generating-rolling principle, complex tool geometry, different chip flow mechanisms in the individual generating positions, extremely localized phenomena in the cutting region and large unconstrained plastic deformation under high strain rates and temperatures. The finite elements method, because of its ability to take into account the complex tool/workpiece interactions, boundary conditions and the thermo-mechanical material response has been recognized as a valuable tool for the analysis of machining operations.

In gear hobbing, the rotation of the gear blank is matched by kinematic linkage to the rotation of a worm-shaped tool (hob) as illustrated in Fig. 1. Through the additional superimposition of an axial feed motion relative to the gear blank, the tool cuts material from the entire teeth gap's width. Considering the direction of the axial feed, up-cut and climb hobbing kinematics can be applied.

2. The developed computational procedure

The developed integrated computational procedure for simulating the gear hobbing process includes a coupled thermo-mechanical FEM analysis and consists of three calculation stages (see Fig. 2):

1. The gear hobbing simulation implemented in MATLAB high-level matrix array language [1],
2. the 3D "solid modeling" of the hob and the workpiece for developing geometry for finite element analysis, and
3. a finite element thermo-mechanical model of the tool-gear penetrations using the DEFORM-3D software [2].

In the present paper, the hobbing of spur gears and the four possible variations to cut helical gears have been simulated, to visualize the chip formation mechanism on individual tool teeth, in successive generating positions. The determined chip geometries were compared with the corresponding ones of removed chips under the same hobbing conditions.

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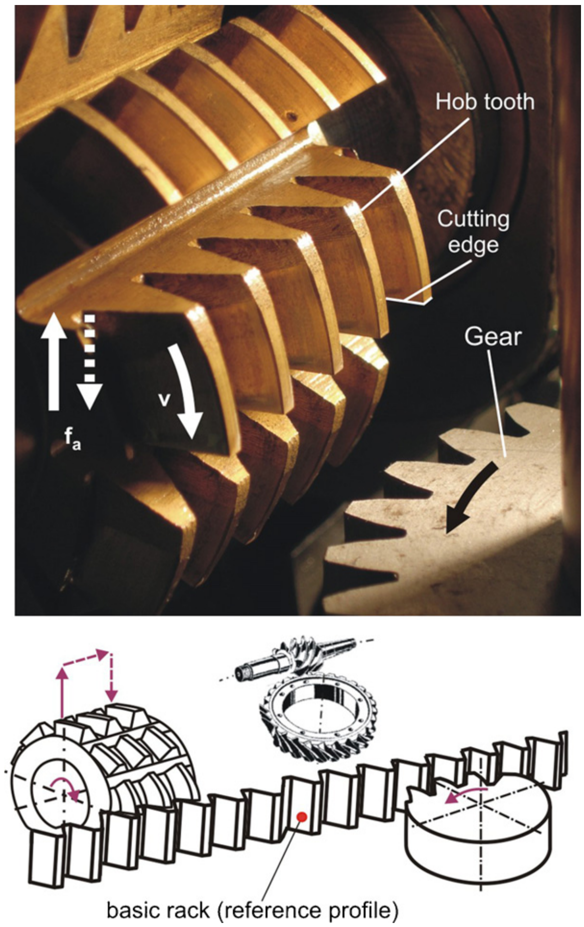

Fig. 1. Gear hobbing kinematics.

2.1. Gear hobbing simulation algorithms

In gear hobbing, each gap between successive teeth is shaped by penetrations of the tool teeth lined up on one or more starts on the hob cylindrical body, into the workpiece material in the subsequent generating positions (GPs). Considering the generating process kinematics, in the case of a hob with one start, each hob tooth penetrates into the next gear gap, in the same generating position and removes a chip with the same geometry as in the previous gear gap. By the axial feed of the cutter, the tooth gaps are formed over the entire width of the wheel.The gear hobbing simulation software FRS/MAT was developed in the matrix-oriented programming language MATLAB [1,3]. This computer supported analysis is based on the geometrical simulation of the cutting teeth penetrations into a gear gap, which is performed considering the hob geometry, the machining data and the kinematics of the actual process [4–6]. The gear hobbing kinematics analysis is accomplished by establishing coordinate systems to describe individual parts within the process kinematic chain, as exhibited in Fig. 3a and b. Transformation matrices describe the relative position of the coordinate systems. Accordingly, the kinematic linkage representation of the gear blank and the tool is determined through sequential transformations (matrix multiplications) [4,5].Six coordinates systems are assigned for the gear hobbing kinematics:

System 1, fixed in the gear gap. The origin is located at the pitch circle with the z_1 axis lying along the helix angle of the gear blank. The x_1 and y_1 axes are normal to the z_1 axis.

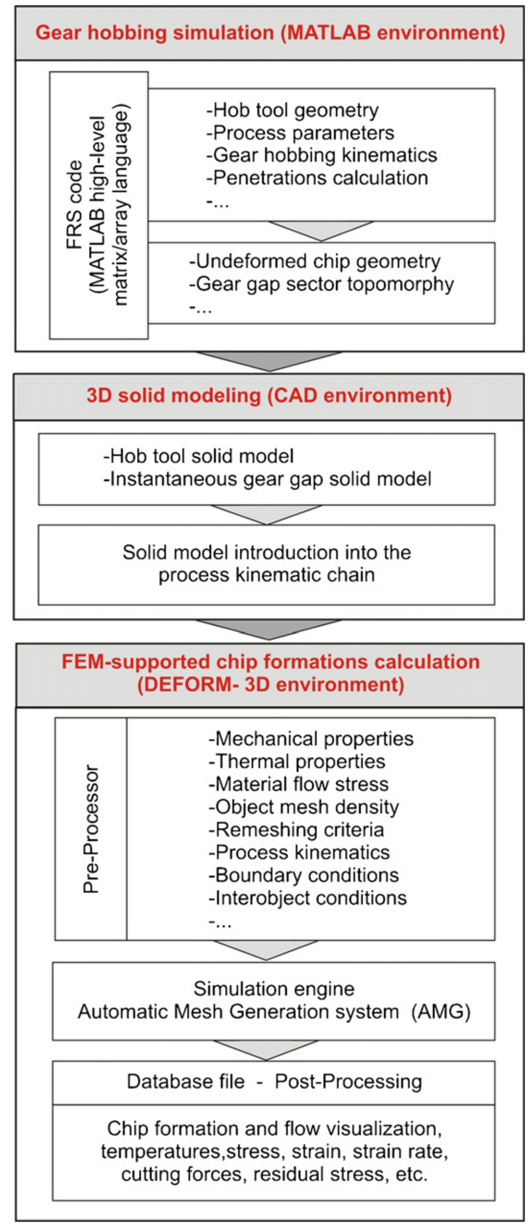

Fig. 2. Procedures for the FEM-supported simulation of gear hobbing.

System 2, rotating coordinate system fixed in gear blank. The origin is located at the center of the gear blank with the z_2 axis lying along the gear blank symmetry axis.
System 3, stationary machine's reference system.
System 4, the origin is lying along y_3 axis: the distance between the hob spindle axis and the gear blank axis is assigned.
System 5, the origin is located along z_4 direction. The x_5 axis is lying along the hob axis inclination angle (pivoting angle).
System 6, the origin of the system is translated along the x_5 axis in order to simulate any tooth of the worm shape tool. The y_6 axis coincides with the symmetry axis of the hob tooth profile.

Taking into account the rotation of the hob and the superimposition of the feed motion (axially, radially, etc.), the trace of the cutter is discretized into a number of static instances, namely into distinguished revolving positions, depending on the required computational accuracy. The trace of the cutting edge generates an enveloping surface of the tooth motion. The enveloping surface of

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