Gerotor Pumps for Automotive Drivetrain Applications: A Multi Domain Simulation Approach

Wolfgang Schweiger, MAGNA Powertrain, Austria
Andrea Vacca, Purdue University, IN, USA

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# GRPs in AWD-Powertrain Systems

<table>
<thead>
<tr>
<th>Absolute speed driven GRPs</th>
<th>Differential speed sensing GRPs</th>
<th>Electric motor driven GRPs</th>
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Problem Statement

• A lot of experience and knowledge is required by the pump designer
• Interactions of different pump tolerance combinations requires extensive test runs
• A trial and error design process is very expensive and time consuming and optimizations are difficult
• Not every parameter can be measured directly

A new approach in computational methods is required
Research Goal

- Development of a multi-domain simulation methodology for GRPs suitable for
  - Pump design and concept considerations in an early stage of development
  - Simultaneous consideration of mechanical and hydraulic effects
  - Consideration of geometrical pump tolerances and their interactions
  - Accurate prediction of the system behavior in the course of a complete system simulation
Literature Overview

**Gear profile generation / optimization**
- Bonandrini G., Mimmi G., Rottenbacher C., 2009-2010

**Geometric and kinematic modeling**

**Analysis of forces and moments**
- Ivanovic L. et al, 2006-2010

**Lumped parameter simulation approach (AMESim)**
- Neyrat S. et al, 2005
- Wieczorek, U. and Ivantysynova, M. 2002
- Furno F., Vasile L., Andersson D., 2009
- Vacca A., Guidetti M., 2011

… several others

An overall approach for the complete system simulation of GRPs and its dynamical interactions with a particular system has never been studied with high level of detail.
GRP Operating Principle

Cover plate  Mid plate  Base plate
Delivery port  Inner rotor  Outer rotor
Suction port  Lateral sealing gaps  Hydrodynamic lubricated bearing

Delivery port  Inner rotor
Suction port  Outer rotor
Base plate  Cover plate  Mid plate
Delivery port  Inner rotor  Outer rotor
Suction port
Modeling Approach

Graphical user interface (GUI)
- Parametric geometry generation
- CAD geometry model
- Pump database
- Geometry import / Export facility

- Numerical calculation of geometry data
  - FEM Model
  - CFD Model

- Lumped parameter fluid dynamic model
- Hydrodynamic bearing model

1) Coupling under development

Dynamic System Simulation

Tools:
- MATLAB/Simulink
- CATIA V5
- ANSYS CFX
- AMESim

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Modeling Approach
Parametric Geometry Generation

- Geometric model for generation of rotor gear profiles based on trochoidal curves

<table>
<thead>
<tr>
<th>Geometrical Parameters</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$r_1$</td>
<td>Radius circle 1 (rolling circle)</td>
</tr>
<tr>
<td>$r_2$</td>
<td>Radius circle 2 (fixed circle)</td>
</tr>
<tr>
<td>$e$</td>
<td>Excentricity</td>
</tr>
<tr>
<td>$a$</td>
<td>Trochoide generating radius</td>
</tr>
<tr>
<td>$\rho$</td>
<td>Envelope radius</td>
</tr>
</tbody>
</table>
Modeling Approach
Fluid Dynamic Model

- Evaluation of flow through the pump due to the displacement action

\[
\frac{dp_i}{df} = \frac{\beta}{\rho_i V_{ch,t} \omega_1} \left( \sum \dot{m}_{i,j} - \omega_1 \rho_t \frac{dV_{ch,i}}{df} \right)
\]

\[
\dot{m}_{i,j} = \frac{p_t - p_f}{\rho_i} A_{i,j}(\varphi) \cdot c_q(RRe_{i,j}) \frac{2(p_t - p_f)}{\rho_i} \sqrt{\frac{h^{3/2}}{12\eta}} \cdot (p_t - p_f)
\]

\[
\dot{m}_{i,j} = \rho_i \left[ -\frac{h^{3/2}}{12\eta} \cdot (p_t - p_f) \right]
\]
Modeling Approach
Numerical Calculation of Geometry Data

• Geometric Model for calculation of characteristic geometry data
Modeling Approach

Fluid Dynamic Model: Implementation in AMESim

- Evaluation of flow through the pump
Graphical User Interface (GUI)

- Design Parameter
- Simulation Parameter
- CAD/FEM Interface
- Pump Layout Window

- Pump Library
- Geometry Import
- Geometry Export

- Result Windows

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Model Validation

Reference Pump 1

Electric motor driven GRP

- $q_v = 0.25\text{cc}$
- $z_i = 12$
- $D_o = 19\text{mm}$
- $B = 7.5\text{mm}$
- $p_{\text{max}} = 30\text{bar}$
- $n_{\text{max}} = 6000\text{rpm}$

Reference Pump 2

Differential speed sensing GRP

- $q_v = 42.5\text{cc}$
- $z_i = 5$
- $D_o = 94\text{mm}$
- $B = 17\text{mm}$
- $p_{\text{max}} = 50\text{bar}$
- $n_{\text{max}} = 500\text{rpm}$
Results

Reference Pump 1

Steady State Pump Operation

T = 50°C, p = 20 bar

<table>
<thead>
<tr>
<th>Pump Tolerance</th>
<th>MIN</th>
<th>NOM</th>
<th>MAX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tip Clearance [mm]</td>
<td>0.025</td>
<td>0.050</td>
<td>0.075</td>
</tr>
<tr>
<td>Lateral Clearance [mm]</td>
<td>0.015</td>
<td>0.020</td>
<td>0.025</td>
</tr>
</tbody>
</table>
Comparison with Test Results

Reference Pump 2

MIN clearance pump
T=60°C, n=40rpm

MAX clearance pump
T=60°C, n=40rpm

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</thead>
<tbody>
<tr>
<td>Tip Clearance</td>
<td>0.020</td>
<td>0.025</td>
<td>0.030</td>
</tr>
<tr>
<td>Lateral Clearance</td>
<td>0.019</td>
<td>0.024</td>
<td>0.029</td>
</tr>
</tbody>
</table>
Complete system simulation
System Simulation
Reference Pump 1

- Complete system simulation

Toil=50 °C

<table>
<thead>
<tr>
<th>Coll. #</th>
<th>Pump #</th>
<th>Pump Tol.</th>
<th>Revs [-]</th>
<th>p_eff [bar]</th>
<th>U_eff [V]</th>
<th>I_eff [A]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>MIN</td>
<td>6072</td>
<td>5.75</td>
<td>2.00</td>
<td>3.09</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MAX</td>
<td>7069</td>
<td>5.81</td>
<td>2.12</td>
<td>3.15</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>MIN</td>
<td>3799</td>
<td>4.73</td>
<td>1.54</td>
<td>2.57</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MAX</td>
<td>12330</td>
<td>5.01</td>
<td>2.15</td>
<td>1.80</td>
</tr>
</tbody>
</table>
Numerical Model for Lateral Sealing Gaps

- Evaluation of lateral leakage flow

Lateral leakage path
Gap height $s$

Fluid Domain 1
Fluid Domain 2

$Q_{\text{leak,ext}}$
$Q_{\text{leak,int}}$
$Q_{\text{eff,Bearing}}$
$Q_{\text{eff,Shaft}}$

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Finite Element Model

Max. Principal Stress

Min. Principal Stress

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Conclusion

- Based on current stage of development the model is already useful for concept considerations in an early phase of product development
- All essential pre- and post-processing operations can be performed out of a central and easy to handle GUI
- The presented modeling approach is general suitable for all possible GRP geometries
- The model can easily be integrated into a complete hydraulic systems
- The modeling approach shows great potentials for a comprehensive and bi-directional coupling of the specific models
Future Work

- CFD Model to consider leakage flow paths and viscous torque losses in the lateral sealing gaps
- Bi-directional coupling of the FEM and CFD model with the lumped parameter fluid dynamic model
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