“Hybrid Analysis of Gear Rolling Process”
Scientific Workshop at Round Table 2013

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“Hybrid Analysis of Gear Rolling Process”
Scientific Workshop at Round Table 2013

- State of the Art / Research – Gear Rolling
- Experimental Rolling Analyses
- Approach by Hybrid Strategy
- Comparing the Results from VISIO and FEM
- Summary and Outlook
State of the Art – Classification of Gears

Stub Teeth Geometries:
- High Power Transmission
- Well Load Capacities
- Strong Sensitivity to Noise

Standard and Normal Teeth Geometries:
- Typical Pressure Angle $\alpha_n = 20^\circ$
- Helix Angle $\beta \leq 20^\circ$
- Tip Clearance Depending on Production Methods

High Teeth Geometries:
- Strong Profile Modification and -Overlap
- Reduced Noise Emission
- Strong Protuberance

$$y = \frac{h_z}{m_n} = \frac{d_a - d_f}{2 \cdot m_n} \quad \text{(Def. acc. to Zirpke)}$$
State of the Art – Gear Rolling

Two-Roller Method

Work Piece Clamping/ Positioning
Initial Rolling
Penetration/ Calibrate

PWZ Special

C-Frame, Rolling Slides / Bear Rolling Spindles with Tools

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lowest/ Highest Centre Distance of Rolling Spindles [mm]</td>
<td>254/ 400</td>
</tr>
<tr>
<td>Mounting Diameter of Rolling Spindles [mm]</td>
<td>80</td>
</tr>
<tr>
<td>Max. Length of Rolling Spindles [mm]</td>
<td>200</td>
</tr>
<tr>
<td>Max. Rolling Force [kN]</td>
<td>400</td>
</tr>
</tbody>
</table>
State of Research – Gear Rolling

Cold Rolled Powertrain Components at Fraunhofer IWU Chemnitz

**Gear Wheels**
- Module Area: 2 ... 5 [mm]
- Tooth Height Range: 5 ... 11 [mm]
- Pressure Angle: 16 ... 24 [°]
- Helix Angle: 12 ... 34 [°]
- Tooth Height Factor: max. 2.7

**Reverse Gears**

**Gear Shafts (Narrow Located & Hollow)**

**Axle Drive Wheels**

**Dimensions of WP Parameters:**

**Rolling Parameters:**
- Rolling Time: 30 ... 45 [sec.]
- Max. Rolling Forces: 80 ... 200 [kN]
- Qualities: 9 ... 11
- Materials: Case-Hardening Steels (16MnCr5, 20MoCr4)
Experimental Rolling Analyses

Gear Parameters:
- High Teeth Geometry \( y = 2.28 \)
- Helix Angle \( \beta = 20^\circ \)
- Module \( m_n = 4,0 \text{ mm} \)
- Number of Teeth \( z = 20 \)
- Material 16MnCr5

Tool Design:
- Number of Teeth \( z = 64 \)
- Material ASP 2012

Device Design:
- Positionally Accurate Electrochemical Grids
- Parallel Grid Generation for
  Radial and Axial Work Piece Pre-Forms
Experimental Rolling Analyses

- Optimization of the Entire-Penetration-Curve at Undivided Pre-Forms
- Evenly Tooth-Forming in 6 Levels of Penetration by Simulation of 2 Calibration-Work Piece-Rollovers in Each Case (t = 3 s)

\[ x_{f,\text{max}} = d_v - d_f = 10.7 \text{mm} \]
Scientific & Technical Objectives of Investigations

**Starting Situation**
- Complex Geometries
- Incremental Forming
- Combined Tool-Kinematics
- Unknown Interactions
  - Machine – Tool – Process

**Approach to Solution**
- Hybrid Strategy
  - Combi. of VISIO & FEM
  - Boundary Conditions from VISIO
  - Feedback on FEM
  - VISIO Review

**Aim**
- Simplified Simulation Models
  - Short Computing Times
  - Exact Results
  - Reduction of Correction Loops (Tool-Production)
  - Development of new Tool-Concepts

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Comparing the Results from VISIO and FEM

- Implementation of FEM-Models:
  - Utilization of Physically Permissible Simplifications of Migratory Forming-Zones (Extrapolation Technique – Same Behavior on Each Teeth)
  - Use of Improved Contact and Friction Models
  - Hybrid Models (Linking of an Analytical Analogous Model for a Local Plastical Zone with a FEM-Model for Overall Structure)
  - Reduction of Meshing (Coarse and Fine Meshing)

- Optimization and Implementation of Current FEM-Calculation (3D):
  - 1/8-Segment of Entire Forming-Zone (Internal Hole Ø 40 mm)
  - Friction-Model ($\mu = 0.2$ Coulomb, $m = 0.4$ Friction Factor)
  - Work Piece with Number of Elements $n = 5551$
  - Rigid Tools ($f_{WZ} = 0.15$ mm/s, $n_{WZ} = 10$ min$^{-1}$, $n_R = 6$)
  - Real Process time: 34 s / Computing Time: 61,276 s $\approx$ 17 h
Summary and Outlook

- Determination of the Work Piece Geometry (High Teeth)
- Construction, Production and Testing of Rolling Tools, Measuring Devices and Clamping Concepts
- Optimization of Grid Applications and Grid Scans for Coordinate Measuring (Orthogonal Grid with Pitch \( p = 1 \) mm and 2 mm)
- Definition of the Initial Shape of Specimens (Axial and Radial Parting Areas)
- Creating a First Model of FEM (Computing Time 17 h)
- 1st Series of Tests for Radial Material Flow Analyses

- 1st Series of Tests for Axial Material Flow Analyses
- Optimization of further FEM- Analogous Models

- Implementation of a Multi-Body Simulation (Integrating the Behaviour of Machine)
- Analytical Optimization of the Work Piece Pre-Forms by Varying the Chamfer of Front Surfaces and Concavity of the Lateral Surfaces / Rolling Process (\( f_{WZ}, n_{WZ}, n_{R}, \ldots \))
- Optimization of the Tool Flanks (Frontal Reinforcement, Flank Entanglements) / Rolling Process (\( f_{WZ}, n_{WZ}, n_{R}, \ldots \))
THANK YOU VERY MUCH FOR YOUR ATTENTION!