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.

KEYWORDS: Gear hobbing, FEM-simulation, chip formation

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 Figure 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 Figure 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.

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
Figure 2: Procedures for the FEM-supported simulation of gear hobbing.
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 Figure 3a and 3b. 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 is fixed in the gear gap. The origin is located at the pitch circle with the z₁ axis lying along the helix angle of the gear blank. The x₁ and y₁ axes are normal to the z₁ axis.

Figure 3: (a) Solid modelling of tool and work gear and (b) assembly into the gear hobbing kinematic chain.
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 $x_4$-axis is lying along the gear blank axis.
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 the cutting edge is considered as the union of the points that belongs to the trace of the cutting edge of the cutting tooth, when it penetrates into a gear gap. The geometry of the gear gap is described by contours on perpendicular section planes to the gear axis. During the relative movement of the hob, the intersection between the tooth’s enveloping surface and the gear reference cutting planes constitute the chip in an individual GP. Thereafter, a calculating procedure is utilized to compute the chip cross sections on the development of the cutting edge, and in this way to determine the distribution of the undeformed chip thickness. A linear interpolation is applied between the reference cutting planes to provide a continuous chip. In sequence, the gear gap geometry is updated for the next tooth penetration by subtracting the intersection area from the gear reference cutting planes. A characteristic result is displayed in Figure 4, calculated by the developed FRS/MAT software /3,7/. The undeformed chip thickness is presented over the development of the cutting edge, on successive section levels in a single generating position by means of a colour scale. A similar graphical presentation of the undeformed chip geometry in the individual GPs is provided by the SPARTA-software /8,9/.

**Figure 4**: Characteristic undeformed chip geometry presentation in a single generating position during gear hobbing calculated by FRS/MAT.
2.2. Solid modeling

Solid modeling is used to develop the 3D geometry applied in the FEM simulation. In the solid modeling procedure two objects for the hob tool were created: a cylinder and a single tooth of the cutter rack (Figure 3a). Utilizing the parametric and associative nature of the solid modeler program (Solidworks) /10/, the single cutting tooth simulates any teeth of the worm shape tool through the translation and rotation of appropriate coordinate systems. The hob tooth profile corresponds to the DIN 3972 standards /11/ or to any other desired geometry. At a final stage, the solid models of the hob tooth and the cylinder are assembled together as presented in Figure 3b. The prescribed coordinate systems were also used in the solid modeling procedure to provide the exact joining of the solid models at any stage of the manufacturing process.

The solid models of the instantaneous gear gap and the hob were created within the environment of the applied solid modeling CAD program and then were stored using the STL neutral file format.

The gear blank consists of a single gear gap and a gear cylinder with radius equal to the external radius of the gear. A point cloud in the 3D space describes the geometry of the gear gap on reference section levels perpendicular to the gear axis, as demonstrated in Figure 5, provided with the gear hobbing simulation software FRS/MAT. Following that, the data are inserted into a CAD system for processing and generating a triangular mesh.

**Figure 5**: Discretization of an instantaneous gear gap geometry and triangular mesh generation.
A large number of triangular elements (facets) are necessary to approximate the complex gear gap surface geometry. In the example displayed in Figure 5, approximately 20,000 facets were used. Considering the difficulties to insert shape information from the CAD into the FEM system, as STL triangulations cannot be used directly for FEM purposes, a new mesh has to be created \( /12/ \). Generation of the FE mesh from the original geometry is implemented using a mesh generation system. The accuracy of the final object geometry that used in the FEM engine is based on the size of the tetrahedral elements. As the mesh density, i.e. the number of the tetrahedral elements, increases the new geometry closely approximates the geometry of the STL file.

2.3. FEM-based modeling of gear hobbing

The applied model using the DEFORM-3D software is based on an implicit Lagrangian incremental formulation, i.e. the finite element mesh is generated in the workpiece and follows its deformation. An unstructured tetrahedral finite element mesh is generated in the workpiece using the Automatic Mesh Generation system (AMG). On the one hand, Lagrangian methods are well suited to simulate transient and discontinuous machining processes; on the other hand, a number of disadvantages are associated with Lagrangian methods. They are computationally expensive, as relative small time steps are required in transient solutions. Moreover, in applying Lagrangian formulations to problems of large plastic deformations, such as machining, the mesh can be distorted severely.

One way to overcome the large plastic deformation is to simulate machining by remeshing the workpiece to offset mesh distortions due to deformation caused by the tool feed. This occurs when a negative Jacobean is encountered (severely distorted elements) or on assignment of certain triggers (remeshing criteria). DEFORM 3D uses the AMG to automatically provide an optimised remeshing process. However, computational errors that occur due to interpolation of the nodal state variables between meshes are a drawback of the remeshing process.

Another important tool incorporated in the used FEM code is the mesh adaption, capable of predicting non-steady chip formation. Weighting factors that specify the relative mesh density to regions of high curvature or of steep strain, strain rate and temperature gradients can be assigned individually. Areas can also be specified geometrically to generate a fine or coarse mesh using mesh density windows. Thus, the adaptive meshing system generates the minimum size elements in chip zone and substantially larger elements away from the chip and cutting zone.

An improved understanding of the implications of minimum length scales encountered in machining is needed for the convergence and efficiency of numerical computations. In order to adequately address this in the solution, a high degree of mesh refinement is required \( /13/ \). The features that require a fine mesh in machining are the mechanical and thermal boundary layers that develop in the contact region and within localized shear bands.

The workpiece was modeled as rigid-viscoplastic, (the flow stress is a function of strain, strain rate and temperature), homogenous, with isotropic yield function (von Mises) and isotropic strain hardening rule.

The cutting tool was modeled as rigid. Based on this assumption there is no need to assign its mechanical properties and thus, only thermal properties were defined. Moreover, compared with the large plastic deformation of the gear material, the tool elastic deflection can be neglected without loss of accuracy. An unstructured tetrahedral mesh is also used on the cutting tooth for thermal calculations. No remeshing is necessary on the tooth.
3. MATERIAL FLOW STRESS LAWS AND BOUNDARY CONDITIONS USED IN THE FEM-CALCULATIONS

One of the critical issues of a FEM simulation is the reliability and accuracy of the flow stress model to represent the material behaviour in metal cutting, since extremely localized phenomena are encountered in the cutting process, characterized by large non-linear unconstrained plastic flow and high deformation rates.

In the constitutive model proposed by S. Lei /14/, material flow stress data of C22 (AISI 1020) were obtained through orthogonal machining experiments. Despite the limitations and restrictions of the plane strain model, it is utilized to describe the non-steady, multi-dimensional stress states, as the occurring ones, when simulating gear hobbing. The flow stress is determined by the product of strain, strain rate and temperature effects that are individually determined, as described by the equation:

\[
\sigma = \sigma_0 \left( \frac{\varepsilon}{\varepsilon_0} \right)^n \left( \frac{\dot{\varepsilon}}{\dot{\varepsilon}_0} \right)^m F(T_H) \]  (1)

In (1) there exist no couplings among strain, strain rate and temperature and also no effect on the strain history. The reference value of the stress is \(\sigma_0\), while the strain and strain rate are normalized with the values \(\varepsilon_0\) and \(\dot{\varepsilon}_0\) respectively; \(n\) and \(m\) are material parameters indicating strain hardening and strain rate hardening coefficients respectively; \(T_H\) is the homologous temperature, i.e. the ratio of the material temperature \(T\), to material melting point temperature \(T_m\), which is assumed to be 1848 K for the applied AISI 1020 steel. \(F(T_H)\) considers the effect of temperature on the stress and is defined in two regions:

\[
F(T_H) = C_1T_H + C_2, \quad T_H \leq 0.472 \quad \text{and} \quad (2)
\]

\[
F(T_H) = C_1(T_H)^2 + C_2(T_H) + C_3 + C_4, \quad 0.472 \leq T_H \leq 0.635 \quad (3)
\]

Equation (3) takes into account the influence of the blue brittleness effect on the flow stress, which is inherent in low carbon steels and is considered to be a result of dynamic strain ageing. The coefficients of the flow stress equation are listed in Table 1. The applicable bounds of this constitutive equation are:

- strain range: 0 up to 2
- strain rate range: up to 50,000 s⁻¹
- temperature range: 25 up to 650 °C.

If the process conditions are in an area outside of the flow stress region, i.e. for strains larger than 2, constant values of the flow stress have been assumed in order to prevent extrapolations.

**Table 1:** Flow stress equation coefficients.

<table>
<thead>
<tr>
<th>(\sigma_0) [MPa]</th>
<th>(\varepsilon_0)</th>
<th>(\dot{\varepsilon}_0)</th>
<th>(n)</th>
<th>(m)</th>
<th>(C_1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>780</td>
<td>0.85</td>
<td>16,000</td>
<td>0.34</td>
<td>0.08</td>
<td>-1.52</td>
</tr>
<tr>
<td>(C_2)</td>
<td>(C_2)</td>
<td>(C_4)</td>
<td>(C_5)</td>
<td>(C_6)</td>
<td></td>
</tr>
<tr>
<td>1.49</td>
<td>135.2</td>
<td>-268.7</td>
<td>169.6</td>
<td>-33.5</td>
<td></td>
</tr>
</tbody>
</table>

Furthermore, the work material properties were first used in the orthogonal machining theory described by Oxley and Hastings /15,16/ implemented into the FEM code. According to Oxley
results of high-speed compression tests of plain carbon steels (0.16-0.55\%) obtained by Oyane /18/, is possible to extrapolate into the machining range by using the velocity-modified temperature concept suggested by MacGregor and Fisher /19/. A linear log stress/log strain relation represents the flow stress properties of the work material:

$$\sigma = \sigma_1 \left( T_{\text{mod}} \right)^n \varepsilon^m$$  \hspace{1cm} (4)

where \(\sigma\) and \(\varepsilon\) are the uniaxial flow stress and strain; the strength coefficient \(\sigma_1\) and the strain hardening exponent \(n\) are functions of the velocity-modified temperature \(T_{\text{mod}}\). The velocity-modified temperature describes the material properties as a relation between the temperature and strain rate. This can be expressed as:

$$T_{\text{mod}} = T \left( 1 - \varphi \log \left( \frac{\dot{\varepsilon}}{\dot{\varepsilon}_0} \right) \right) \hspace{1cm} (5)$$

where \(T\) is the temperature, \(\dot{\varepsilon}\) is the strain rate and \(\varphi\) and \(\dot{\varepsilon}_0\) are constants. Equation (5) demonstrates the expected qualitative result that an increase in strain-rate is equivalent to a decrease in temperature. However, at temperatures less that the recrystalization temperature, equation (5) can only be regarded as approximate /20/. Oxley’s equation for AISI 1020 steel was included in tabular format in the material database of DEFORM-3D. The related applicable limits are:

- strain range: up to 5
- strain rate range: up to 20,000 s\(^{-1}\)
- temperature range: 20 up to 1,300 \(^{\circ}\)C.

The tool/chip boundary conditions are quite complex, influenced by a number of factors such as cutting speed, feed rate, etc. /21/. While several models were presented to determine the friction boundary conditions, an accurate description is still unavailable and the correlation with experimental data is poor. Researchers present conflicting viewpoints concerning the nature of the tool-chip frictional conditions to the point where definitive conclusions cannot be drawn /22/. In the present paper, a shear friction law was assumed by considering only high normal stresses on the sticking region, defined by the relationship:

$$\tau_f = m k_{\text{chip}}$$  \hspace{1cm} (6)

where \(m\) (0<\(m<1\)) is the friction factor and \(k_{\text{chip}}\) is the material shear yield stress:

$$k_{\text{chip}} = \sigma / \sqrt{3}$$  \hspace{1cm} (7)

with \(\sigma\) being the effective yield stress under pure uniaxial tension. The constant shear friction factor \(m\) was varied in the range of 0.60-0.95 to investigate the sensitivity on the simulated chip flow and chip geometry. Additional work has been carried out to explore the friction boundary conditions and to provide a reliable model for the gear hobbing process /3/.

4. CHIP FORMATION IN GEAR HOBBING OF SPUR GEARS DETERMINED BY FEM-BASED CALCULATIONS AND SELECTION OF APPROPRIATE MATERIAL FLOW STRESS LAW

The undeformed chip cross-sections, on the development of the cutting edge, in successive tool revolving positions are presented in five characteristic GPs in Figure 6. In this manufacturing case, the material removal from a tooth gap takes place in 26 individual GPs. This case was considered as a test one to demonstrate the possibilities of the developed FEM hobbing simula-
tion and to select the most appropriate material flow stress law. The data of GP-9 are input into the developed FEM procedure to enable the visualization of the complicated chip formation mechanism and to provide information of the occurring stresses, temperatures, strains, strain rates, etc. The performed FEM-calculations are associated to up-cut gear hobbing, while cutting experiments were conducted in conjunction, for the model validation. The associated chip flow is visualized in four successive tool rotational positions (steps), as shown in Figure 7. At section (I) the chip is generated when the leading and the trailing flank starts to penetrate into the gear material, at low chip thicknesses. Following that, a three-flank chip is formed, since the tooth head starts to cut, as shown in section (II). The material removal between sections (II) and (III) is dominated by intense chip flow obstruction due to the reciprocal collision of chip distinct segments. The complicated chip flow obstruction at this region exhibits a remarkable influence on the tool wear progress, specifically at the transient cutting edge regions from the cutting tooth head to the flanks, as reported in extended investigations /6,23,24/. Finally, the chip removal is completed and the tool exits from the workpiece gap (see section (IV)).

![Figure 6](imageURL)

**Figure 6**: Chip formation in characteristic generating positions during up-cut gear hobbing, calculated by FRS/MAT.
Two opposite views of the real chip, the upper side view and a rake side view corresponding to the simulated GP –9, are provided in Figure 8. Moreover, the same views of the FEM-calculated chip according to Lei’s and Oxley’s flow stress laws are also illustrated in this figure. As it can been seen in the table inserted at the bottom of the figure, the mean undeformed chip thickness of the tooth head region is approximately $h \approx 0.25$ mm calculated by FRS/MAT, with a mean undeformed length of $l \approx 16$ mm. Considering the real chip dimensions, the mean chip thickness in the tooth head region amounts to $h_{ch} \approx 0.6$ mm with a mean length of $l_{ch} \approx 6.7$ mm. On the one hand, an overestimation of the chip plastic deformation in the FEM-based calculations is evident, considering the real and the simulated chip, when using the Lei’s flow stress law. On the other hand, using as input data the material flow stress after Oxley, the plastic deformation of the real chip is underestimated but the calculated chip geometry is closer to the real one, as the corresponding chip dimensions in Figure 8. Therefore, the Oxley material flow stress law /17/ was applied in the performed FEM-calculation presented in the following sections.
5. CHIP FORMATION DETERMINED BY FEM BASED CALCULATIONS IN GEAR HOBBING OF HELICAL GEARS

For manufacturing helical gears by hobbing, there are two variations depending on the helix angle directions of the cutting tool and the gear blank cylinder. Equi-directional hobbing is set when the helix angle directions of the hob ($\gamma$) and the gear blank ($\beta$) are the same, while in the opposite case, counter-directional hobbing is applied. Hence, a different pivoting angle ($\eta = \beta \pm \gamma$) results in these machining cases. In this way, four possible cutting variations i.e. the up-cut equi-directional and counter-directional, as well as the climb equi-directional and counter-directional gear hobbing occur, as illustrated in Figure 9.

FEM simulations of the four possible cutting variations for the cutting of helical gears were performed to investigate the chip formation mechanism in characteristic GPs, where "three flank" chips are removed. The chip formation affects the stresses and temperatures that limit the tool life of the cutting tooth and the surface integrity of the work gear flank. A number of phenomena can be predicted using the finite element analysis, i.e. chip flow obstruction during chip generation and potential chip collision with the gear flanks, as well. The latter can result into pinching and crushing of the generated chip between the cutting edge of the hob and the tooth flank of the work gear /25/. For the above-mentioned reasons, the most critical GPs concerning chip formation and flow were selected for FEM simulation. In order to validate the FEM model comparative experiments were carried out in gear hobbing. The obtained results are presented in the following sections.
5.1. Up-cut counter-directional kinematics

In this manufacturing case a total number of 36 GPs are required to generate the involute gear tooth profile. The development of the cutting edge is divided into three regions corresponding to the tooth head (H-H), the Leading and the Trailing Flank (LF, TF) respectively. Simulation data provided by the developed software FRS/MAT for GP -16, which is considered one of the most critical positions concerning the tool wear development /6,23,24/, were input into the FEM system to investigate the complicated chip formation mechanism and to get information about the occurring stresses, temperatures, strains, strain rates, etc.

In Figure 10 the chip formation proceeds in the order (I), (II), (III) and (IV) according to the process kinematics. The corresponding revolving positions are superimposed on the undeformed chip geometry as shown at the bottom part of the figure. As the cutting tooth engages the work gear, the LF and then the TF penetrate into the gear material. Next, the tooth head starts to cut and a 'three-flank' chip is formed. As cutting proceeds further, the chip segments on the LF and TF are moving towards the chip segment generated on the cutting head and finally collide (beyond section (II)). Finally the material removal is completed and the tool exits from the gear gap (see section (IV)).

5.2. Climb counter-directional kinematics

In the investigated climb counter-directional kinematics gear hobbing test case, 31 GPs are required to create the gear gap geometry. The data of GP 7 provided by the FRS/MAT software were input into the developed FEM system to simulate the chip formation mechanism. The chip formation in four characteristic stages of the simulation, (I), (II), (III), (IV) is shown in Figure 11.
Figure 10: Chip formation in a generating position during up-cut counter-directional gear hobbing.

The same revolving positions are superimposed on the undeformed chip geometry as shown at the bottom part of the figure. In contrast to up-cut kinematics, the tooth head is penetrating first into the work gear and an entirely different plastic deformation of the work gear material results due to the opposite axial feed direction. The cutting proceeds in the following sequence: first, the tooth head penetrate into the gear gap where the maximum undeformed chip thickness of \( h_{\text{max}} \approx 0.42 \text{ mm} \) occurs. As the hob tooth moves towards section (II), the LF first and then the TF starts to cut. The chip is moving towards the tooth root of the hob and curls during the last stages of the chip formation (see section (IV)).

Next, the penetration of the tooth head into the work gear is completed and at the final revolving positions the material is removed only by the LF and the TF. Beyond section (IV) the TF acts alone until the end of cutting. An interesting result of the FEM simulation is the chip collision with the machined work gear flank at the final stages of chip formation. Using the developed FEM-model important process data such as the temperature, stress and strain fields developed in the
chip can be continuously monitored during the chip formation and flow, as exhibited in Figure 12.

Although the chip formation and flow are well described by the developed FEM-supported procedure, the results accuracy concerning temperature, stresses and strains are affected by the discretization grade of the gear and hob solid geometry./26/ Thus, more efficient and less time-consuming FEM-algorithms have to be developed.

5.3. Comparison between real and FEM-calculated chip geometries

Various investigations have been conducted to check the validity of the developed FEM-based method, to compare among others the real chip geometries with the FEM-determined ones, considering known material constitutive laws as described in a previous section. Characteristic comparisons can be seen in Figure 13. These chips were removed in gear hobbing with different cutting kinematics (climb, or up-cut hobbing) and tool helix directions related to the work.
gear flank inclination (equi, or counter directional). A comparison of few characteristic chip dimensions reveals that the developed FEM model describes sufficiently the real chip geometry. Hence, it is possible to optimise the tool design in order to facilitate the chip flow, to decrease cutting loads in endangered cutting edge regions, to predict collisions of the chips with the instantaneous gear flanks in the various GPs etc.

Figure 12: Continuous FEM-supported determination of temperature, stress and strain fields in a generating position during gear hobbing.

Figure 13: Comparison between real and FEM-calculated chip geometries.
6. CONCLUSIONS

A FEM-supported methodology was introduced to simulate the chip formation and flow in gear hobbing. The developed FEM model capabilities have been demonstrated in terms of chip flow and morphology in cutting of spur gears as well as in the four possible cutting variations of helical gears. An insight of the complex chip formation mechanism is provided, enabling the clarification of phenomena like the chip flow obstruction and the chip collision with gear flanks in individual generating positions during the manufacturing of a gap. Moreover, the FEM calculations provide an effective tool for predicting occurring temperatures, strain and stresses and thus for approaching the real loads of the cutting teeth during gear hobbing.

7. REFERENCES

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2. DEFORM 3D, version 6.1 (Beta 3), Scientific Forming Technologies Corporation.


