

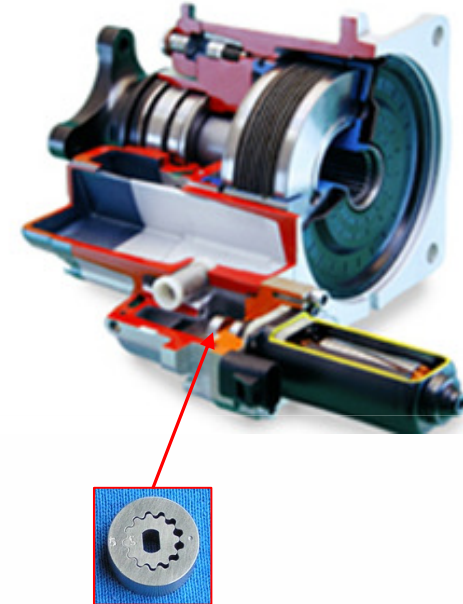
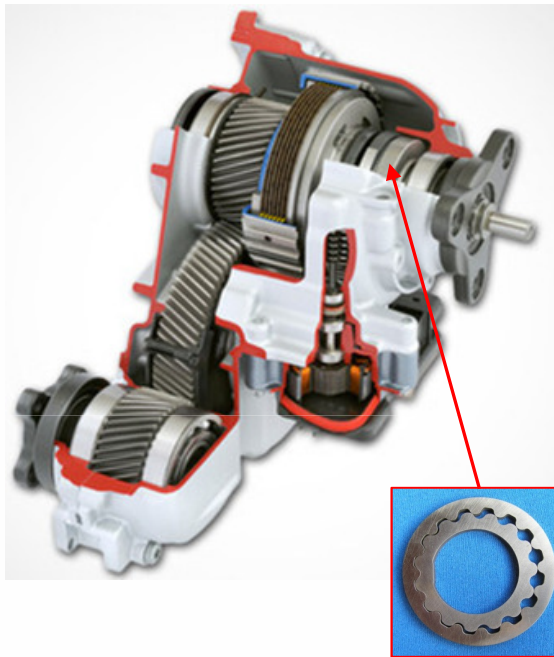
Gerotor Pumps for Automotive Drivetrain Applications: A Multi Domain Simulation Approach

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GRPs in AWD-Powertrain Systems



Absolute speed driven GRPs	Differential speed sensing GRPs	Electric motor driven GRPs
500 ... 9000 rpm	- 500 ... + 500 rpm	0 ... 6000 rpm
max. operating pressure \leq 30 bar		

GRPs in AWD-Powertrain Systems



Absolute speed driven GRPs	Differential speed sensing GRPs	Electric motor driven GRPs
500 ... 9000 rpm	- 500 ... + 500 rpm	0 ... 6000 rpm
max. operating pressure \leq 30 bar		
 Two circular metal gears with a serrated outer edge and a central hole, shown against a blue background.	 Two circular metal gears with a complex, multi-lobed internal profile and a central hole, shown against a blue background.	 Five circular metal gears of various sizes and designs, some with serrated edges and some with different internal profiles, shown against a blue background.



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

- Litvin F. L., Feng P.-H., 1996
- Hsieh C.-F., Hwang Y.-W., 2007-2009
- Bonandrini G., Mimmi G., Rottenbacher C., 2009-2010

Geometric and kinematic modeling

- Fabiani M., Mancò S., Nervegna N., Rundo M. et al., *"Modeling and Simulation of Gerotor Gearing in Lubricating Oil Pumps"*, SAE Paper 1999-01-0626, March 1999

... several others

Analysis of forces and moments

- Ivanovic L. et al, 2006-2010

Lumped parameter simulation approach (AMESim)

- Mancò S., Nervegna N., Rundo, M. et al, 2004-2009
- Neyrat S. et al, 2005
- Wieczorek, U. and Ivantysynova, M. 2002
- Furno F., Vasile L., Andersson D., 2009
- Vacca A., Guidetti M., 2011

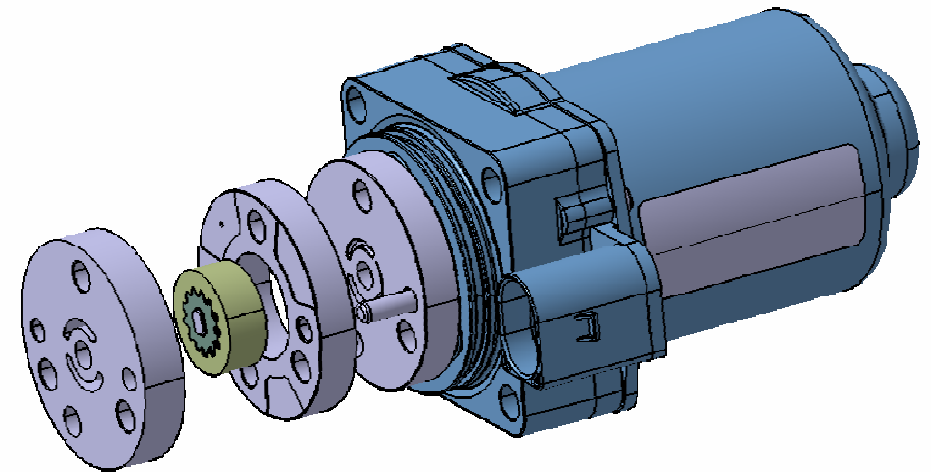
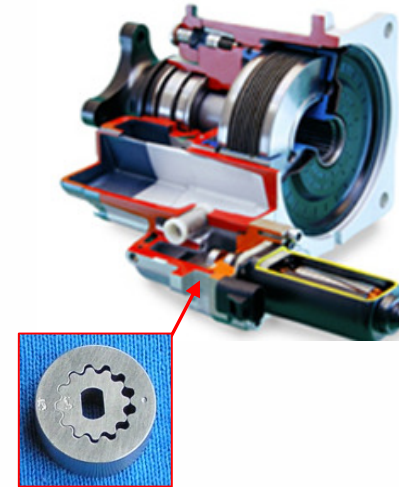
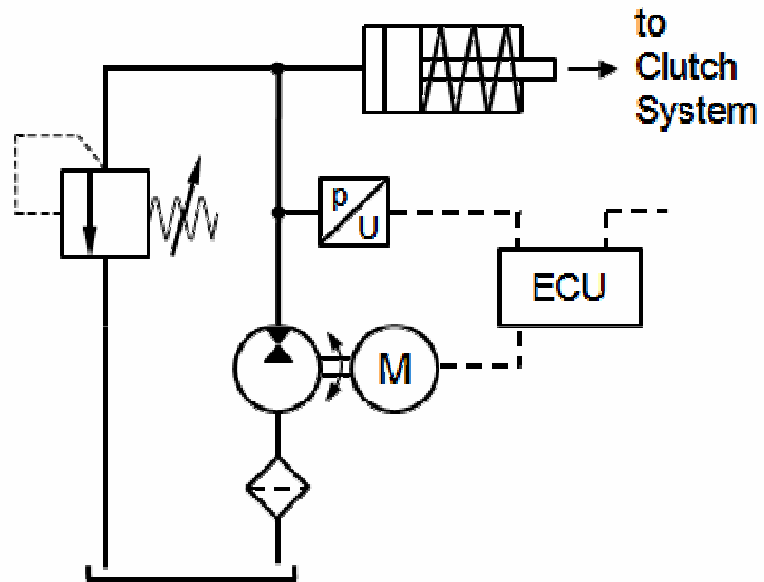
↖ Axial piston machines

→ Vane pumps

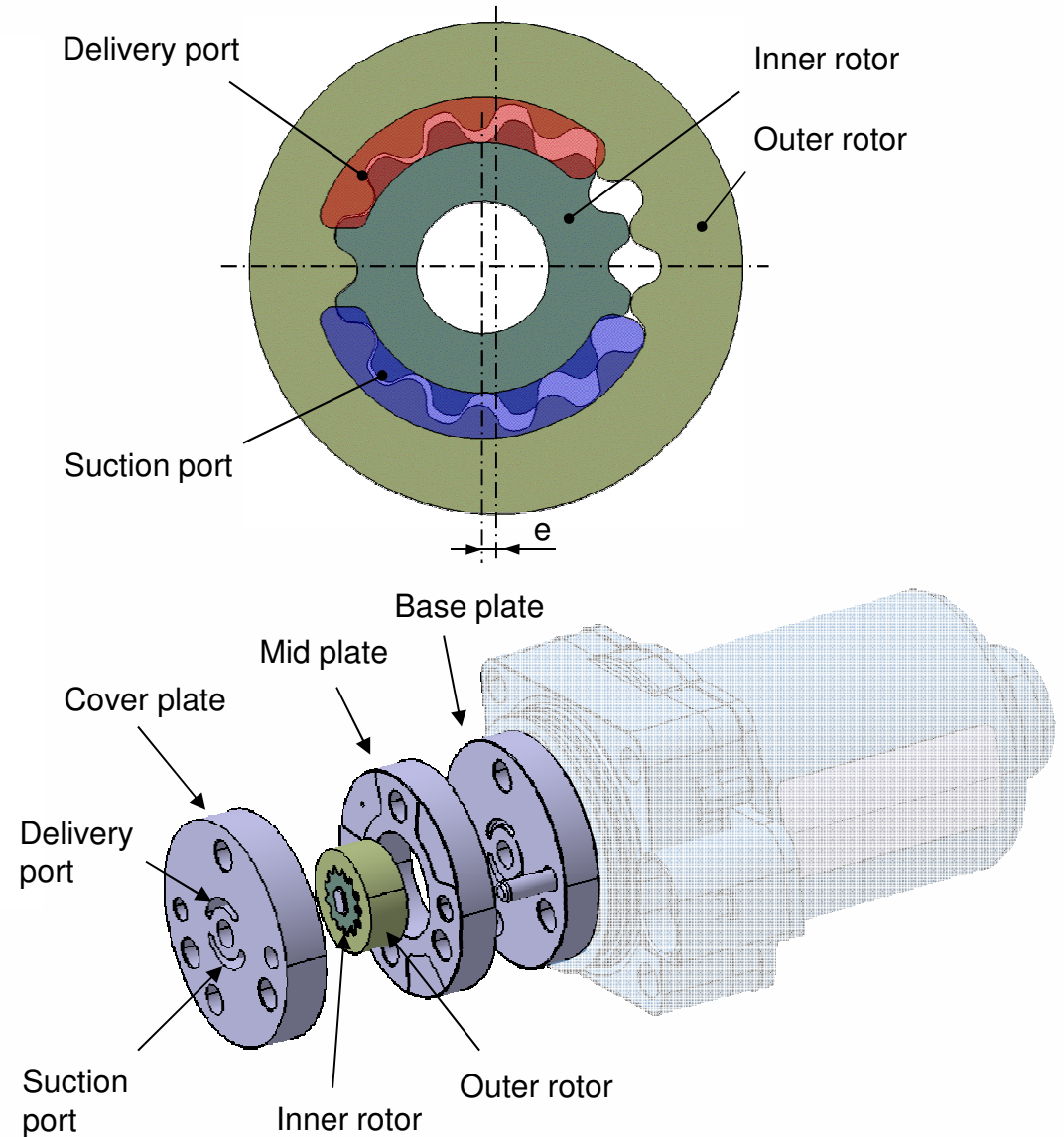
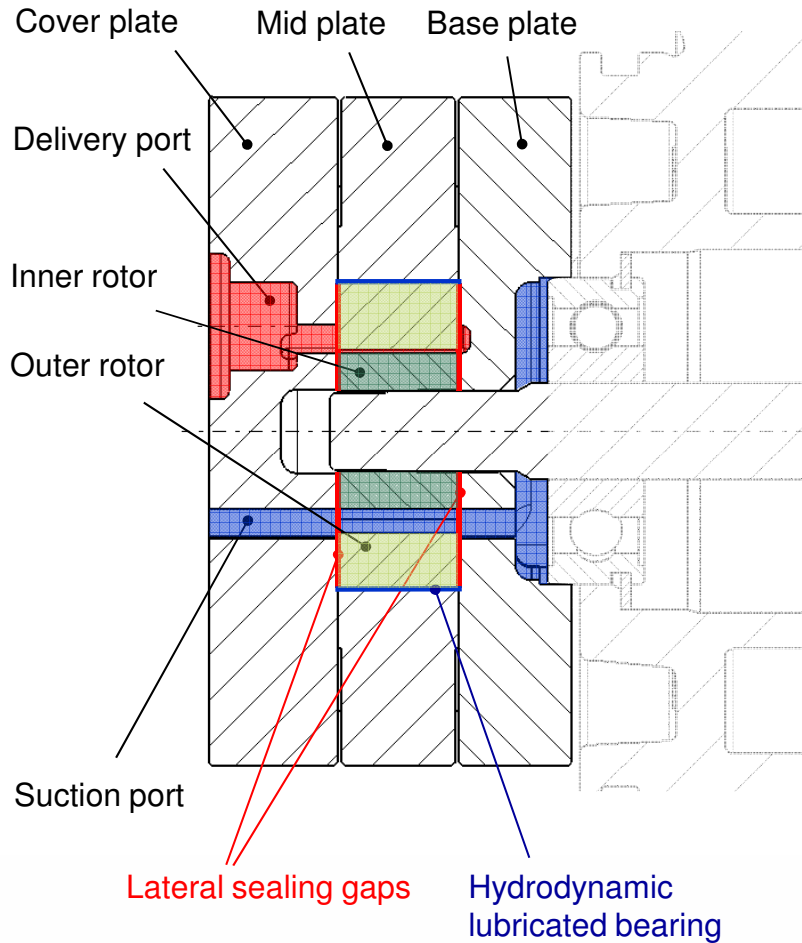
↘ External gear pumps

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.

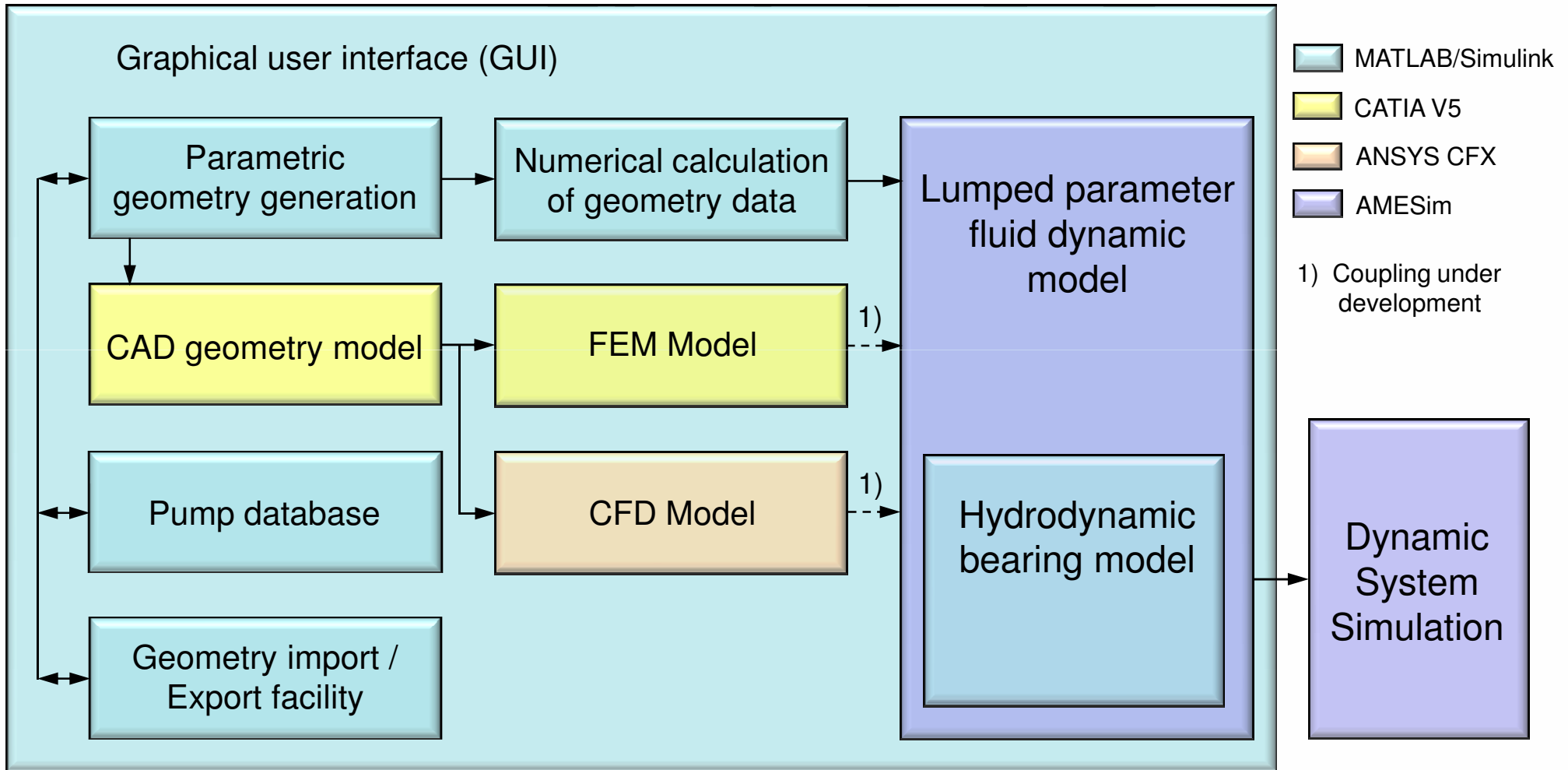
GRP Operating Principle



GRP Operating Principle



Modeling Approach

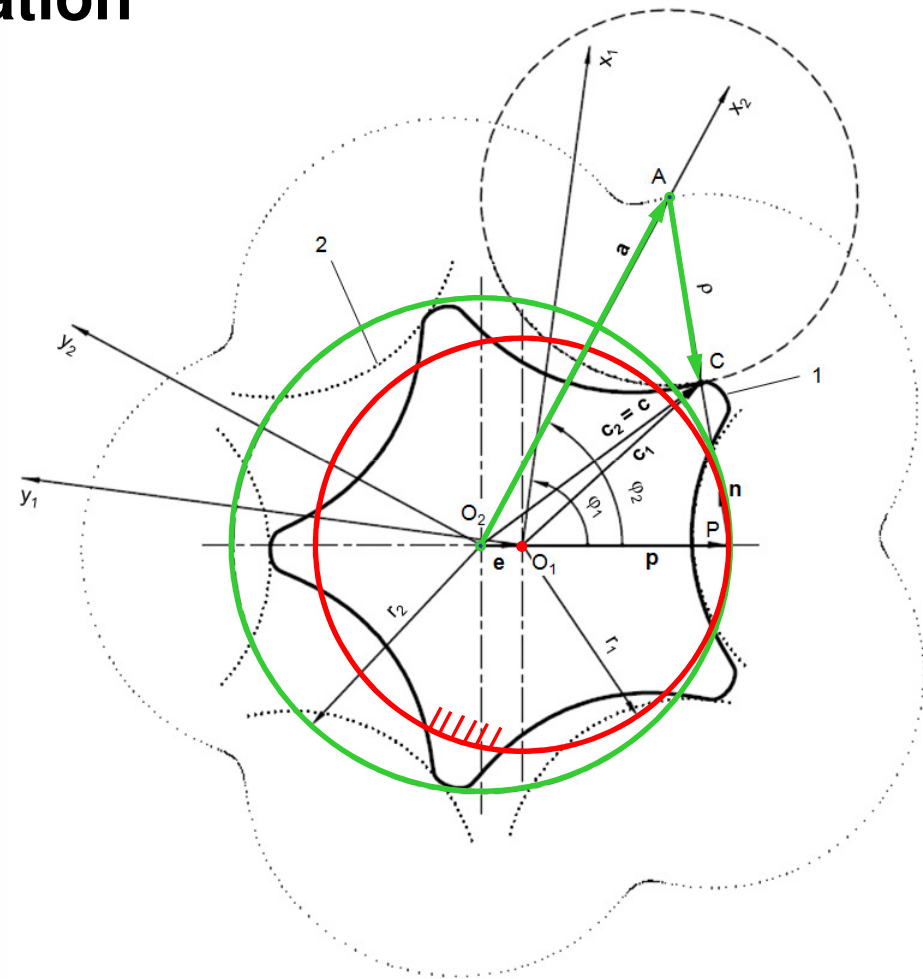


Modeling Approach

Parametric Geometry Generation



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



Geometrical Parameters

r_1	Radius circle 1 (rolling circle)
r_2	Radius circle 2 (fixed circle)
e	Excentricity
a	Trochoide generating radius
ρ	Envelope radius

Modeling Approach

Fluid Dynamic Model

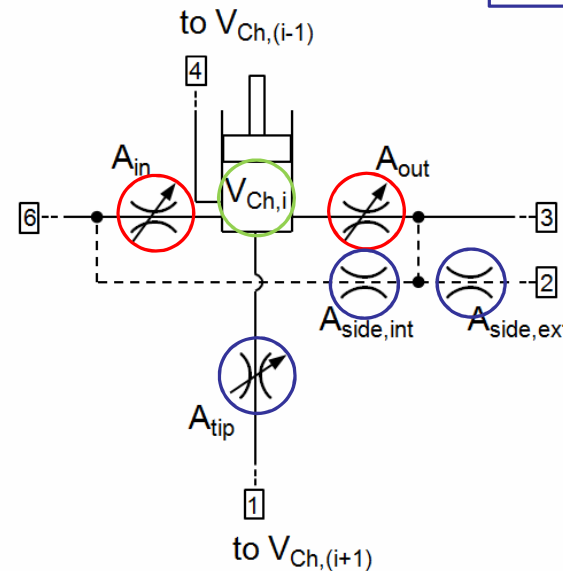
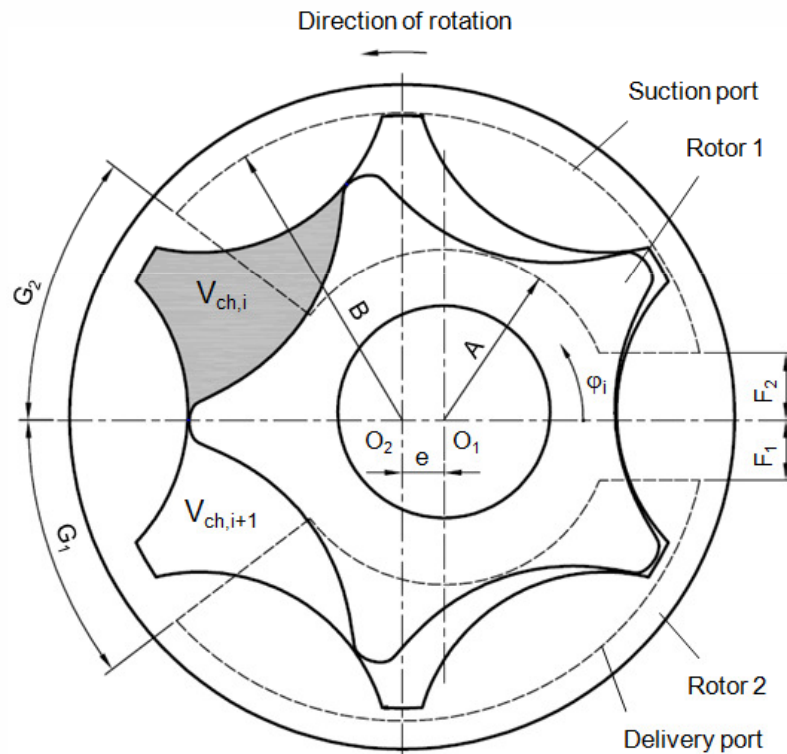


- Evaluation of flow through the pump due to the displacement action

$$\frac{dp_t}{d\varphi} = \frac{\beta}{\rho_i V_{ch,i} \omega_1} \left(\sum \dot{m}_j - \omega_1 \rho_t \frac{dV_{ch,t}}{d\varphi} \right)$$

$$\dot{m}_{t,j} = \frac{p_i - p_j}{|p_i - p_j|} \rho(\bar{p}_{1,j}) \cdot A_{t,j}(\varphi) \cdot c_q(Re_{t,j}) \sqrt{\frac{2(p_i - p_j)}{\rho(\bar{p}_{1,j})}}$$

$$\dot{m}_{t,j} = \rho(\bar{p}_{1,j}) \cdot \left[-\frac{h^3 b}{12\eta l} \cdot (p_i - p_j) \right]$$

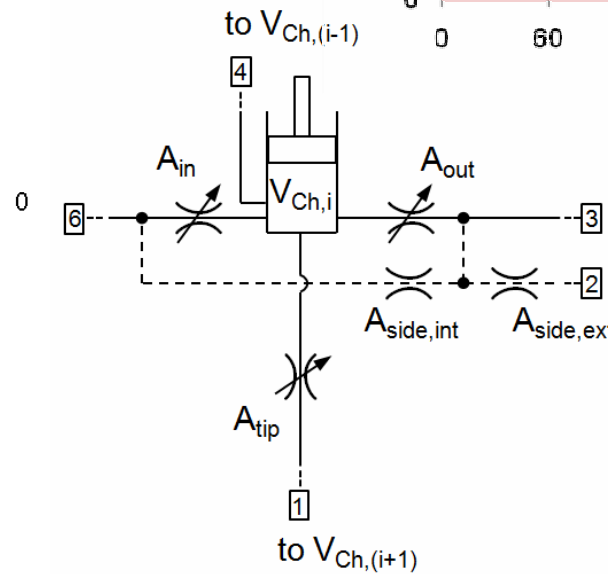
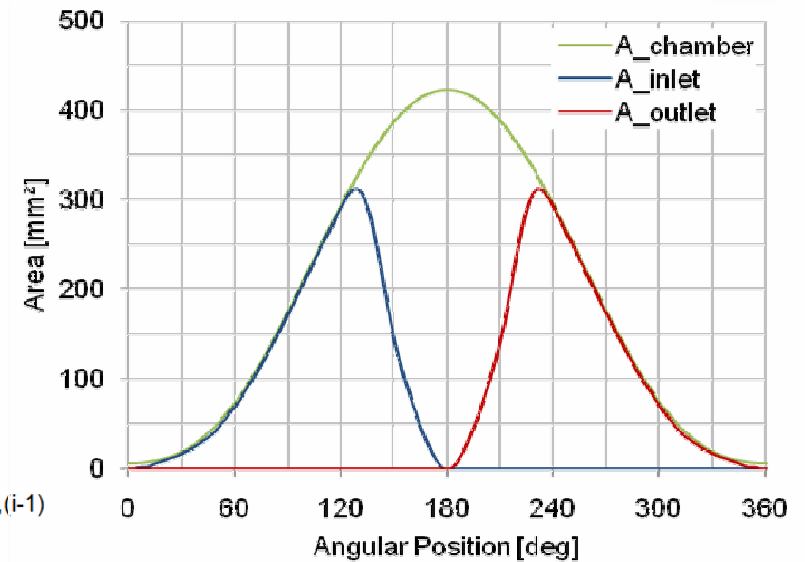
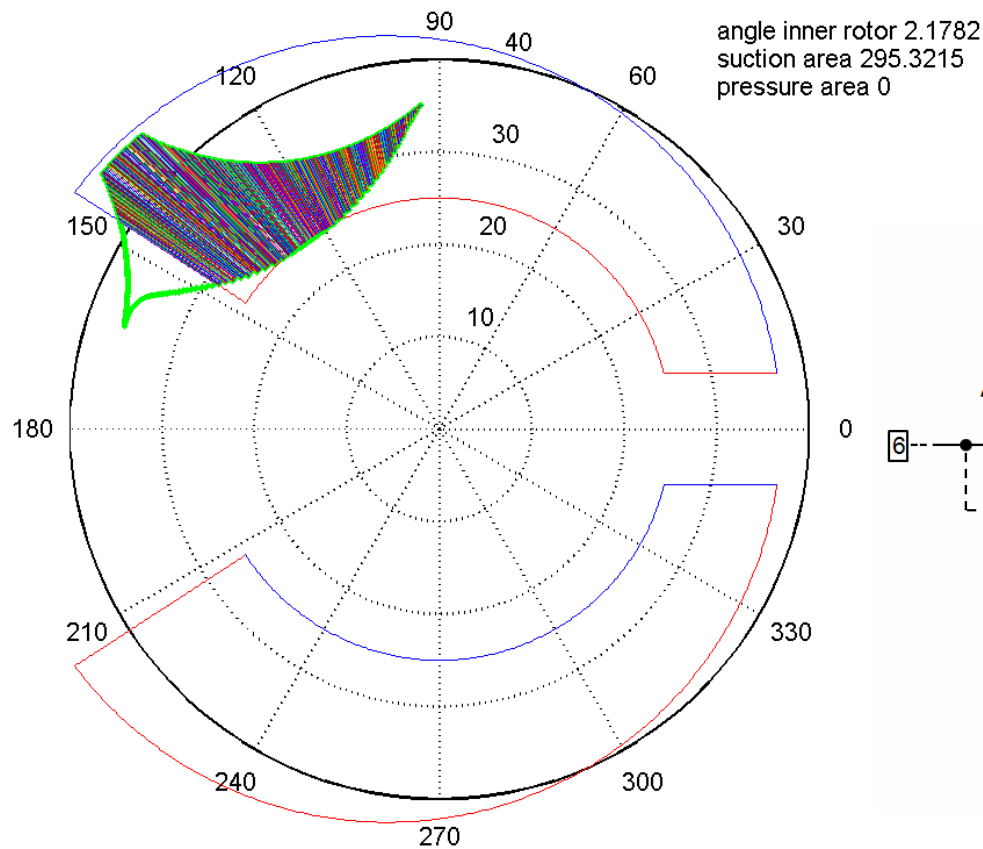


Modeling Approach

Numerical Calculation of Geometry Data



- Geometric Model for calculation of characteristic geometry data

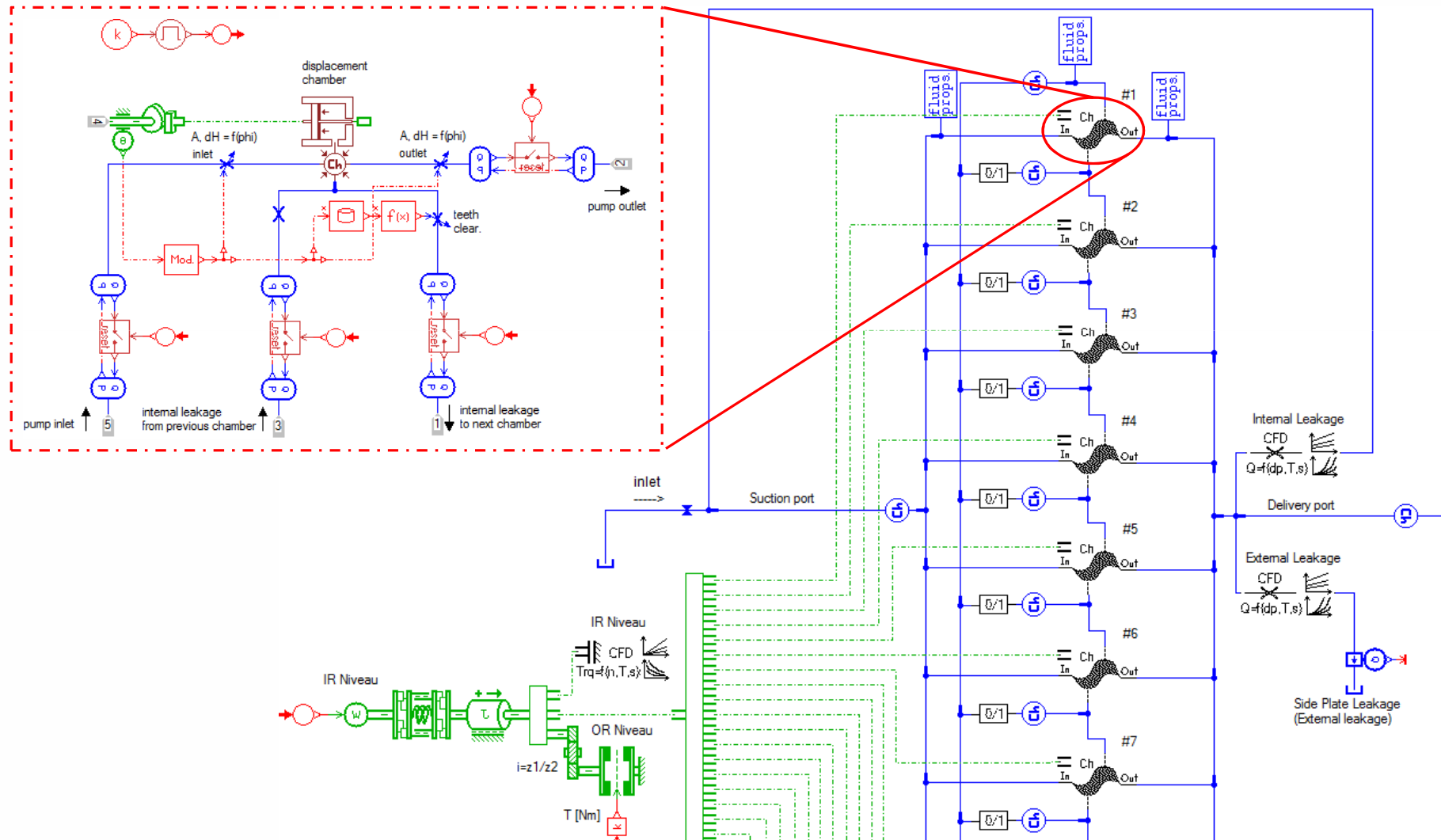


Modeling Approach

Fluid Dynamic Model: Implementation in AMESim



- Evaluation of flow through the pump



Graphical User Interface (GUI)

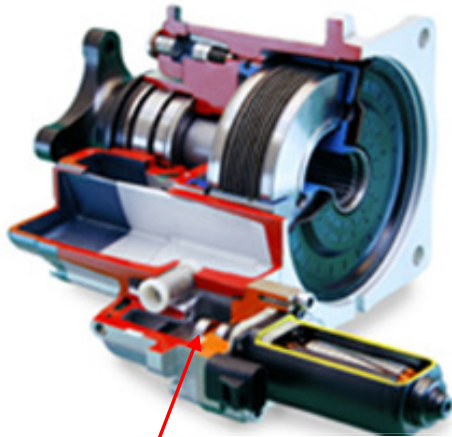


The screenshot displays the Maha Fluid Power GUI with several key sections:

- Design Parameter:** Includes rotor profile settings (K, z1, a, rho, e), tolerance settings (Inner/Outer Rotor Offset, Lateral Clearance, OD-Housing Clear, IR-Shaft Clearance, Tip-Clearance), porting dimensions (A, B, F1, F2, G1, G2), and outer/inner rotor dimensions (OD, ID, Width, Displ.).
- Simulation Parameter:** Defines pump operating conditions (Fluid Type: SHELL TF 0870, Final Time, Print Interval, Toil, n1, n2, p1, p2) and simulation result plot options (Speed Characteristics, Rotation Angle Characteristics).
- CAD/FEM Interface:** Sets meshing parameters (Inner/Outer Rotor element size: global/local) and material properties (Young Modulus, Poisson Ratio) for the rotor set and shaft.
- Pump Layout Window:** Shows a 2D layout of the pump components with plot options for Inner Rotor, Outer Rotor, Inlet Port, and Delivery Port. It also includes rotation controls (Rotate CCW/CW, Step Size) and resolution settings.
- Pump Library:** Allows loading predefined parameter sets (e.g., CGero) and saving custom ones.
- Geometry Import/Export:** Provides fields for importing rotor data files and buttons for exporting inner/outer rotor and suction/delivery port data.
- Classification Analysis:** Includes a 'Start Classification' button.
- Analysis Window:** Contains two graphs: 'Flow Rate - Speed Characteristic' and 'Torque - Speed Characteristic'. A 'Result Windows' callout points to these graphs.
- Pump Performance (Mean Values):** Lists key performance indicators such as Pump Rotary Speed, Pump Efficiency (eta_vol, eta_mh, eta_total), Flow/Torque Irregularity (delta_Q, delta_T), Hydrodynamic Bearing parameters (h0, beta, Epsilon, So), and shaft life (cL).

Model Validation

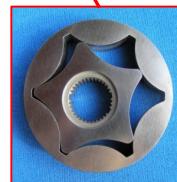
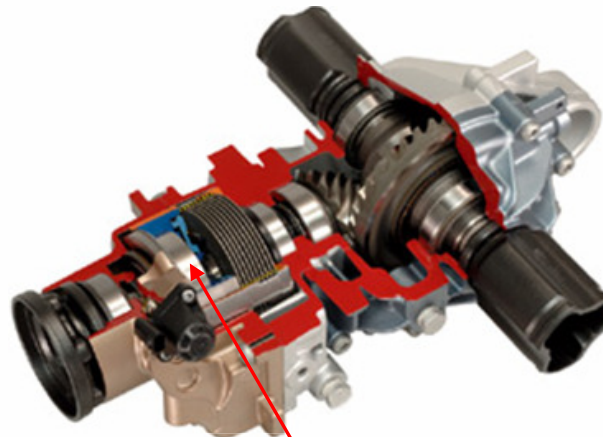
Reference Pump 1



Electric motor driven GRP

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

Reference Pump 2



Differential speed sensing GRP

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

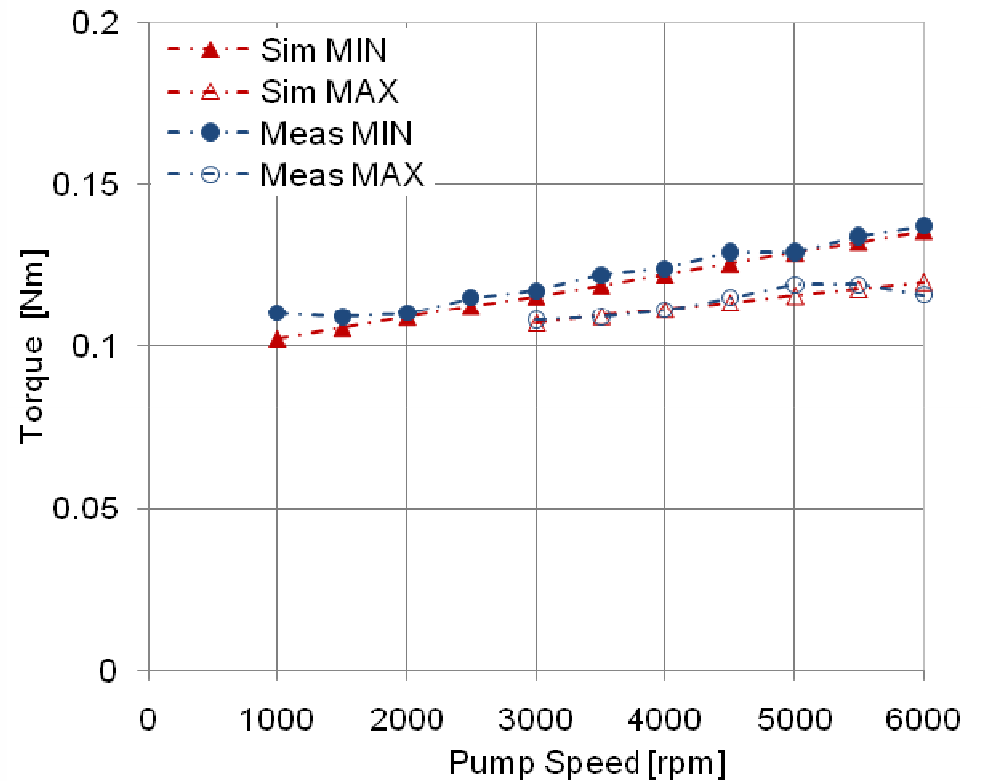
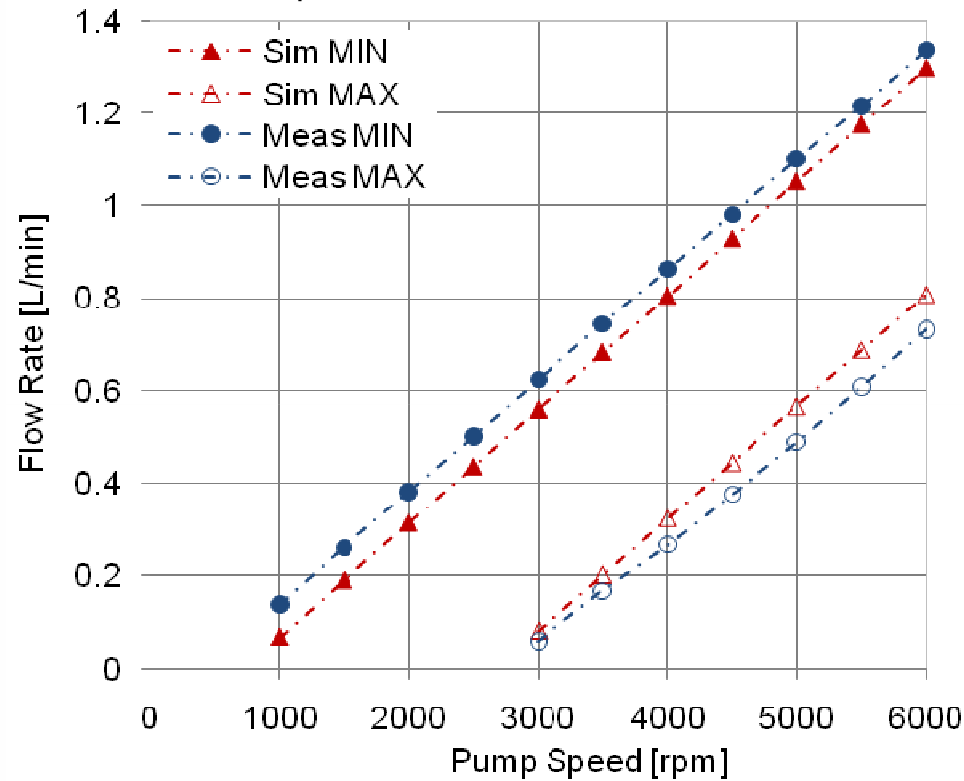
Results

Reference Pump 1



Steady State Pump Operation

T=50°C, p=20bar



Pump Tolerance	MIN	NOM	MAX
Tip Clearance [mm]	0.025	0.050	0.075
Lateral Clearance [mm]	0.015	0.020	0.025

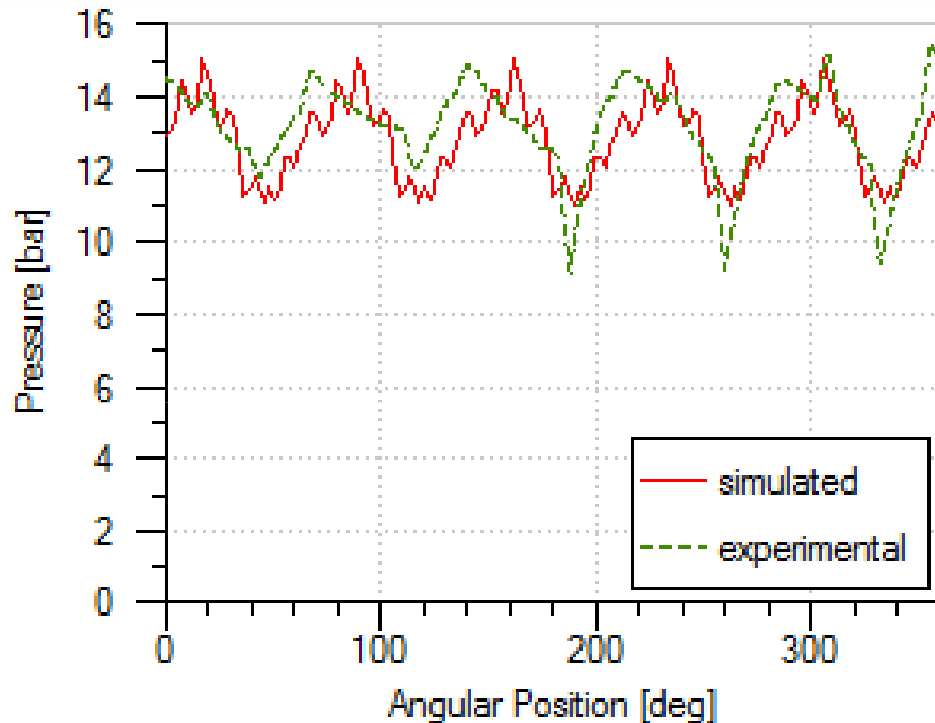
Comparison with Test Results

Reference Pump 2



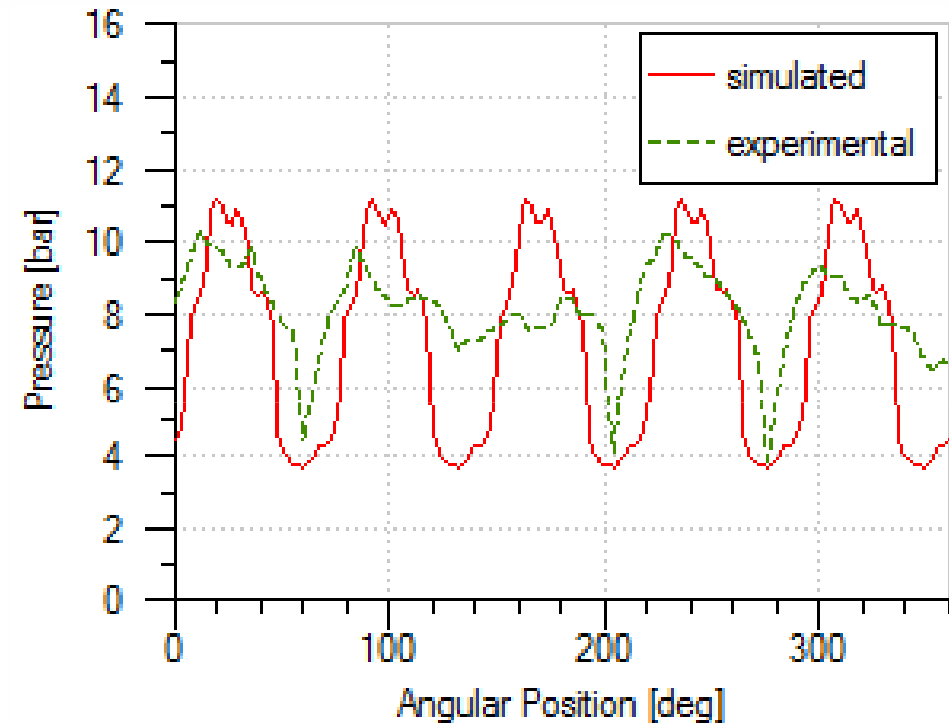
MIN clearance pump

T=60°C, n=40rpm



MAX clearance pump

T=60°C, n=40rpm



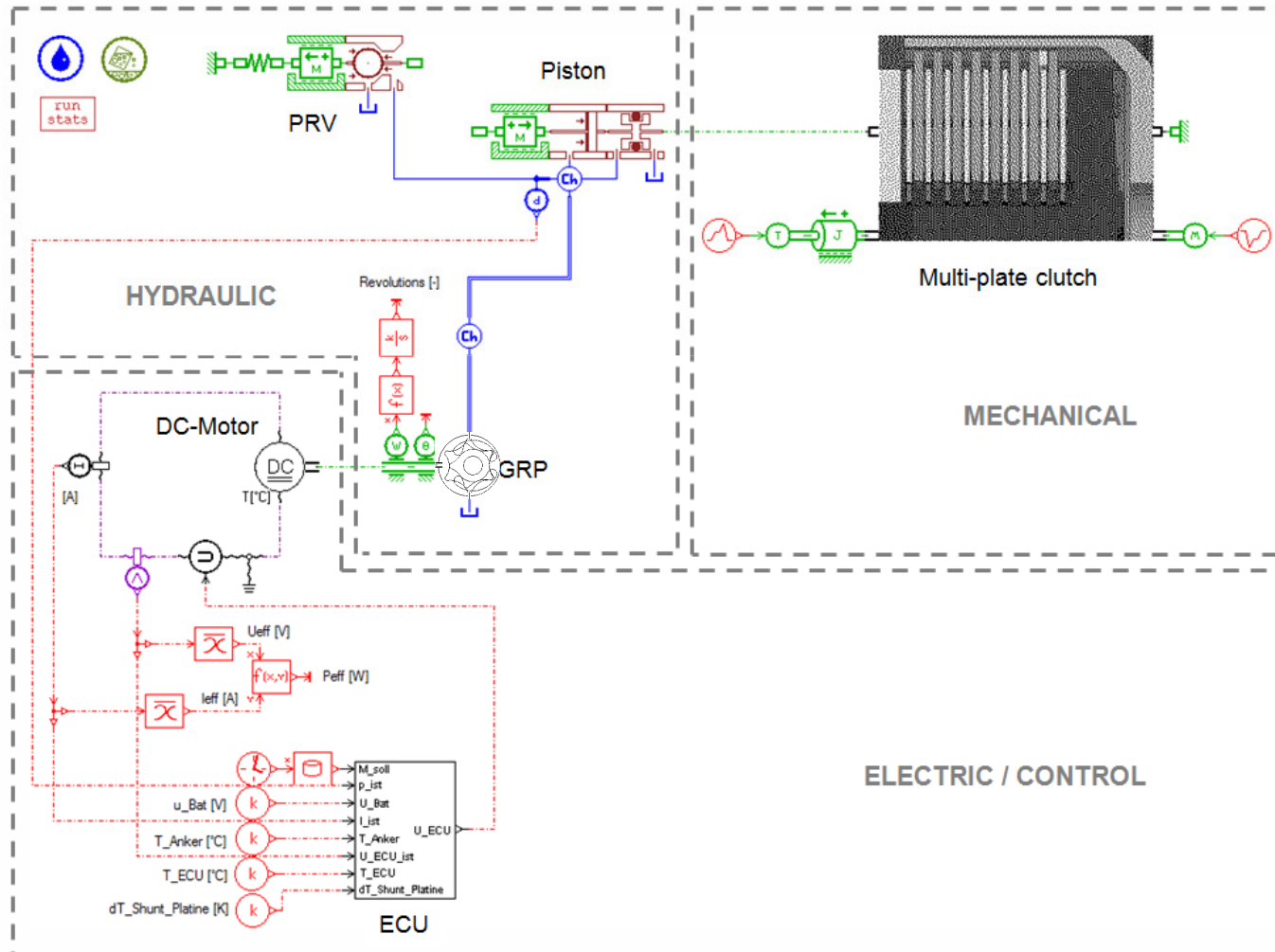
Pump Tolerance	MIN	NOM	MAX
Tip Clearance	0.020	0.025	0.030
Lateral Clearance	0.019	0.024	0.029

System Simulation

Reference Pump 1



- Complete system simulation



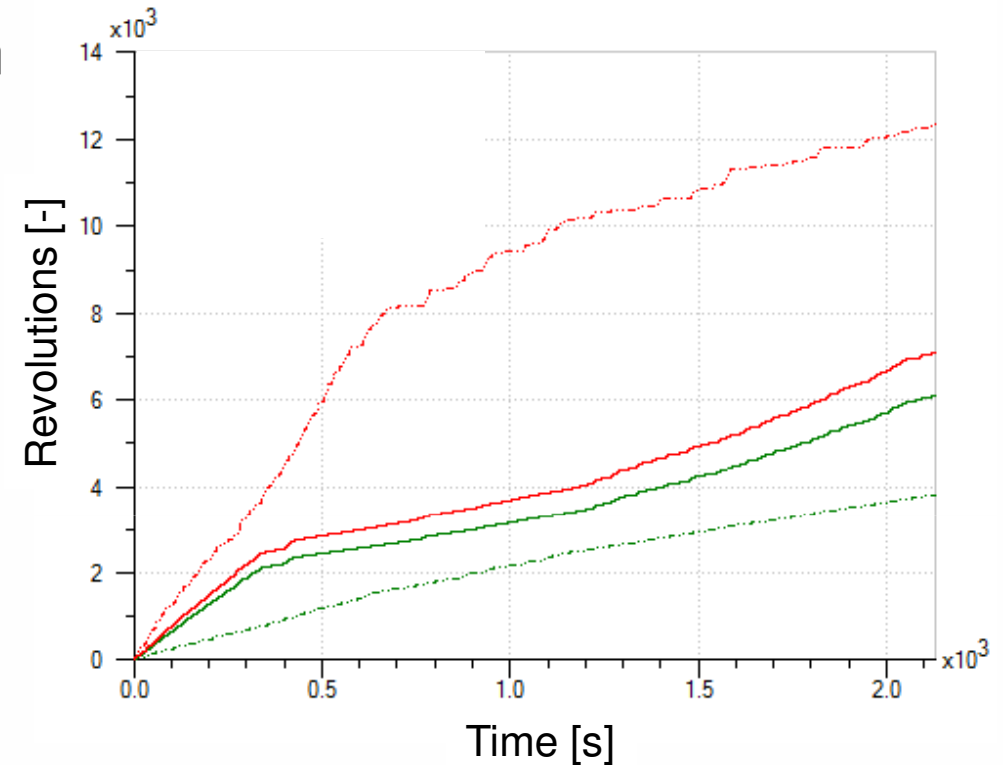
System Simulation

Reference Pump 1



- Complete system simulation

— Pump A (MIN Clear., Coll. 1)
 — Pump A (MAX Clear., Coll. 1)
 - - - Pump B (MIN Clear., Coll. 2)
 - - - Pump B (MAX Clear., Coll. 2)



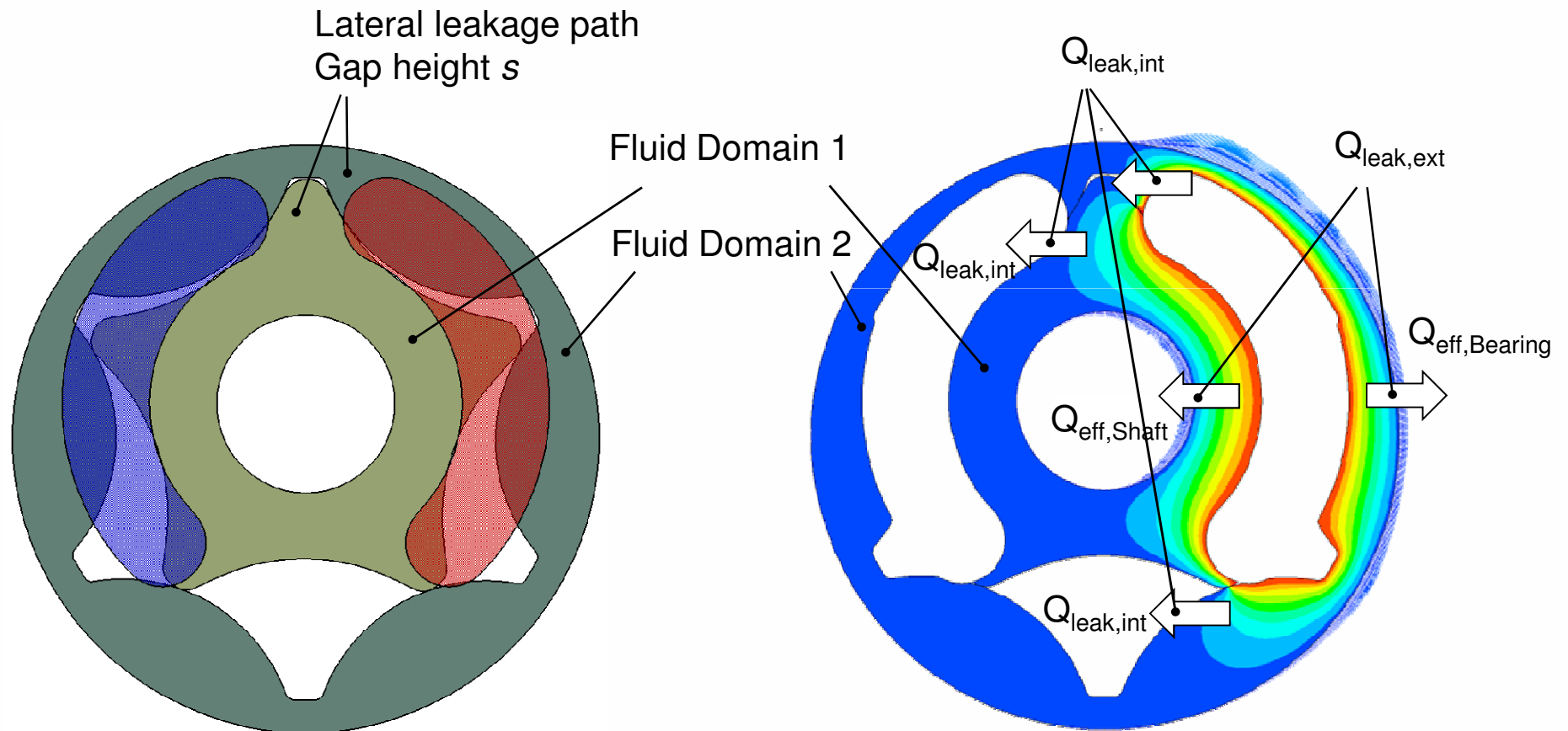
Toil=50 °C

Coll. #	Pump #	Pump Tol.	Revs [-]	p_eff [bar]	U_eff [V]	I_eff [A]
1	A	MIN	6072	5.75	2.00	3.09
		MAX	7069	5.81	2.12	3.15
2	B	MIN	3799	4.73	1.54	2.57
		MAX	12330	5.01	2.15	1.80

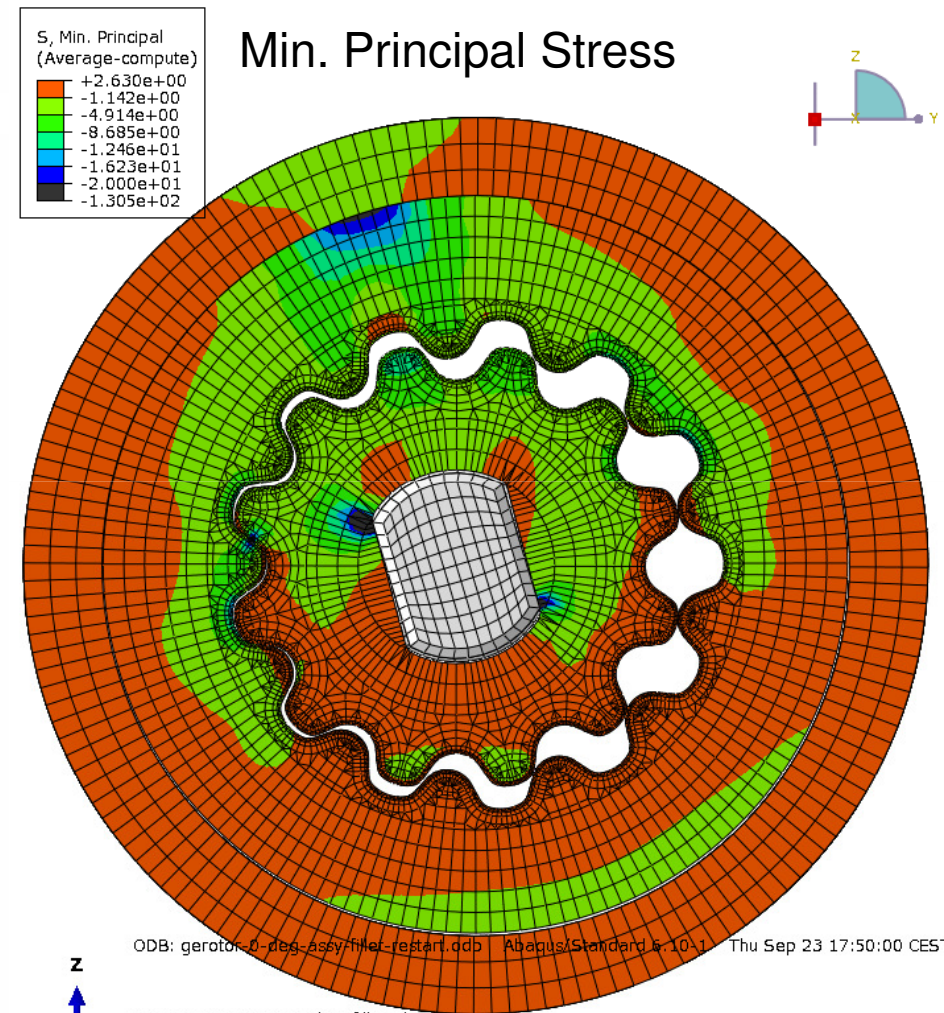
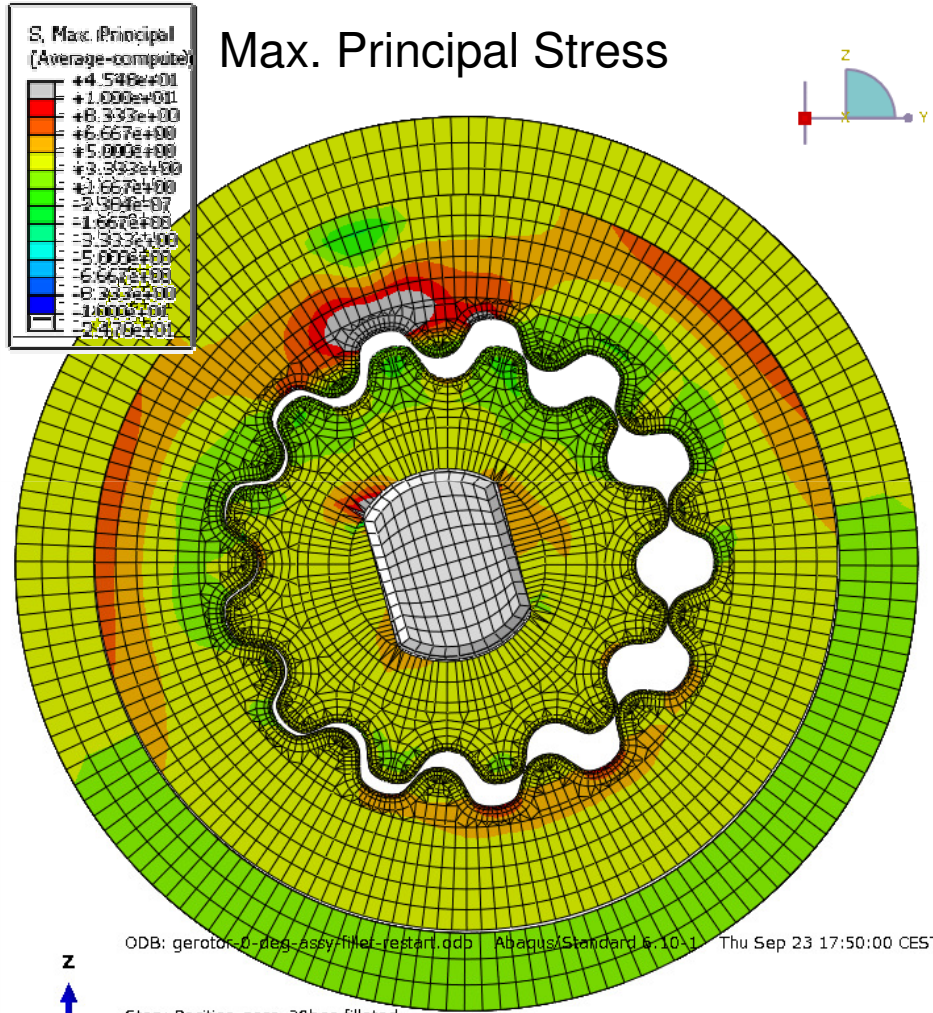
Numerical Model for Lateral Sealing Gaps



- Evaluation of lateral leakage flow



Finite Element Model



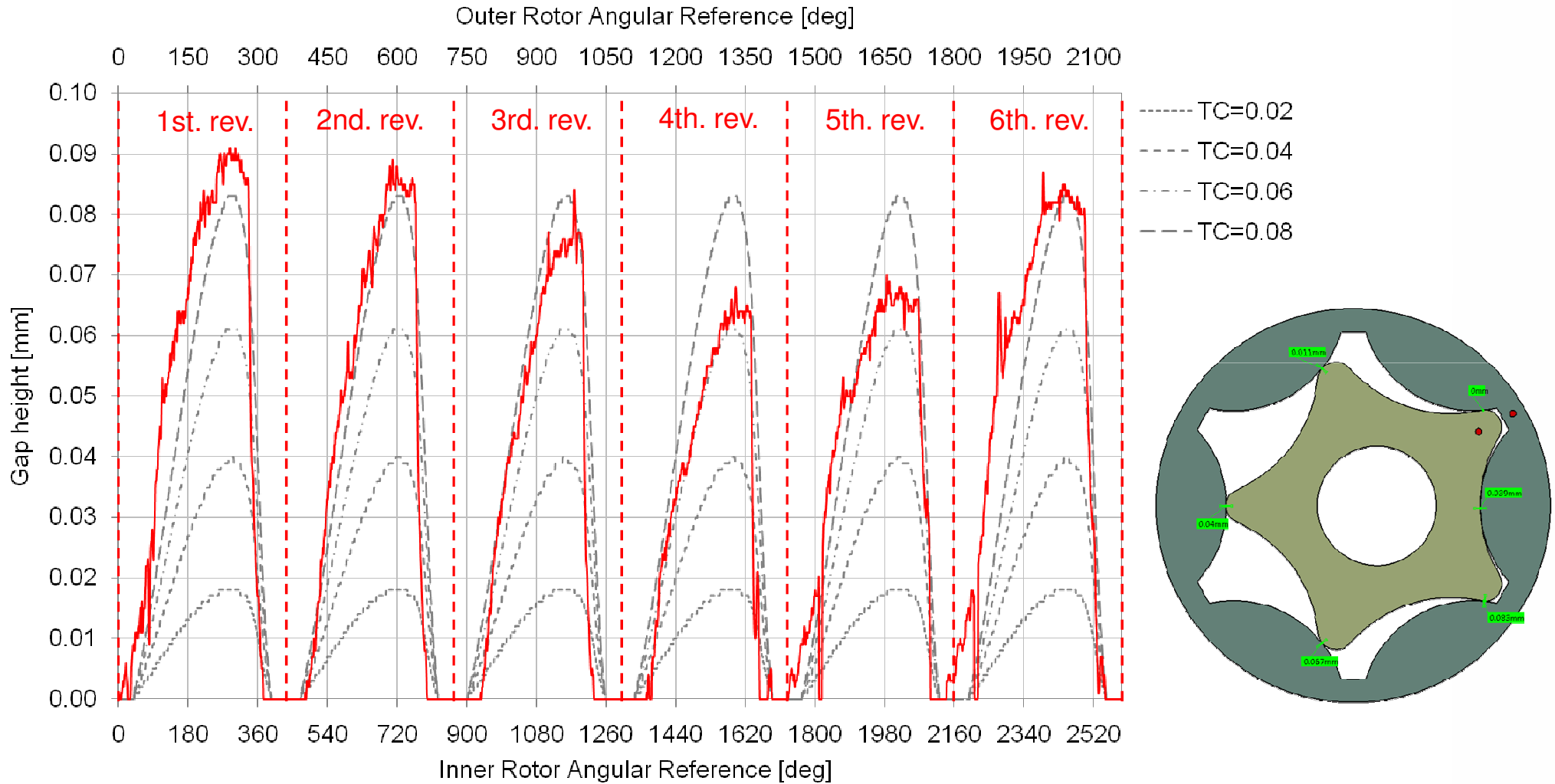
z

Step: Position-zero-30bar-filleted
 Increment 44: Step Time = 1.000
 Primary Var: S, Max. Principal
 Deformed Var: U Deformation Scale Factor: +1.000e+00

z

Step: Position-zero-30bar-filleted
 Increment 44: Step Time = 1.000
 Primary Var: S, Min. Principal
 Deformed Var: U Deformation Scale Factor: +1.000e+00

Radial Sealing Gaps

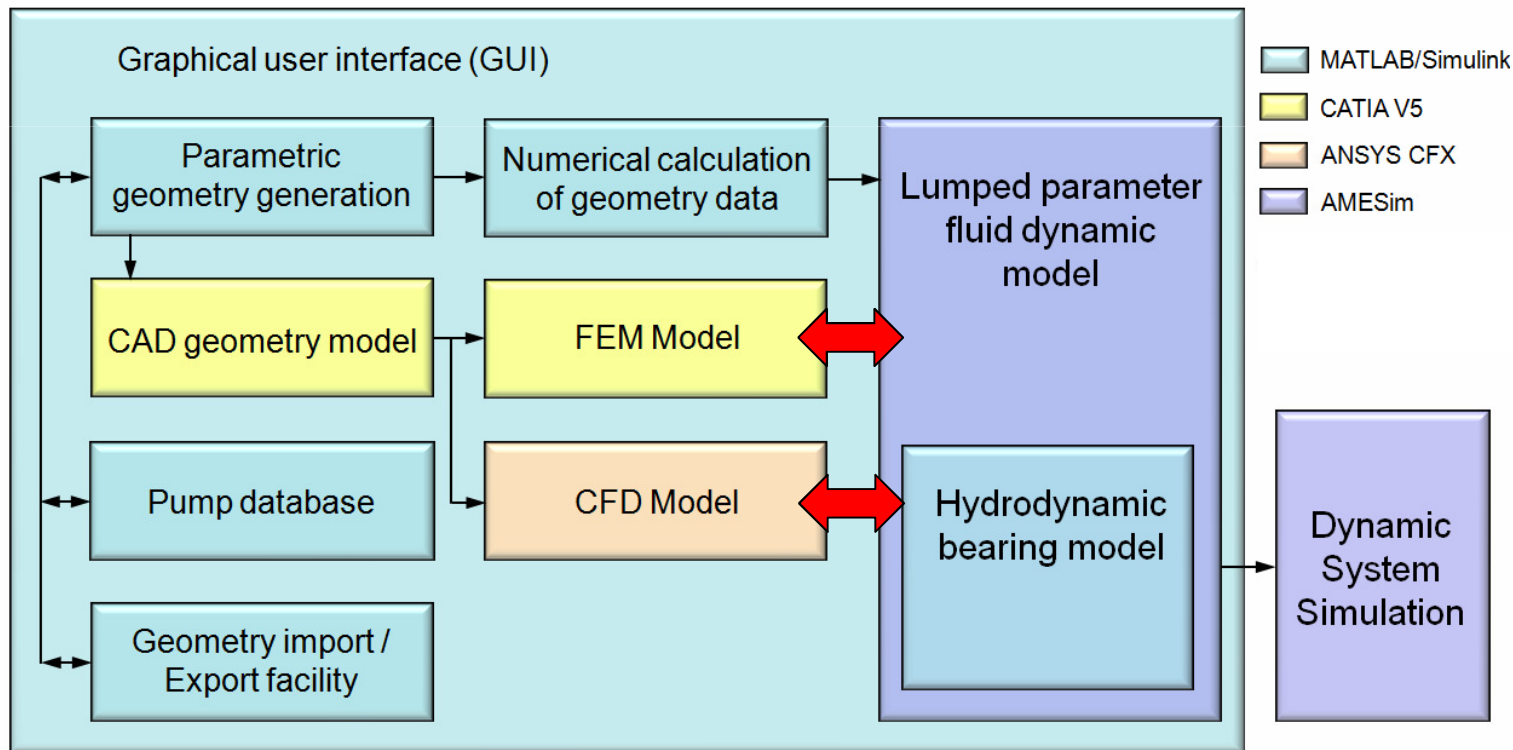


Conclusion

- **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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