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

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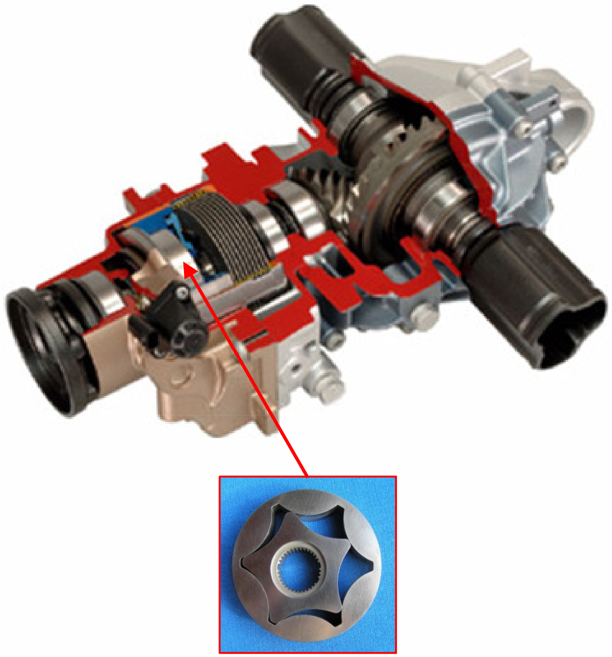
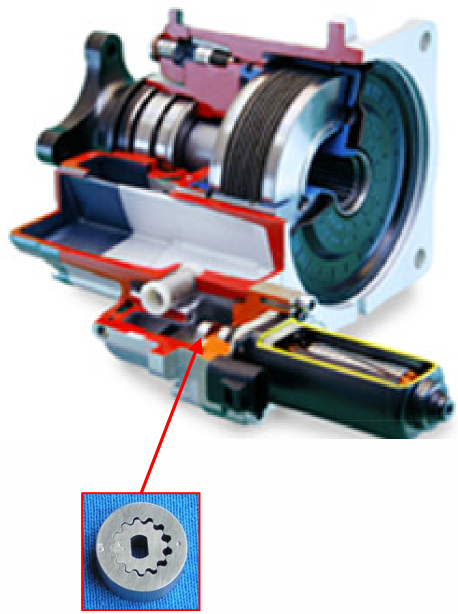
GRPs in AWD-Powertrain Systems





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

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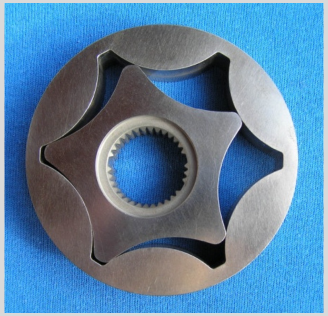
 	 	     

Problem Statement

- 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

- 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

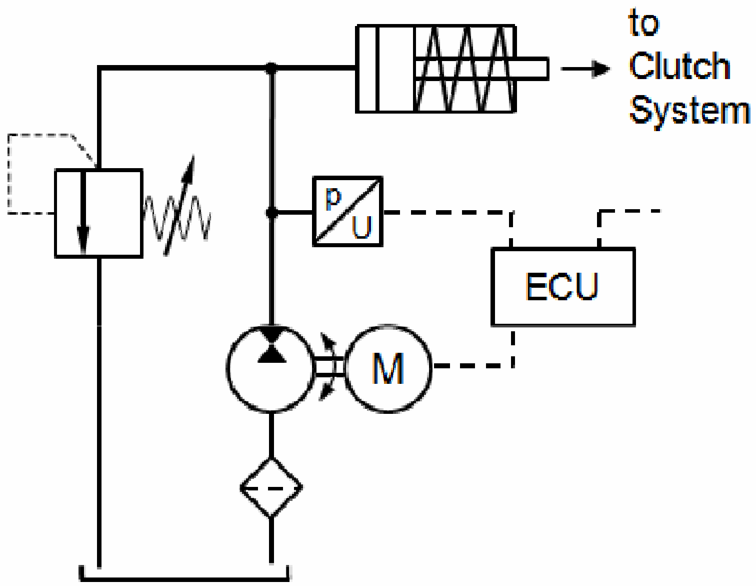
Axial piston machines

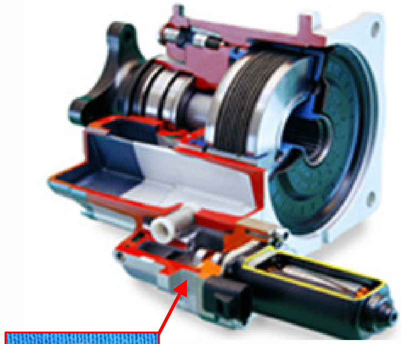
Vane pumps

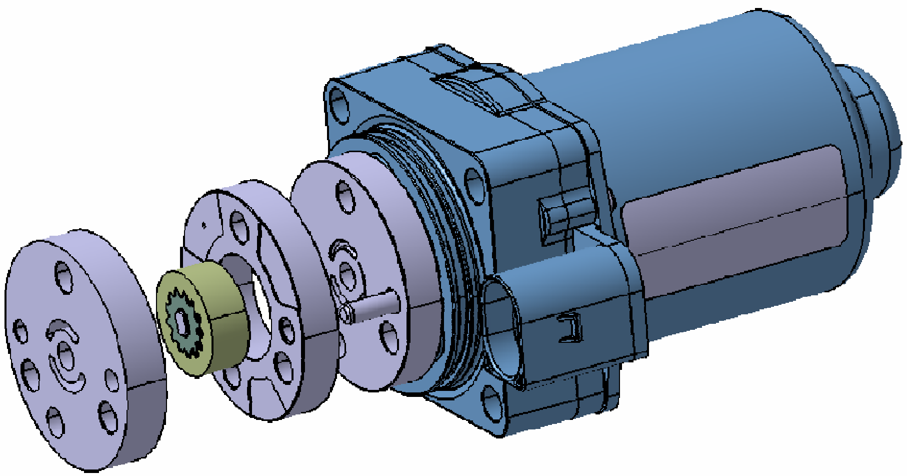
External gear pumps

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.

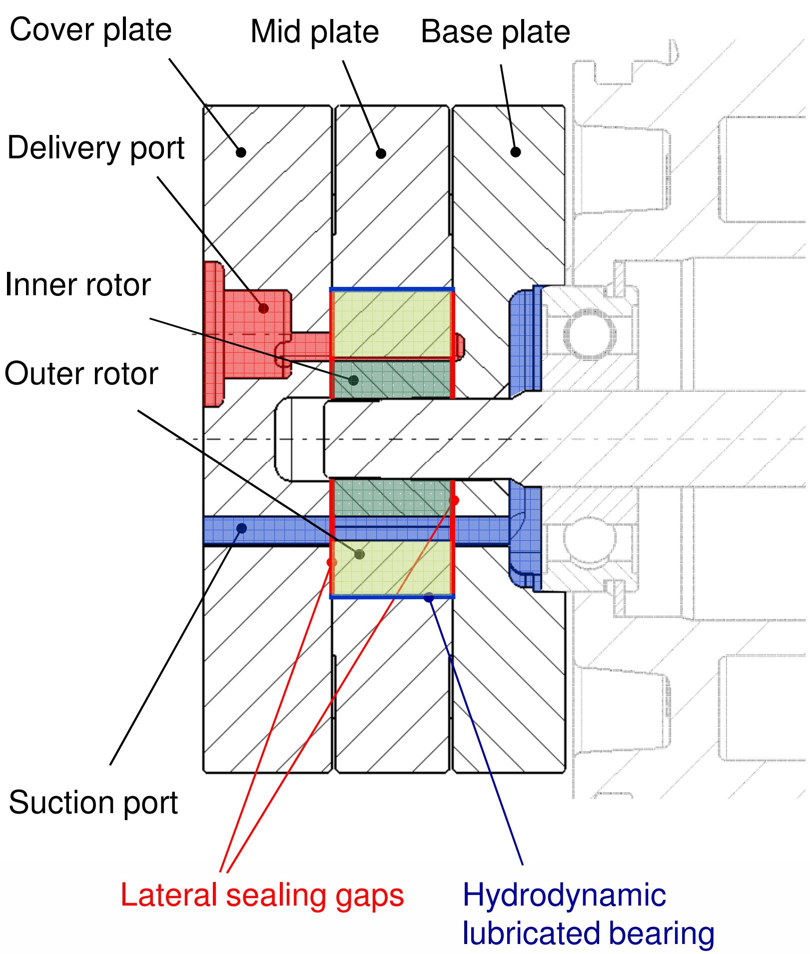
GRP Operating Principle

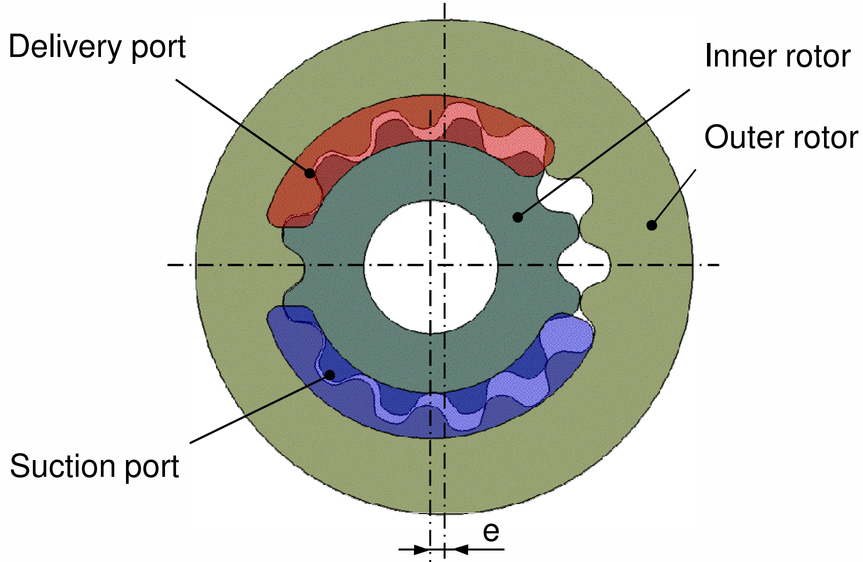


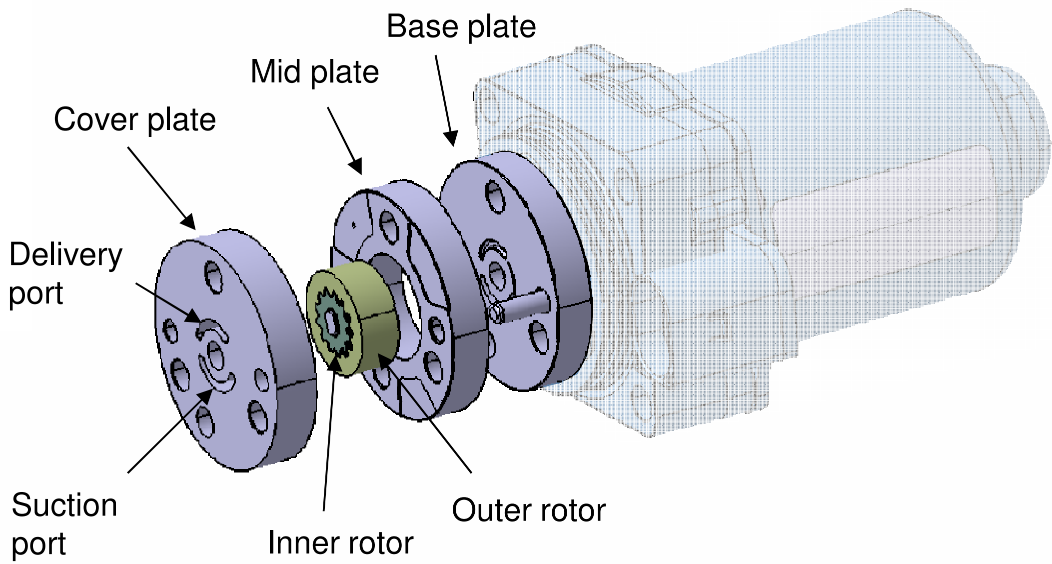




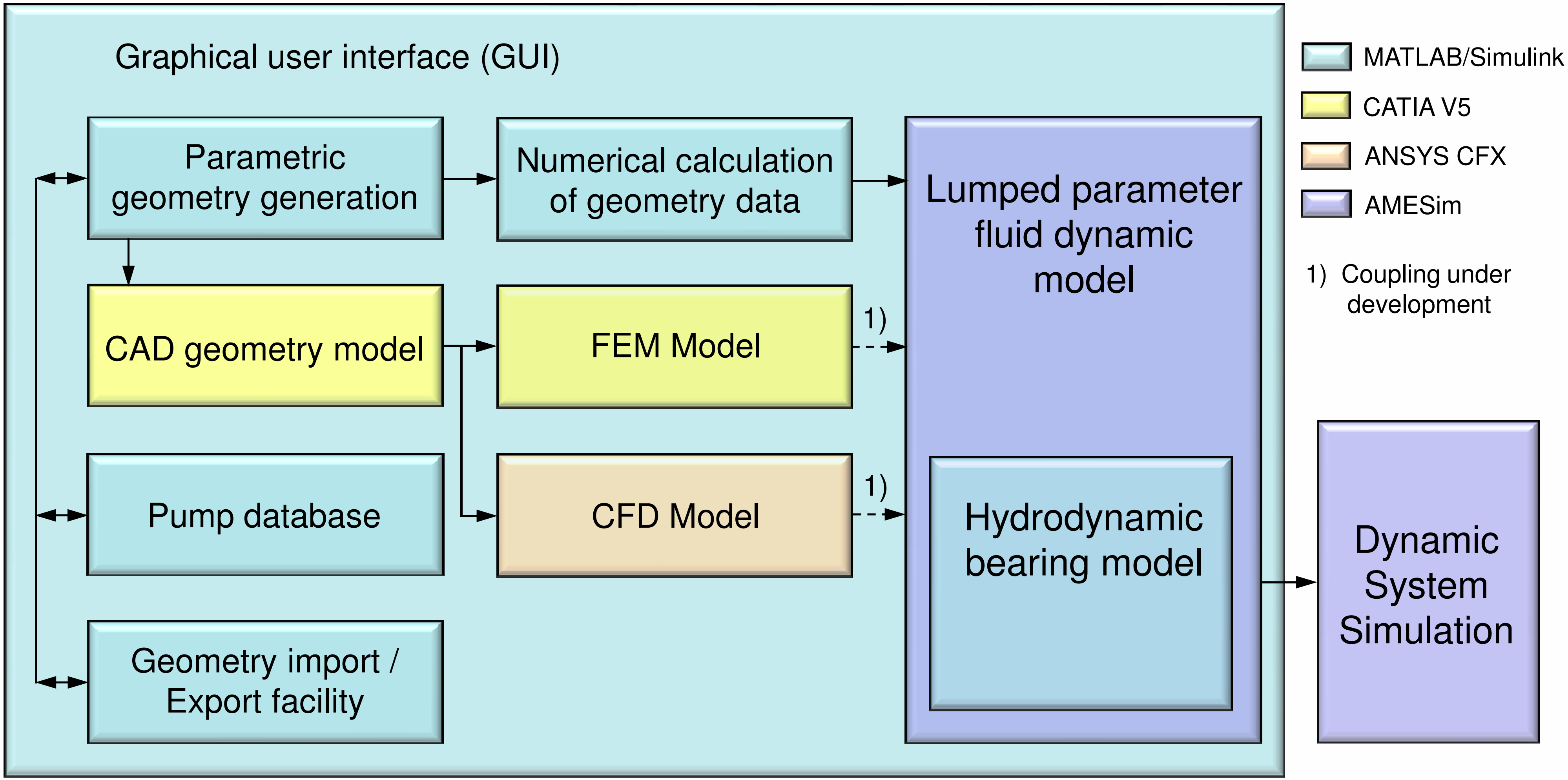
GRP Operating Principle





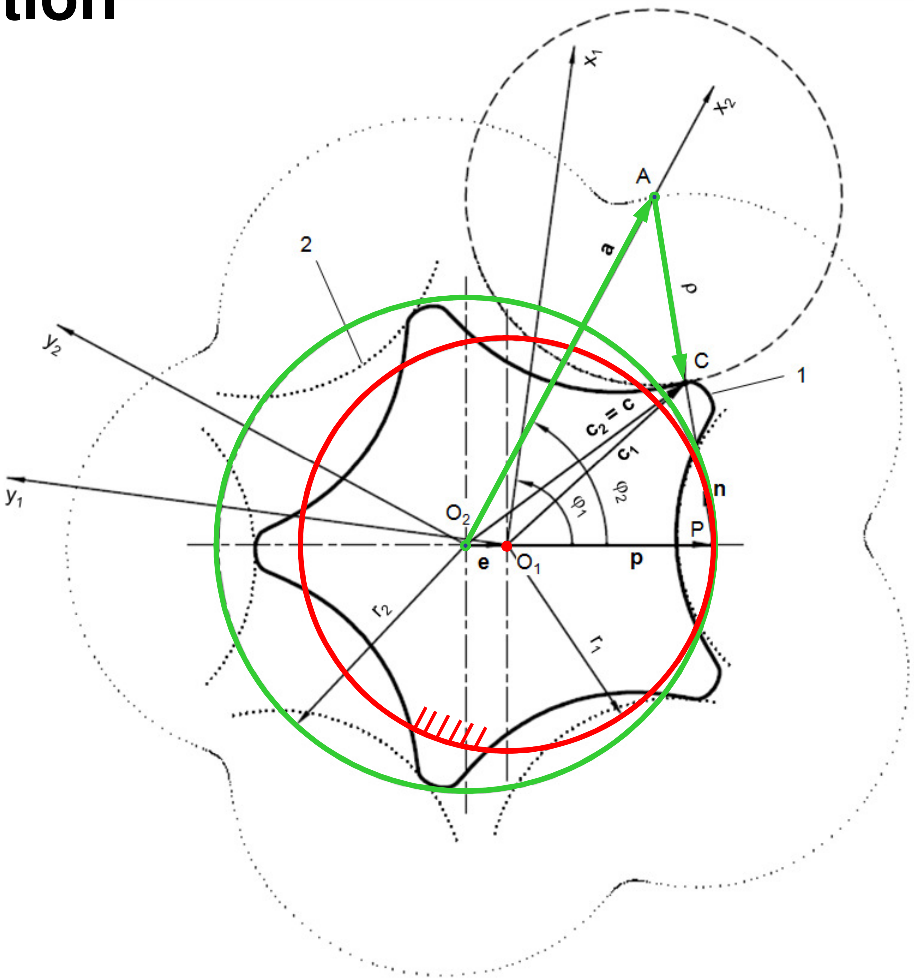


Modeling Approach



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

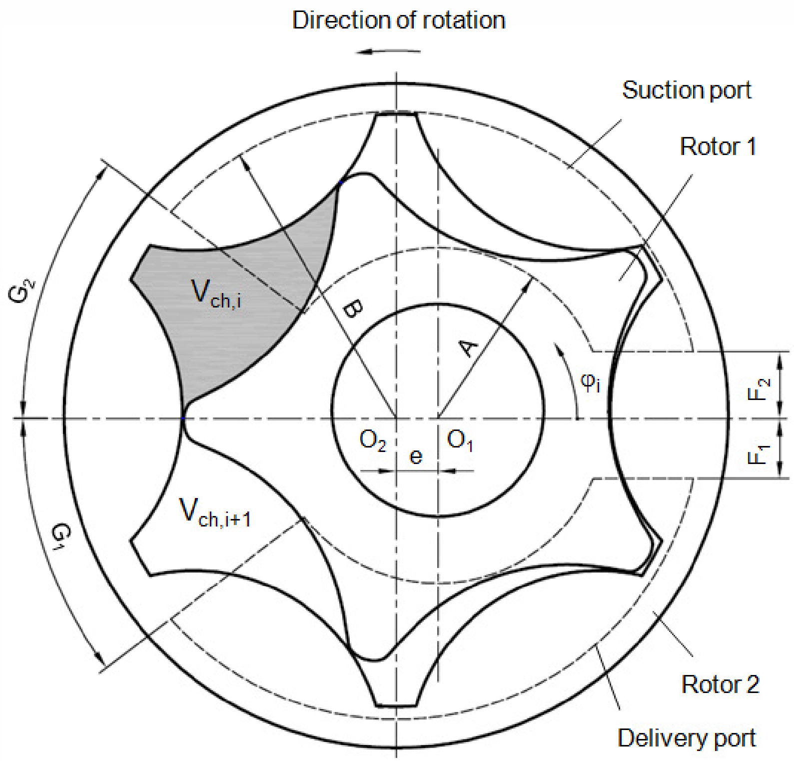
Modeling Approach
Fluid Dynamic Model

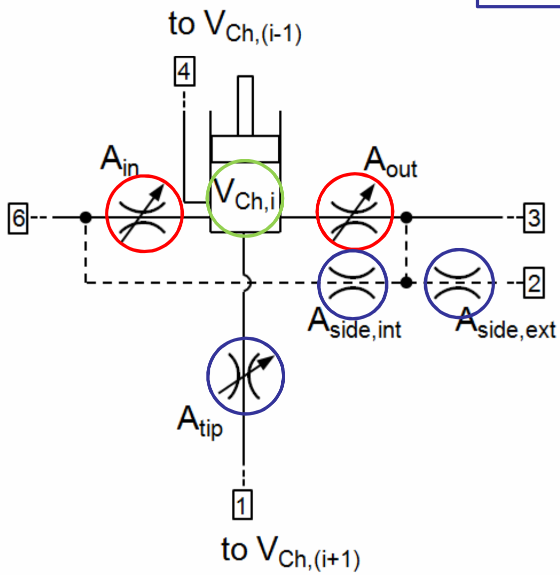
- **Evaluation of flow through the pump due to the displacement action**

$$\frac{dp_i}{d\varphi} = \frac{\beta}{\rho_i}\frac{1}{V_{ch,i}\,\omega_1}\left(\sum \dot{m}_j - \omega_1 \rho_i \frac{dV_{ch,i}}{d\varphi}\right)$$

$$\dot{m}_{i,j} = \frac{p_i - p_j}{\left|p_i - p_j\right|}\rho(\overline{p_{i,j}})\cdot A_{i,j}(\varphi)\cdot c_q(Re_{i,j})\sqrt{\frac{2(p_i - p_j)}{\rho(\overline{p_{i,j}})}}$$

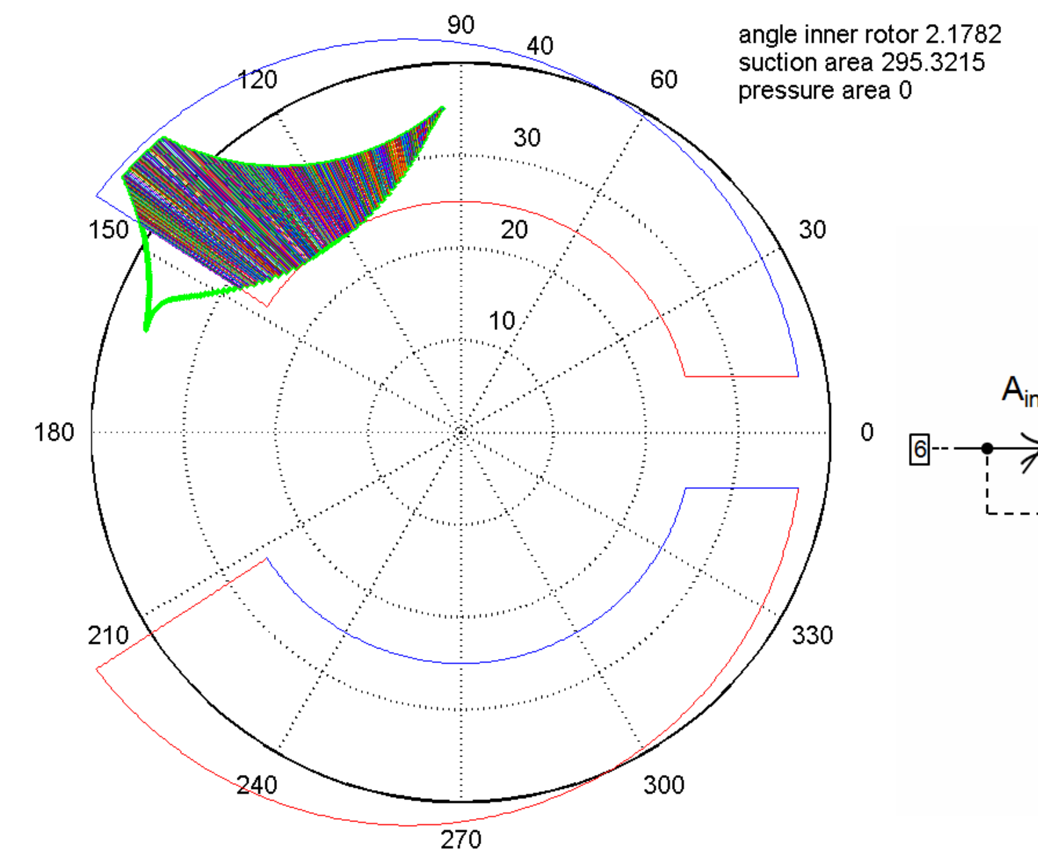
$$\dot{m}_{i,j} = \rho(\overline{p_{i,j}})\cdot\left[-\frac{h^3 b}{12\eta l}\cdot(p_i - p_j)\right]$$

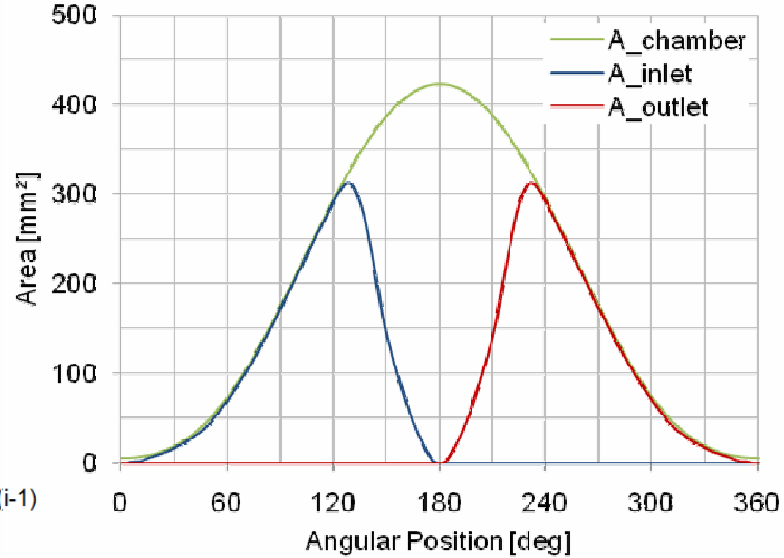


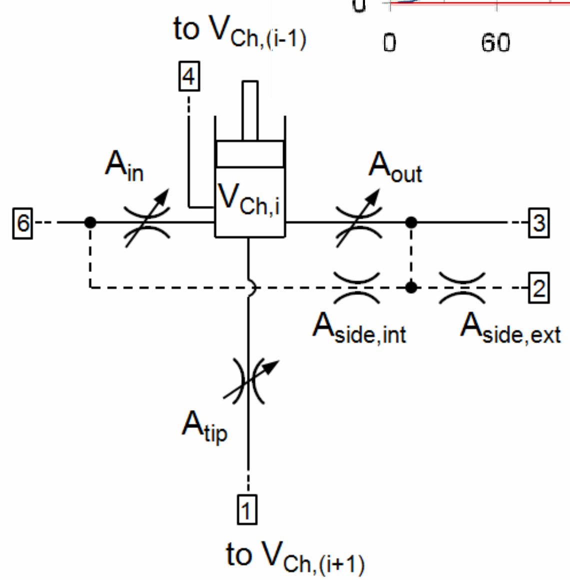


Modeling Approach
Numerical Calculation of Geometry Data

- **Geometric Model for calculation of characteristic geometry data**



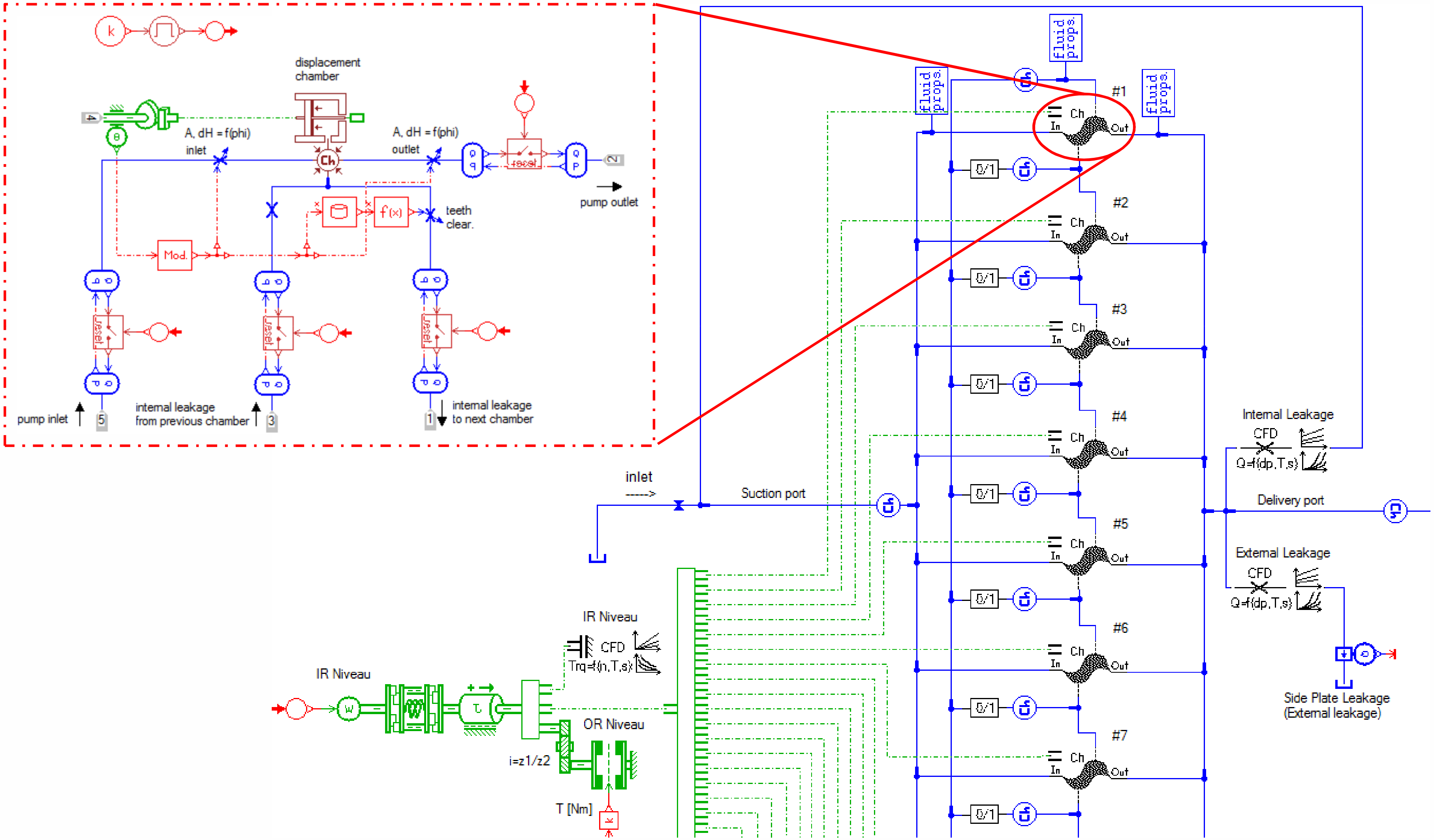




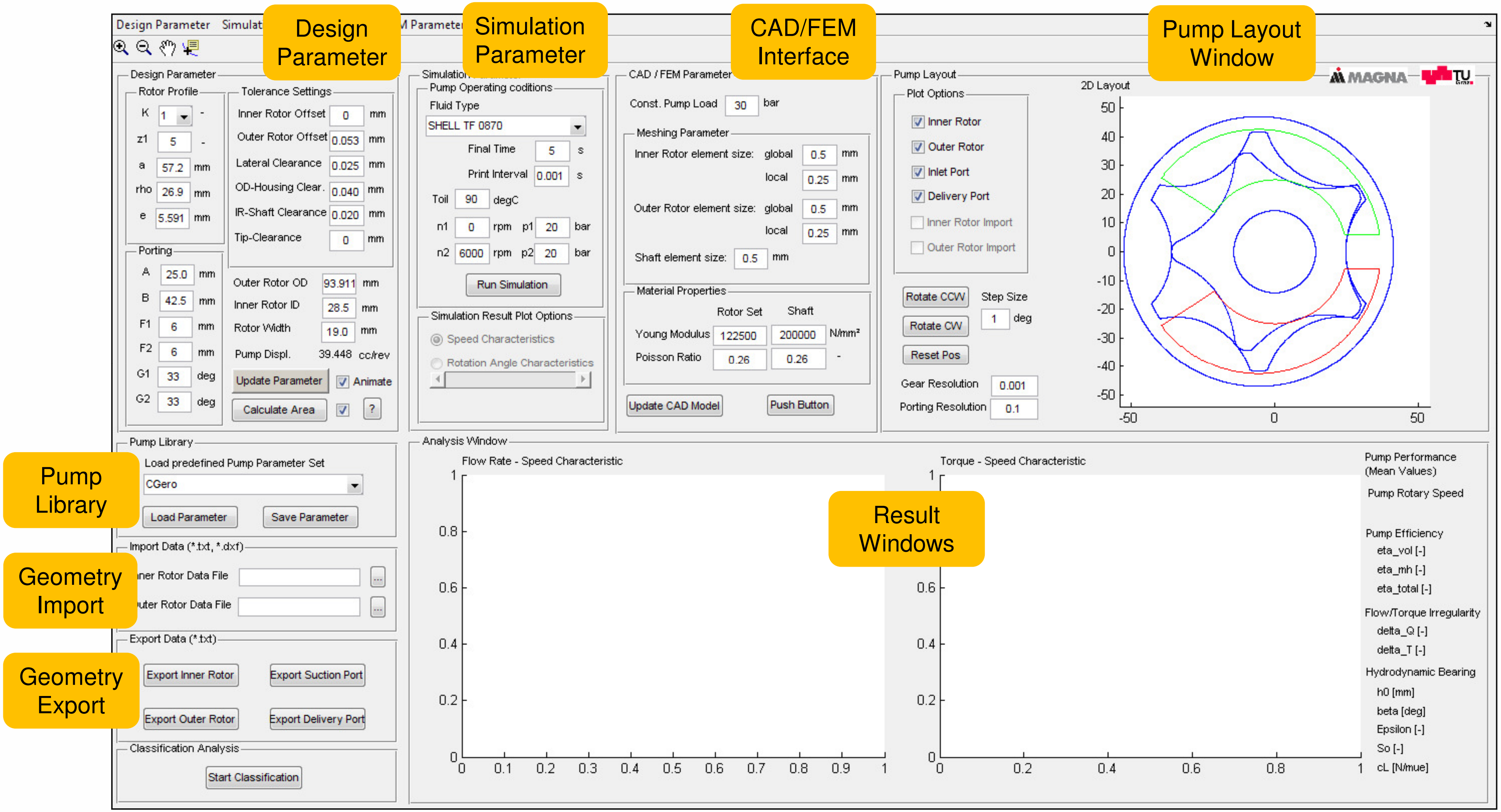
Modeling Approach

Fluid Dynamic Model: Implementation in AMESim

- **Evaluation of flow through the pump**

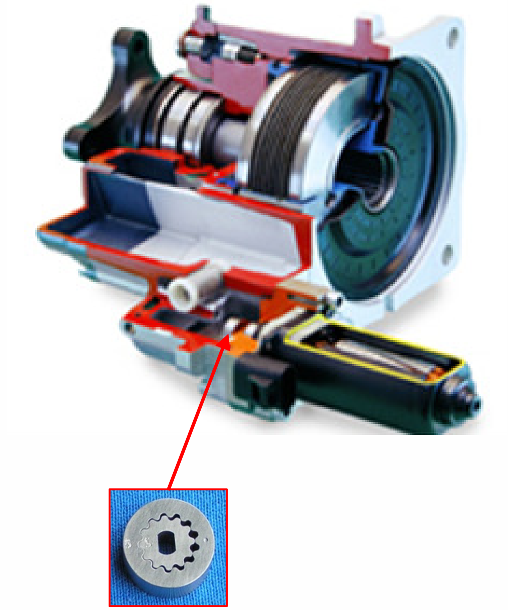


Graphical User Interface (GUI)

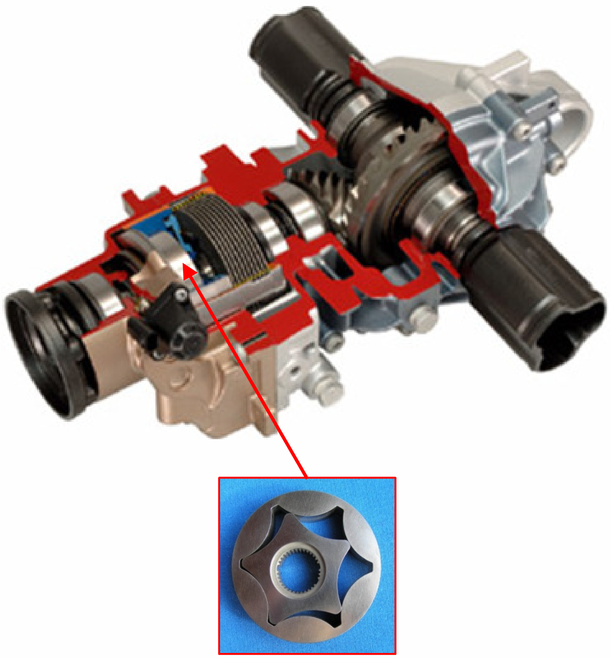


Model Validation

Reference Pump 1



Reference Pump 2



Electric motor driven GRP

q_v = 0.25cc
zi = 12
D_o = 19mm
B = 7.5mm
p_{max} = 30bar
n_{max} = 6000rpm

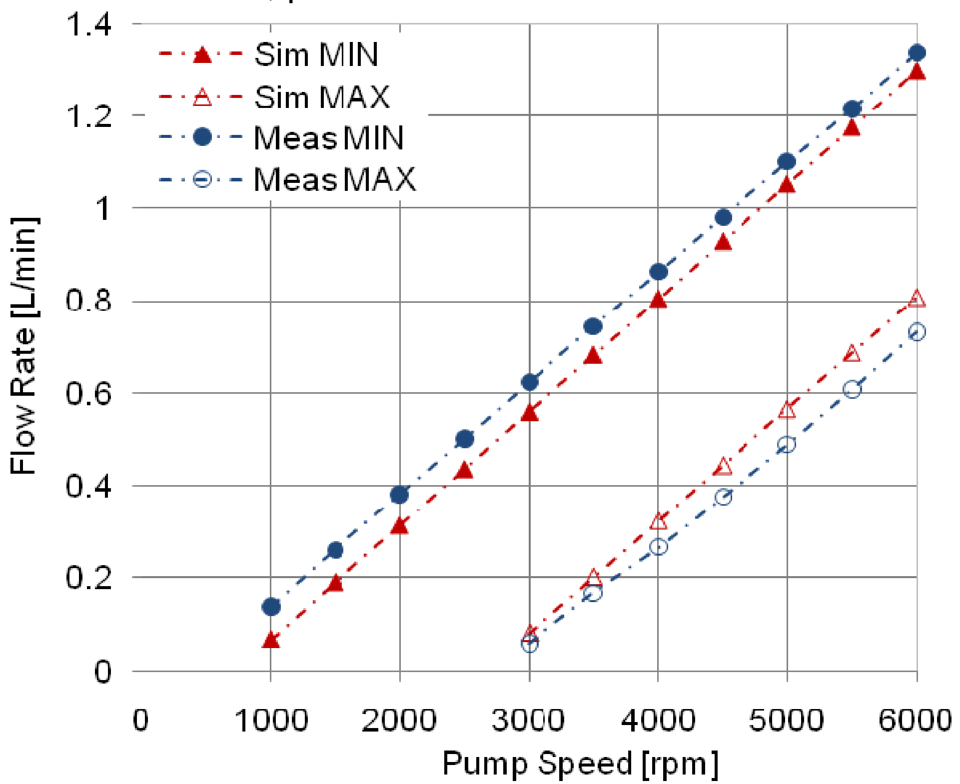
Differential speed sensing GRP

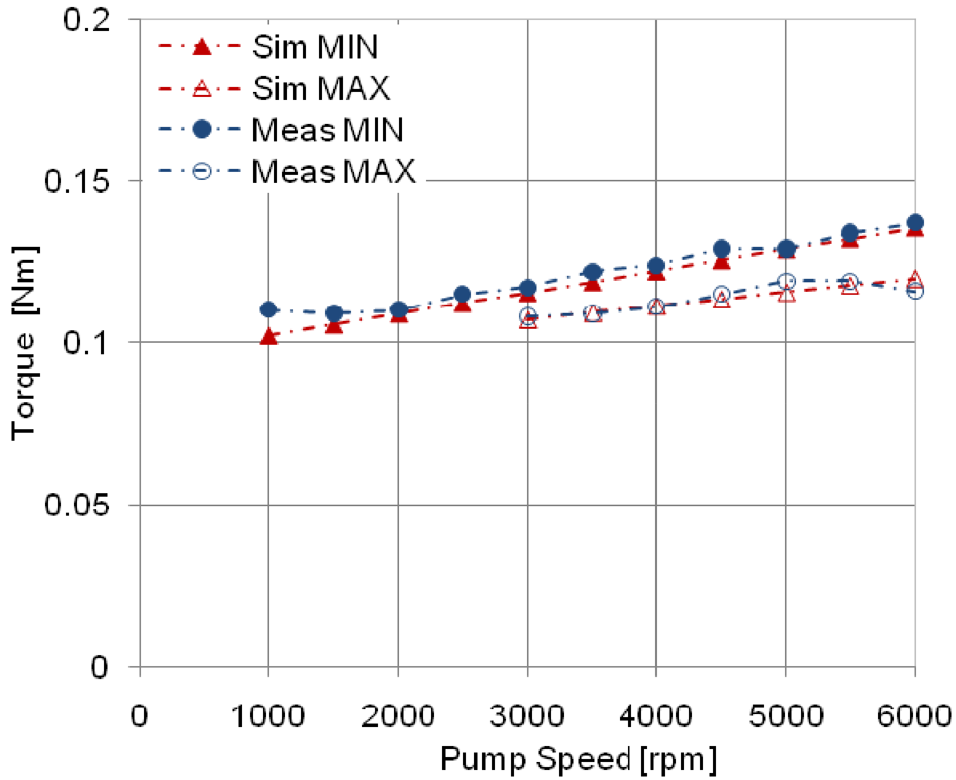
q_v = 42.5cc
zi = 5
D_o = 94mm
B = 17mm
p_{max} = 50bar
n_{max} = 500rpm

Results
Reference Pump 1

Steady State Pump Operation

T=50°C, p=20bar



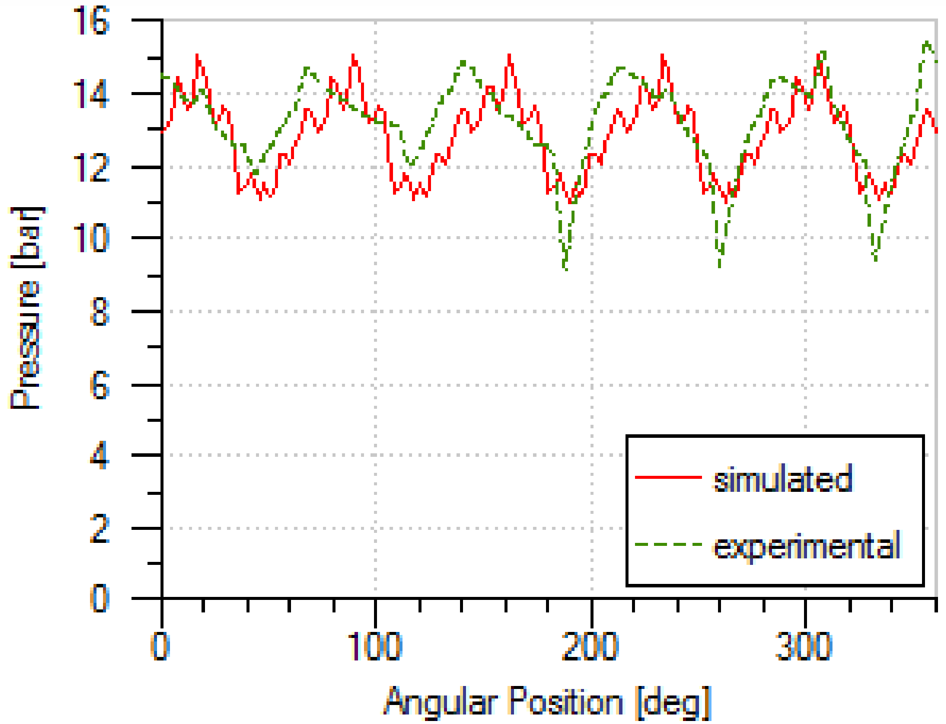


Pump Tolerance	MIN	NOM	MAX
Tip Clearance [mm]	0.025	0.050	0.075
Lateral Clearance [mm]	0.015	0.020	0.025

Comparison with Test Results
Reference Pump 2

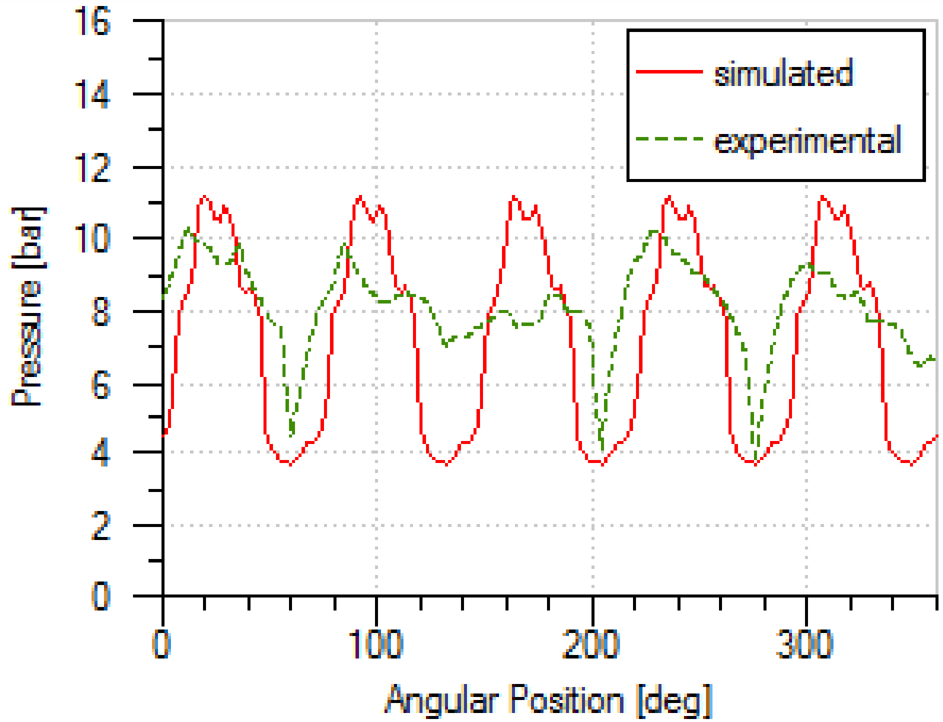
MIN clearance pump

T=60°C, n=40rpm



MAX clearance pump

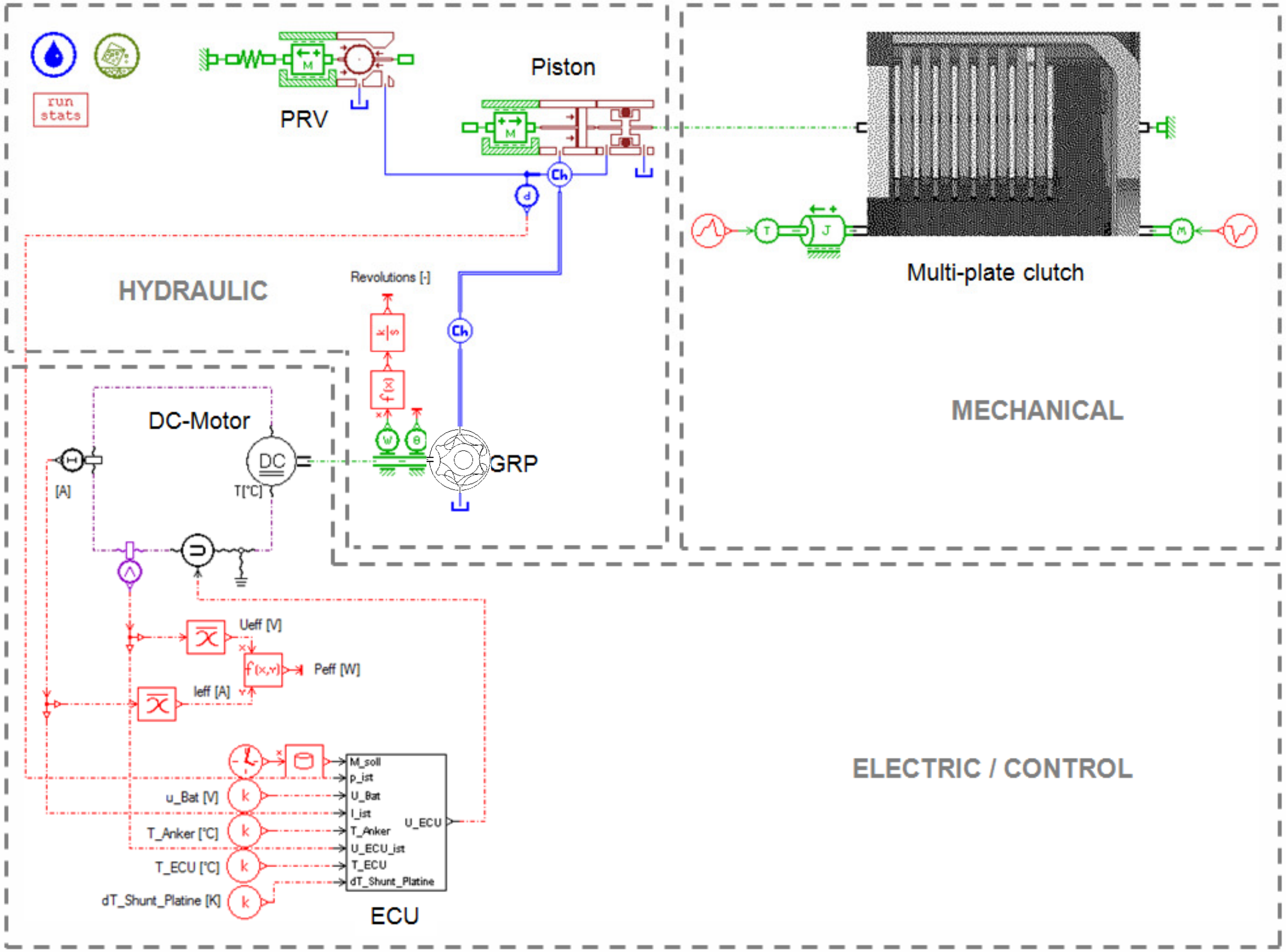
T=60°C, n=40rpm



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

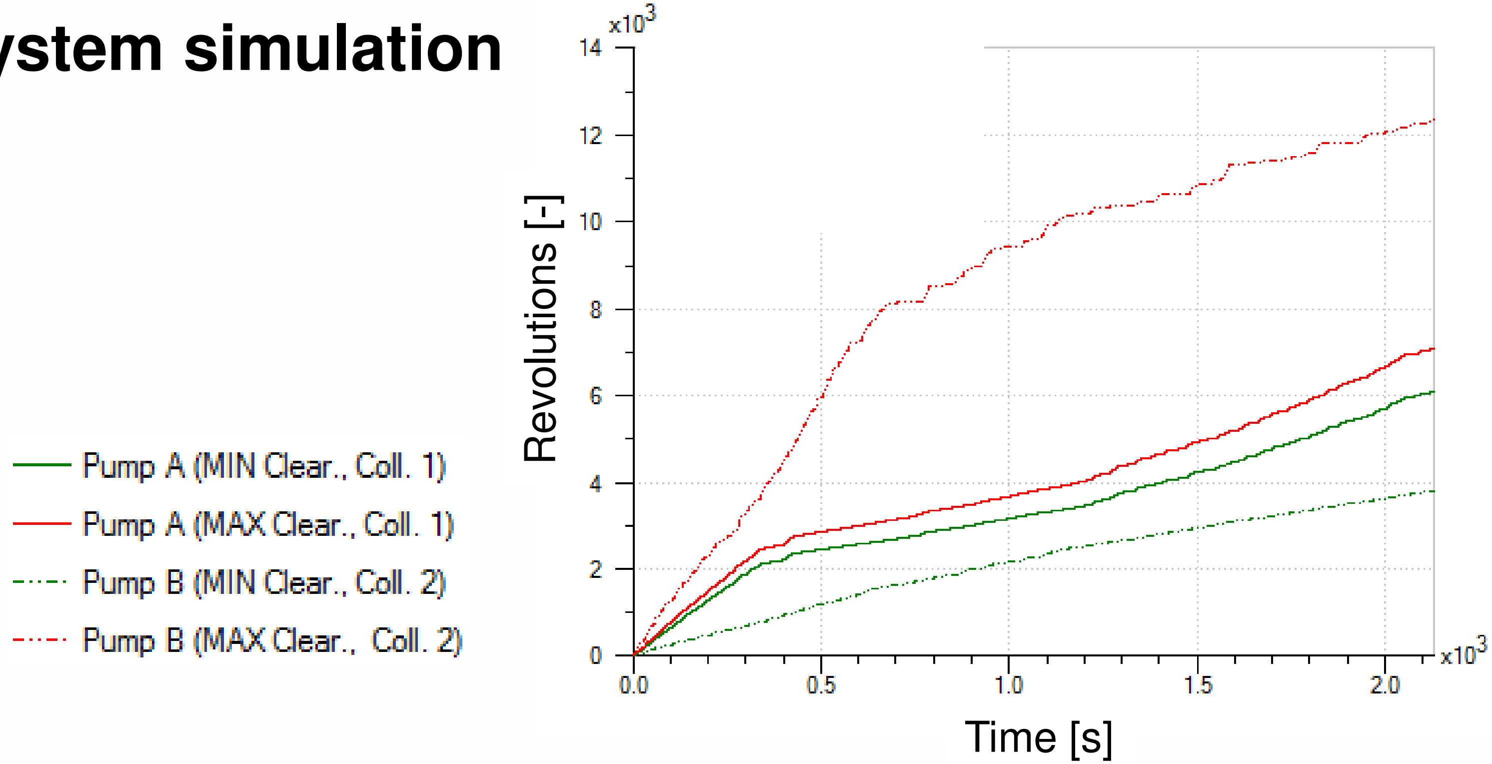
System Simulation
Reference Pump 1

- **Complete system simulation**



System Simulation
Reference Pump 1

- **Complete system simulation**

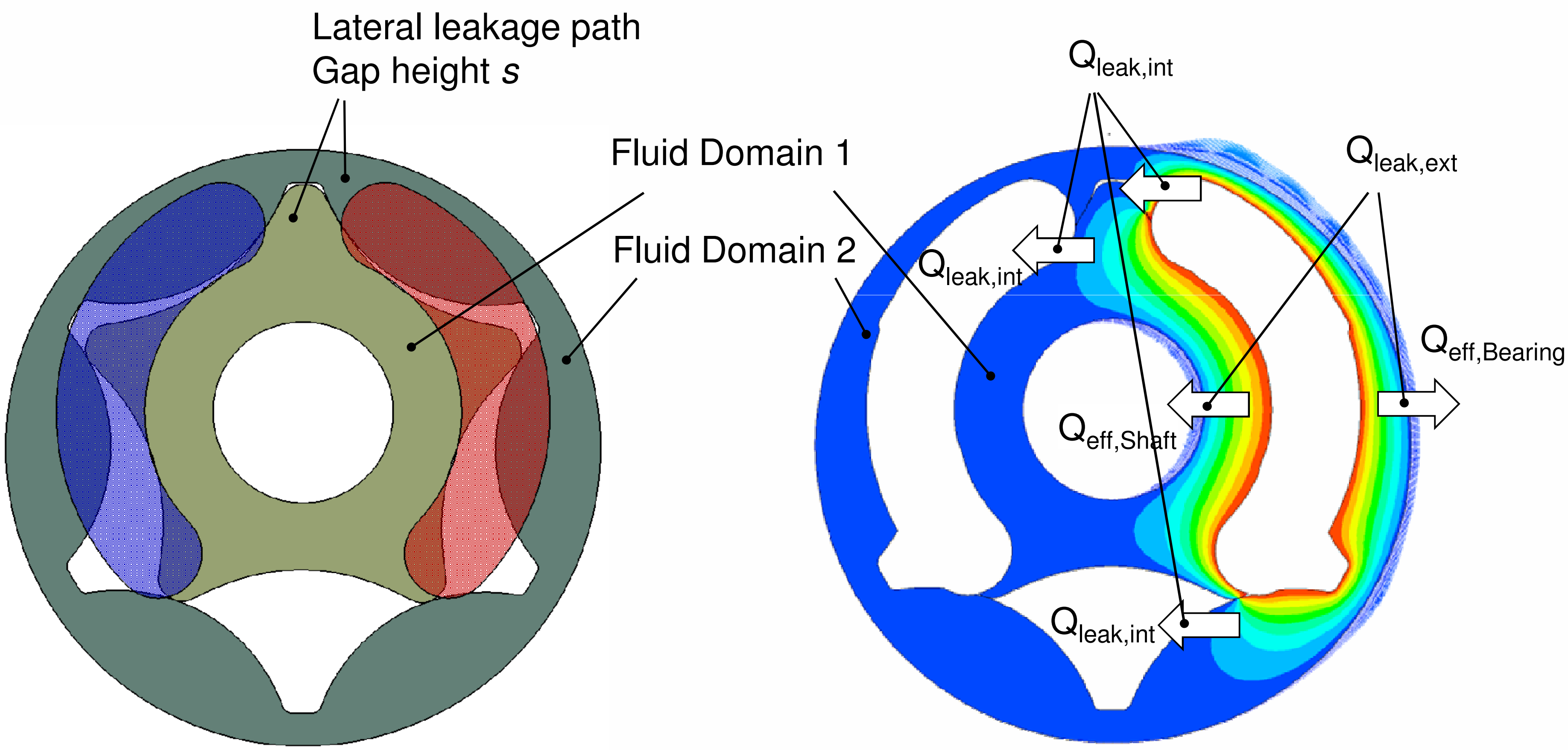


Toil=50℃

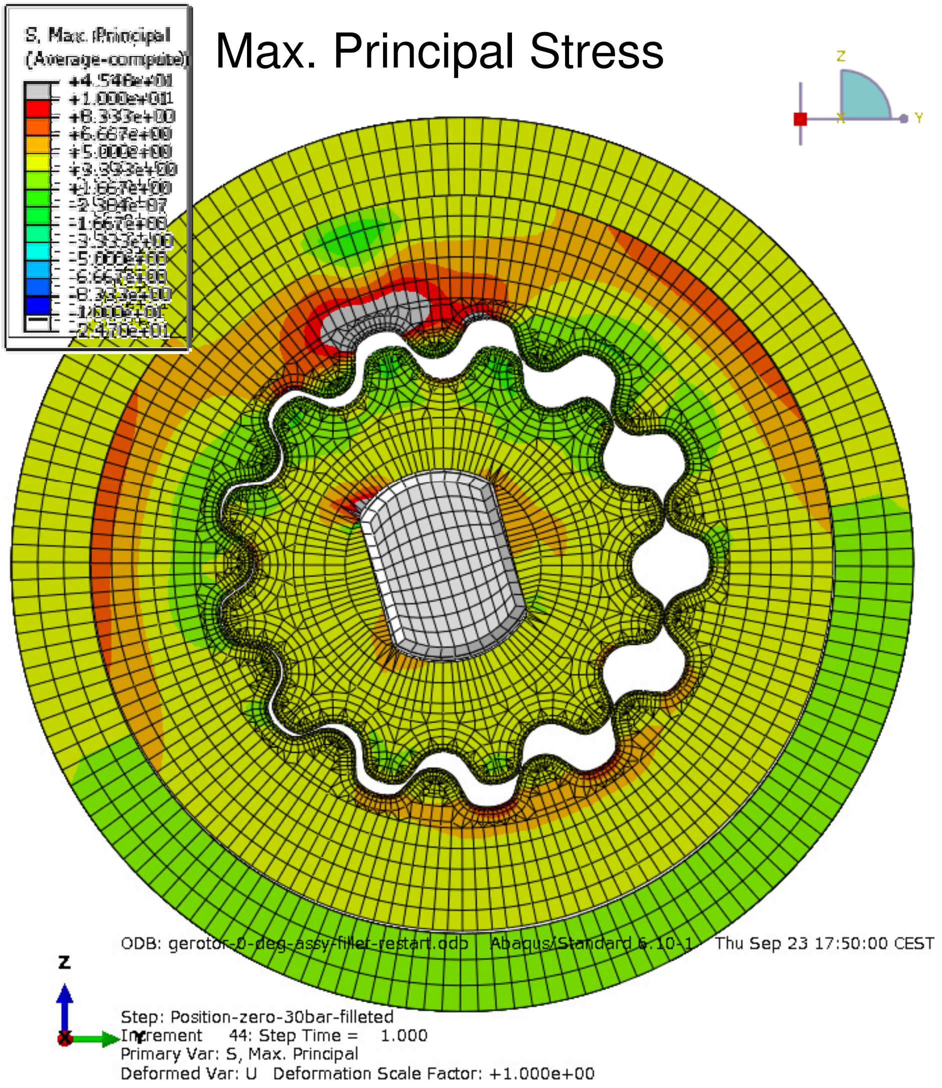
Coll. #	Pump #	Pump Tol.	Revs [-]	p_eff [bar]	U_eff [V]	I_eff [A]
1	A	MIN	6072	5.75	2.00	3.09
		MAX	7069	5.81	2.12	3.15
2	B	MIN	3799	4.73	1.54	2.57
		MAX	12330	5.01	2.15	1.80

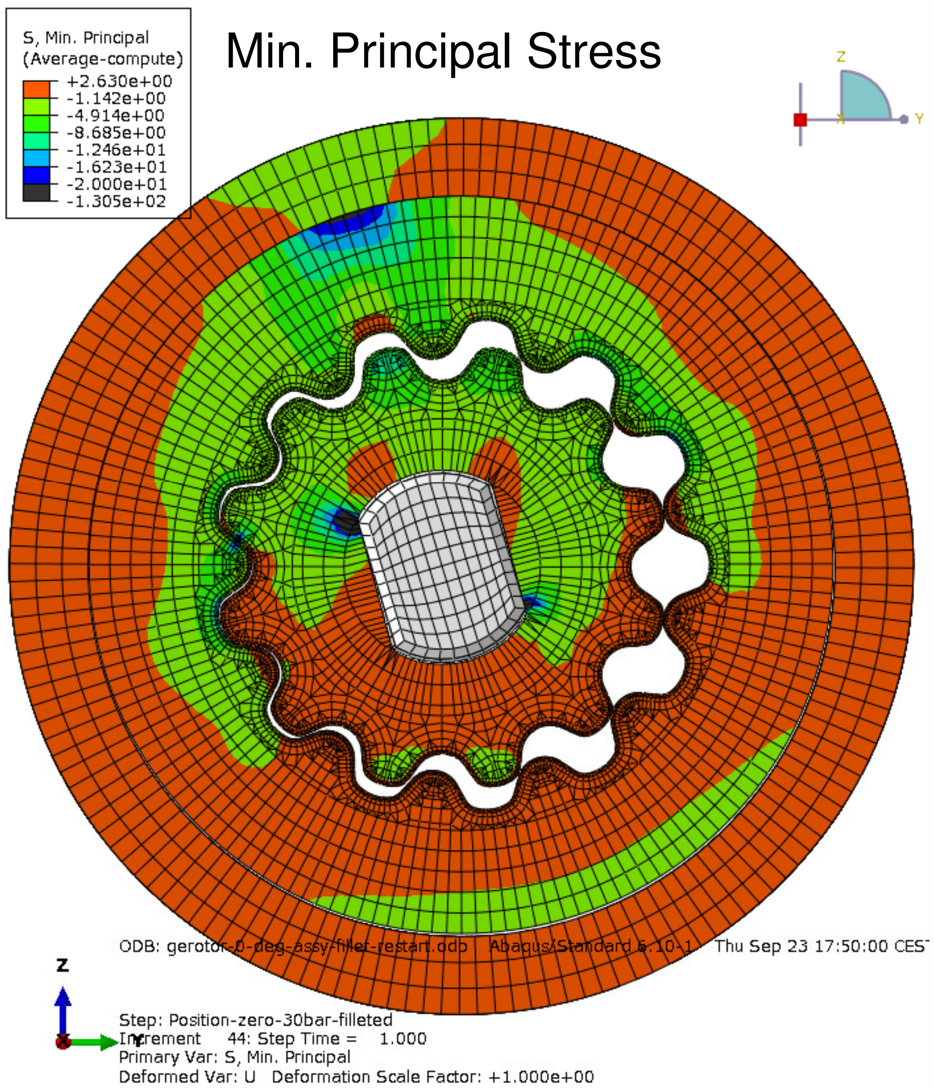
Numerical Model for Lateral Sealing Gaps

- **Evaluation of lateral leakage flow**

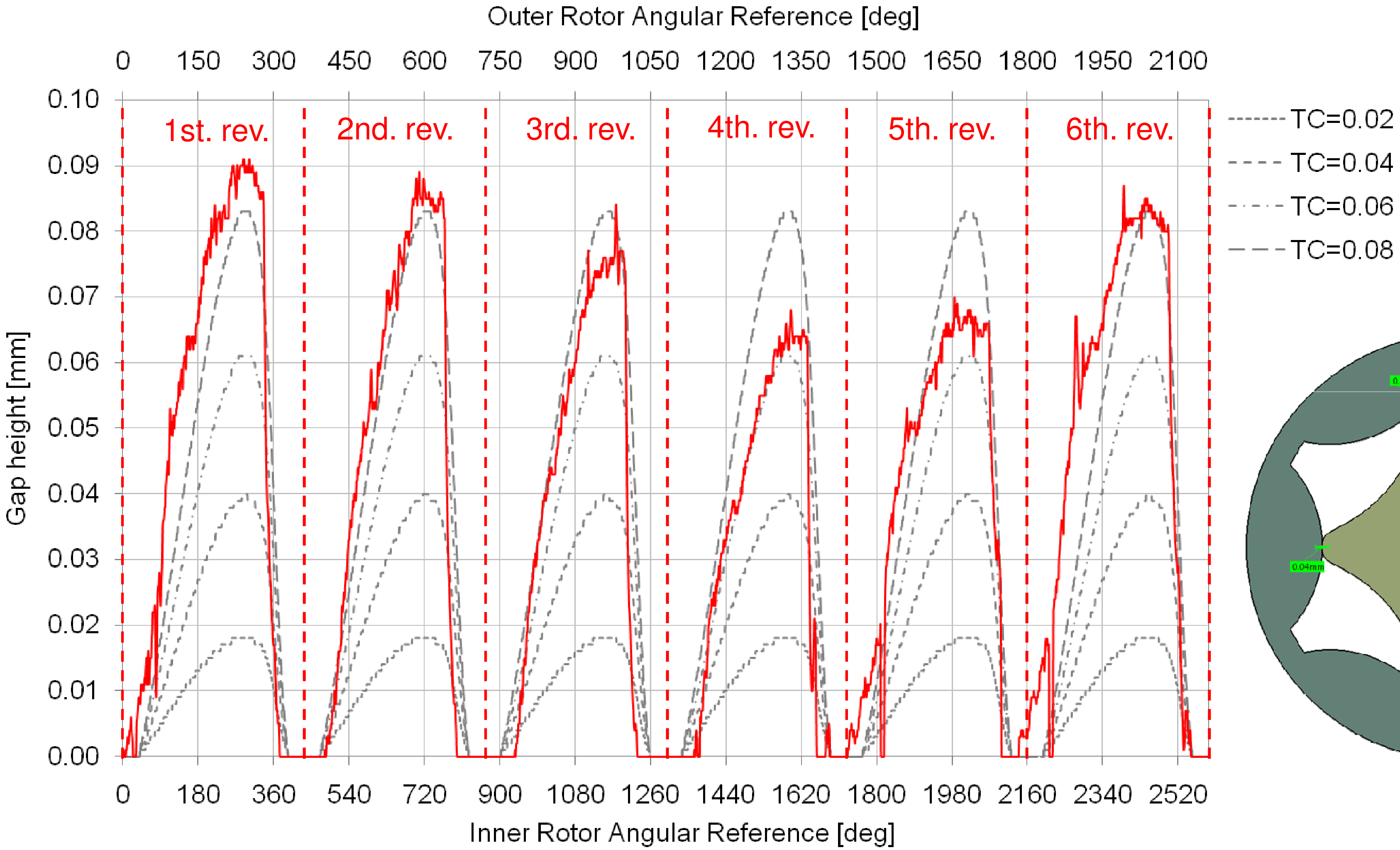


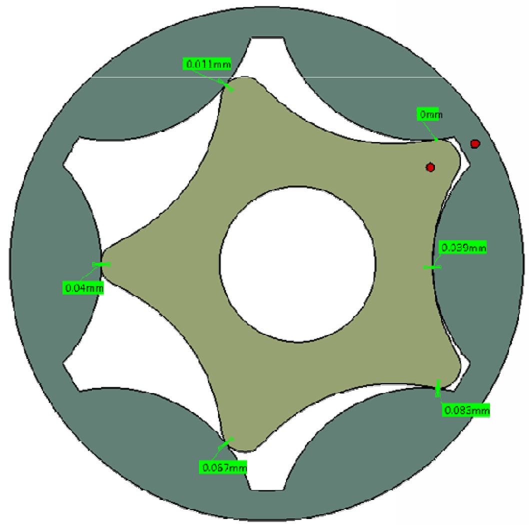
Finite Element Model





Radial Sealing Gaps



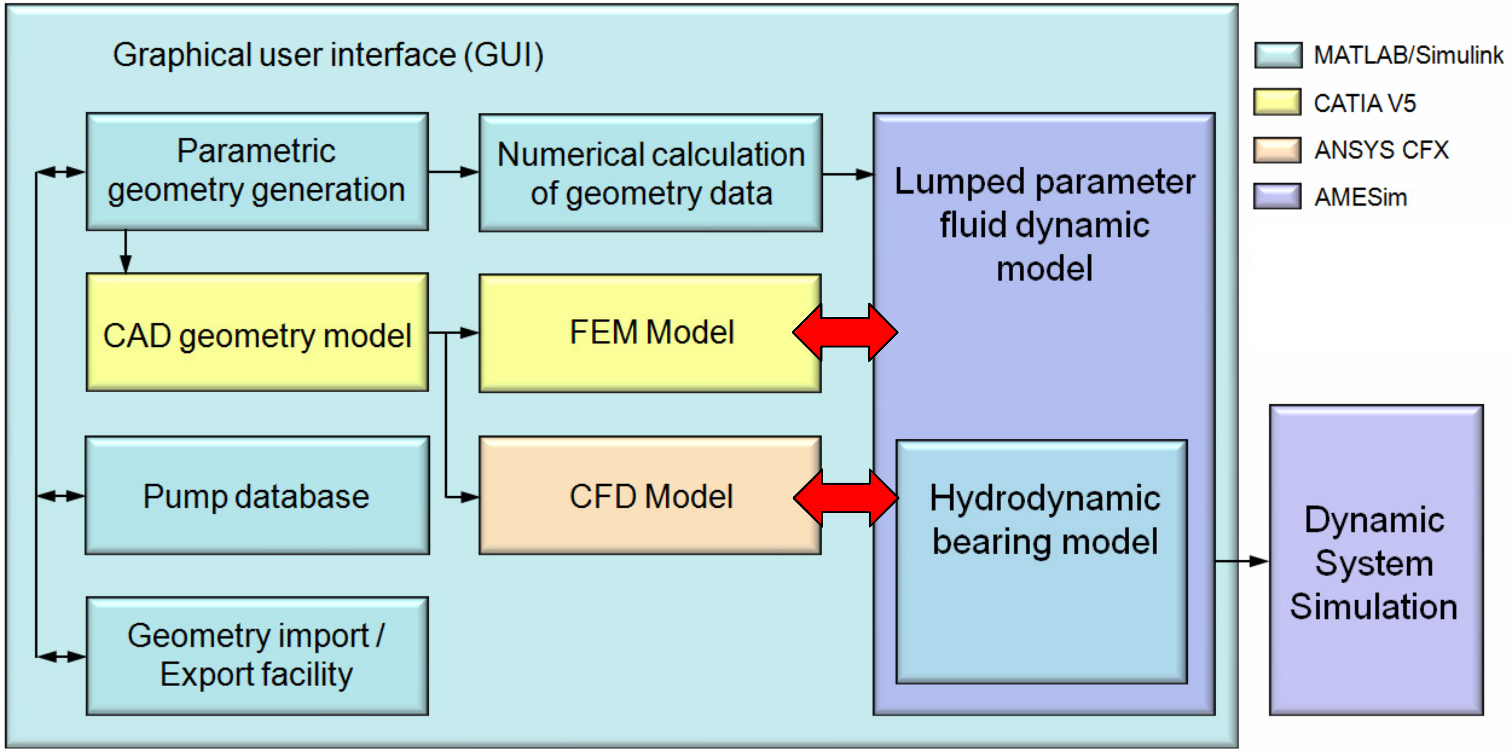


Conclusion

- 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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