research activities on Gear Pumps/Motors
- Highlights -
Projects List:

1. Modeling: the simulation tool HYGESim (HYdraulic GEar machines Simulator)
2. Pump / motor testing
3. Optimization of standard designs
4. Proposal, analysis and optimization of new designs
5. Analysis of solutions for variable displacement units
Project 1: The simulation tool HYGESim (a)

Goals
• Entire simulation of external gear machines (pumps/motors) considering main physical phenomena
• Tool versatile, useful for verification/design purposes

Main features of the HYGESim (HYdraulic GEar machines Simulator)
• detailed geometrical model
• developed within AMESim®
• detailed model for fluid properties
• simulation of the complete inlet/outlet hydraulic systems
• evaluation of flow delivery features
• evaluation of internal pressure peaks
• calculation of gears’ axes of rotation micro-motion
• evaluation of casing wear

Fig 1a - HYGESim icon within AMESim simulation environment
Fig 1b – hydrodynamic pressure in the gap between gears and bushings evaluated by HYGESim CFD module
Project 1: The simulation tool HYGESim (b)

Structure of the model

Different versions of HYGESim are available, as a function of the level of details considered in the simulation.

*Fig 1c - HYGESim structure*

*Fig 1d – different HYGESim submodels*
Project 1: Simulation tool HYGESim (c)

Modeling insights

Fig 1e – detailed evaluation of all internal geometrical features

Fig 1f – evaluation of internal control volumes as a function of gears (centers and angular) position

Fig 1g – accurate evaluation of pressure forces acting on the gears
Project 1: Simulation tool HYGESim (d)

**Modeling insights**

**CFD module implemented in O-Foam**
- evaluation of leakage flow in the lubricating gap at gears’ lateral sides
- calculation of thrust forces
- possibility of simulating a tilt angle (no-flat gap)

**Fig 1h** – the lubricating gap considered by the CFD module

**Fig 1i** – Automatic meshing during gear revolution considering the presence of grooves
Project 1: Simulation tool HYGESim (e)

Typical results

Fig 1j – Forces acting on the gears and contact force

Fig 1k – Pressure in a tooth space volume and detection of cavitation

Fig 1l – Evaluation of outlet flow pulsation
Project 1: Simulation tool HYGESim (f)

Typical results

Fig 1m – radius of the casing after the operation

Fig 1n – example of pressure distribution on gear lateral surface (flat gap)

Fig 1o – pressure distribution on gear lateral surface (tilted gap)
Project 1: Simulation tool HYGESim (g)

**Typical results**

*Fig 1p* – evaluation of radial forces and of pressure distribution on lateral bushings

*Fig 1q* – calculation of axial force on bushings or sliding bearing blocks
Project 1: Simulation tool HYGESim (h)

Model validation

HYGESim predictions have been successfully validated on the basis of various comparisons between simulation results and experimental data. See project 2 for more details about the experimental apparatus.
Dr. Andrea Vacca  
MAHA Assistant professor  
Purdue University

Activities on gear pumps/motors

Project 1: Simulation tool HYGESim (i)

Model validation

![Figure 1t - measured vs. compared casing wear (pump, driven gear side)](image)

![Figure 1u - Energy of fundamental frequency terms in delivery pressure ripple (pump)](image)

Conclusions – Final remarks of Project 1

- HYGESim is an advanced and unique tool for the analysis of main aspects related to the operation of external gear machines
- HYGESim can be utilized for design purposes. Source of losses, noise emissions can be investigated using HYGESim. HYGESim can also be utilized for the analysis of new design solutions (see also following projects)
Project 1: Simulation tool HYGESim (j)

For more details..

• write to mahaav@ecn.purdue.edu

• see published papers:
**Project 2: Pump/Motor testing (a)**

**Goals**
- Development of innovative measurements techniques for external gear machines
- Deep understanding of operating phenomena
- Verification of HYGESim predictions

**Performed tests**
- Steady state measurements
- Pressure ripple measurements (pumps)

*Fig 2a – Example of system used for the steady state characterization (motor)*

*Fig 2b – Schematic of the experimental apparatus to permit an easy comparison with HYGESim predictions*

*Fig. 2c – Measured FFT and calculation of energy parameters to attenuate spread effects (for clear comparisons with HYGESim prediction)*
**Project 2: Pump/Motor testing (b)**

**Performed tests**

- Wear measurements

*Fig 2d – Measurement of the casing wear at different axial position*

- Internal tooth space pressure measurements

*Fig 2e – Micro-transducer inside a tooth space volume*

*Fig 2f – Measurement system inclusive of telemetry*
Project 2: Pump/Motor testing (c)

Performed tests

Fig 2g – Apparatus inclusive of telemetry system and pressure ripple measurements

Conclusions – Final remarks of Project 2

- Experimental apparatus have been conceived for specific and precise tests on external gear machines
- Performed tests have permitted a clear understanding of the main features related to the operation of pumps and motors
- Particular attention has been made on developing procedure for testing and data post-processing suitable for the comparisons with numerical results
Project 2: Pump/Motor testing (d)

For more details..

- write to mahaav@ecn.purdue.edu
- see published papers:
Project 3: Optimization of Standard Designs (a)

**Goals**
- Proposal of new designs characterized by improved performance
- Targets considered for the definition of the optimization problem: efficiency, noise emissions, internal pressure peaks, gross or local cavitation

**The approach**
Stochastic optimization based on HYGESim simulation results

**Main features of the algorithm:**
- valid for generic cases (depending on selected input parameters and objective functions)
- multi-objective optimization features (deep analysis of possible optimal alternatives)
- analysis of single/mutual influence of input factors on objective functions
- procedure completely automated

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Fig 3a – Scheme of the optimization approach based on HYGESim results
Project 3: Optimization of Standard Designs (b)

Implementation of the optimization procedure

Selected optimization environment: modeFrontier®

Fig 3b – Simplified representation of the optimization workflow. Black icons are representative of simulation tools executed by the procedure automatically.

Fig 3c – Definition of some considered objective functions.
Project 3: Optimization of Standard Designs (c)

Example of optimization

Selected input parameters

Fig 3d – Shape of recesses machined on the sliding bearing blocks

Results

Obtained after more than 400 configurations considered by the optimization algorithm

<table>
<thead>
<tr>
<th>OBJECTIVES</th>
<th>OF₁ Pressure ripple [Δ%]</th>
<th>OF₄ Volumetric efficiency [Δ%]</th>
<th>OF₂ TSV pressure peak [Δ%]</th>
<th>OF₃ Cavitation [Δ%]</th>
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<tbody>
<tr>
<td>TARGET</td>
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<td>maximize</td>
<td>minimize</td>
<td>minimize</td>
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</tbody>
</table>

Fig 3e – Measured steady-state characteristics (improvements achieved by C₁ are evident)

C₁: better on volumetric efficiency
C₂: lower noise emissions
Project 3: Optimization of Standard Designs(d)

Conclusions – Final remarks of Project 3

• The developed optimization procedure is general. It can be used to optimize other design parameters using the same workflow and same formulation for the objective functions
• Other optimization targets can be easily included in the procedure as additional objective functions

For more details..

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• see published papers:
Project 4: Proposal, analysis and optimization of new solutions

Goals

• Proposal of innovative, high efficient designs for external gear machines
• Targets considered for the definition of the optimization problem: efficiency
  \textit{(same as project 3)}
  \begin{tabular}{p{.6\textwidth}p{.3\textwidth}}
  \textbf{noise emissions} & \\
  \textbf{internal pressure peaks} & \\
  \textbf{gross or local cavitation} & \\
\end{tabular}

Considered ideas

1. Uses of internal pre-compression volumes opportunely connected to tooth space volumes
   \textbf{Target achieved}: reduction of flow pulsation
2. Uses of intermediate volumes connected to delivery and meshing zone
   \textbf{Target achieved}: reduction of flow pulsation; increment of efficiency

Approach of analysis

• Extensive use of the simulation tool HYGESim for the understanding of the phenomena involved in the new solution
• Adoption of the optimization procedure described in Project 3

Conclusions – Final remarks of Project 4

• The potentials of the new ideas and of the optimization procedure (project 2) is highlighted by numerical results and preliminary tests
• The design of other possible new ideas can be defined using the same optimization procedure

For more details.. write to mahaav@ecn.purdue.edu
Project 5: Analysis of solutions to realize variable displacement units

**Goals**
- Proposal of innovative designs characterized by the possibility of realizing variable displacement without a significant increment of costs

**Considered ideas**

1. Variable displacement obtained changing the distance between gears
   **Target**: analysis of maximum displacement range
   design of the solution

2. Variable displacement obtained varying the length of the active contact between the gears
   **Target**: design of the solution

3. Variable displacement obtained varying the timing of the connections in the meshing zone (low cost solution)
   **Target**: analysis of maximum displacement range
   design of the solution
   *(schematic drawing not reported, not yet published)*

**Approach of analysis**

- Extensive use of the simulation tool HYGESim for the understanding of the phenomena involved in the proposed design
- Use of simulation tool modeFrontier to optimize the parameters

For more details,... write to mahaav@ecn.purdue.edu