Modeling of the Flow Comparator as Calibration Device for High Pressure Natural Gas Flow Metering in Modelica

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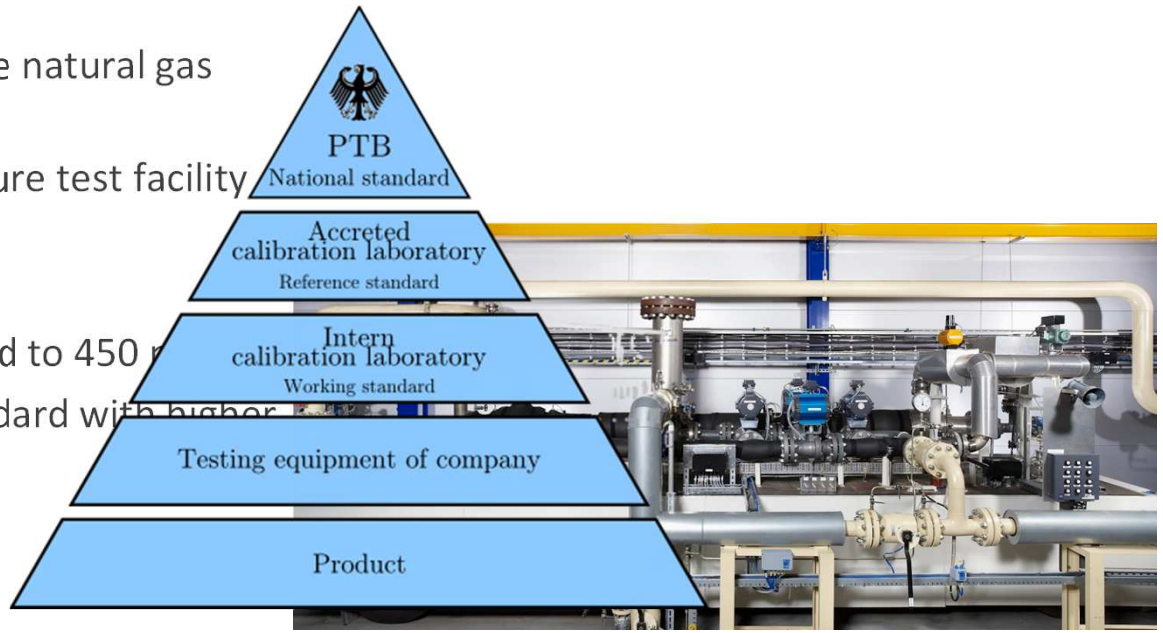
Piston Prover

- Continuous calibration chain
- Traceability to base units with primary standards

- Primary standard for high pressure natural gas flow
- Operated at pigsar™, a high pressure test facility for gas meters

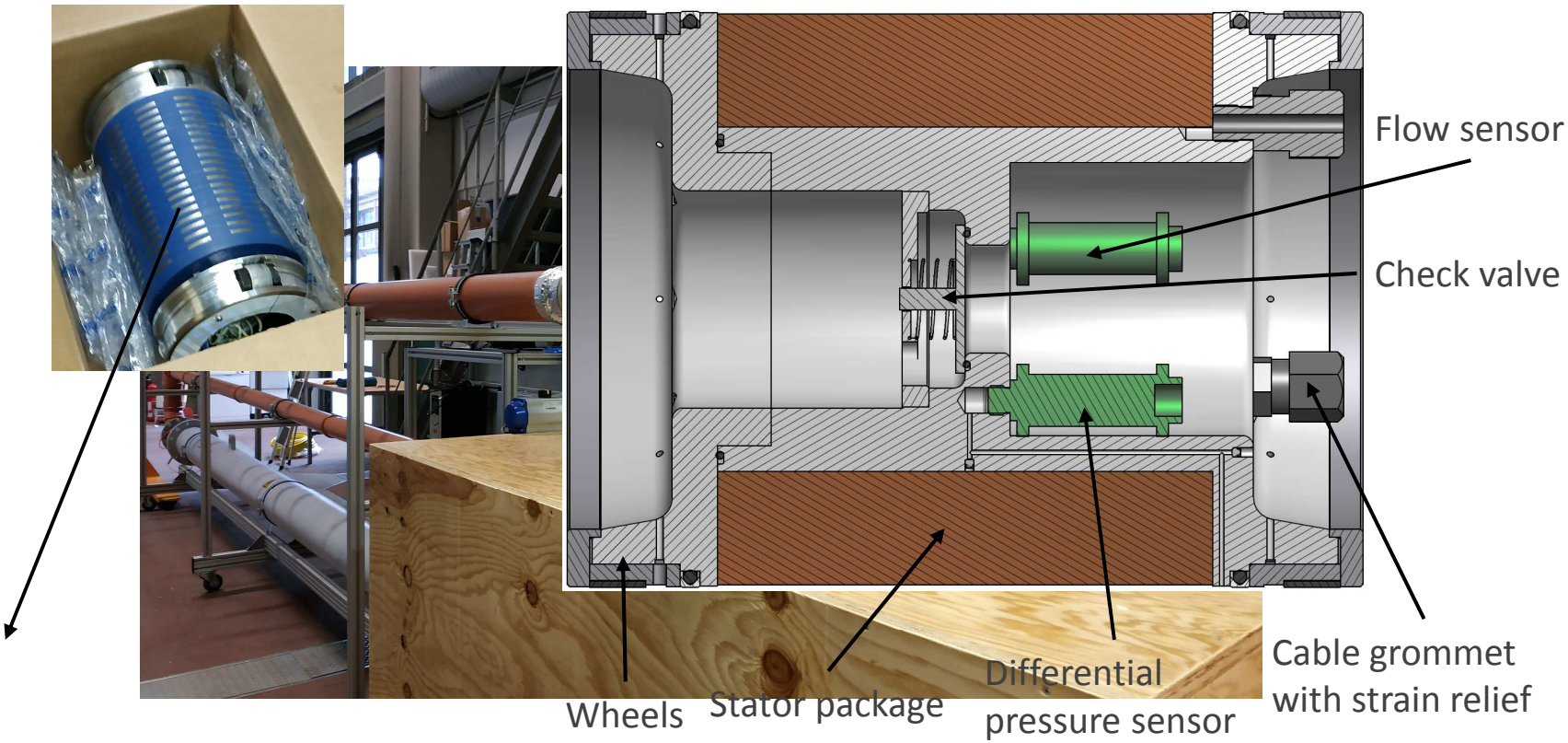
- Operating volume flow rate limited to 450 r

→ Development of new primary standard with higher volume flow rate

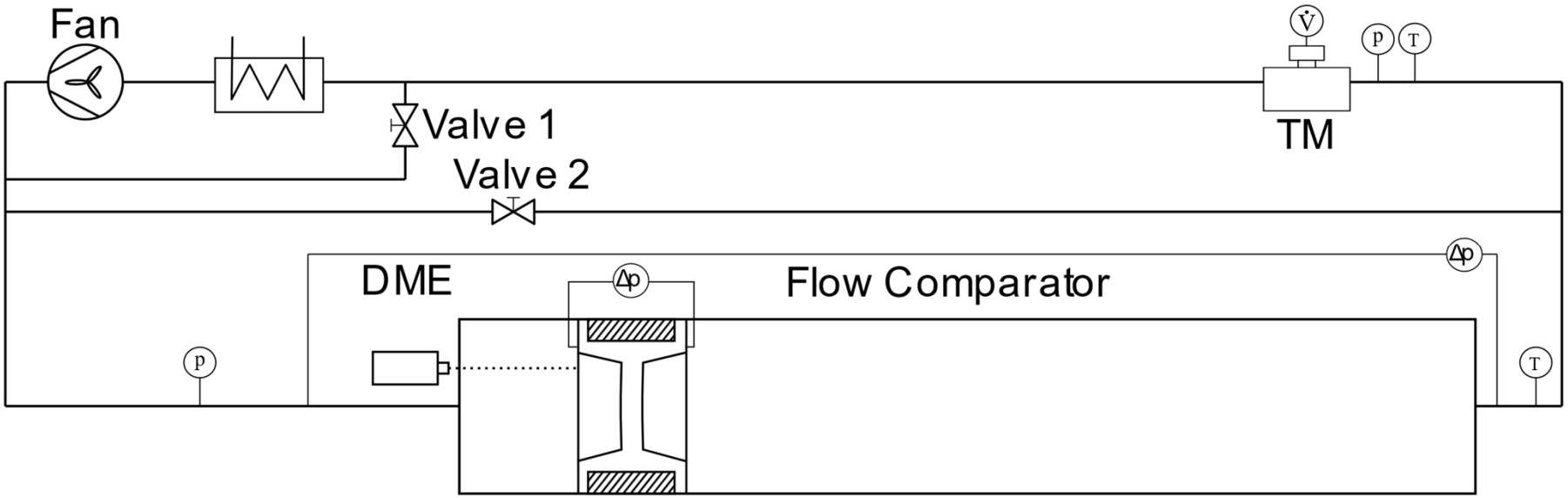


Source: www.pigsar.de

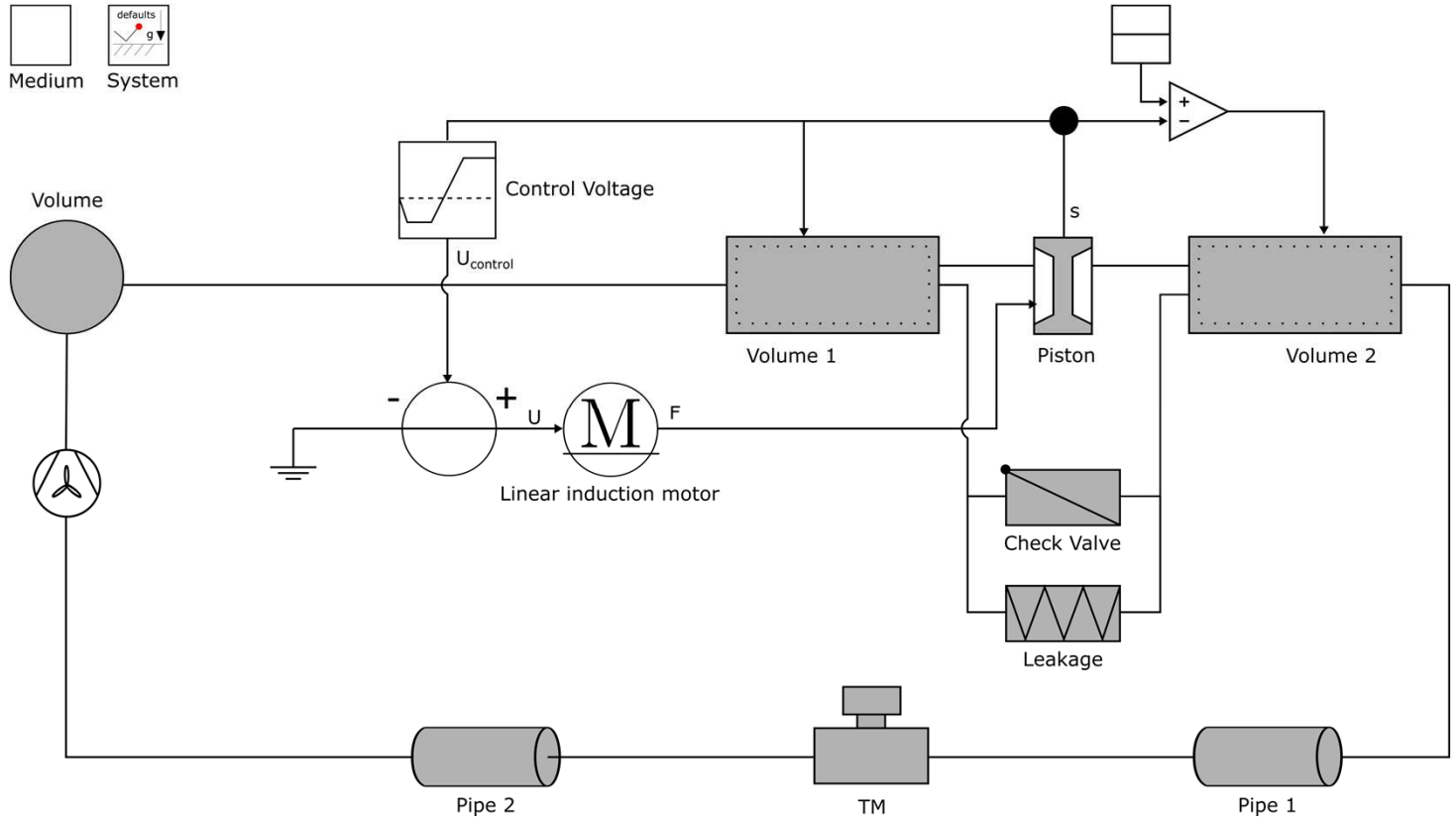
Flow Comparator Prototype



Experimental Setup



Model overview



Model assumptions

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Assumptions:

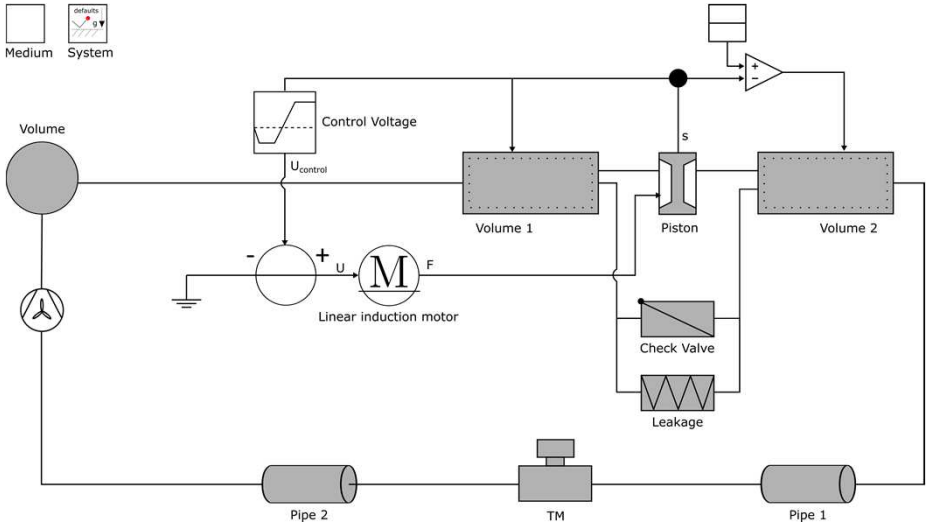
- One dimensional gas flow
- The gas flow is adiabatic
- Potential energy of the gas and heat transfer in the gas is neglected
- Pressure losses are proportional to the dynamic pressure

Boundary Conditions:

- p_{inlet} = const.
- T = const.

Operating Point:

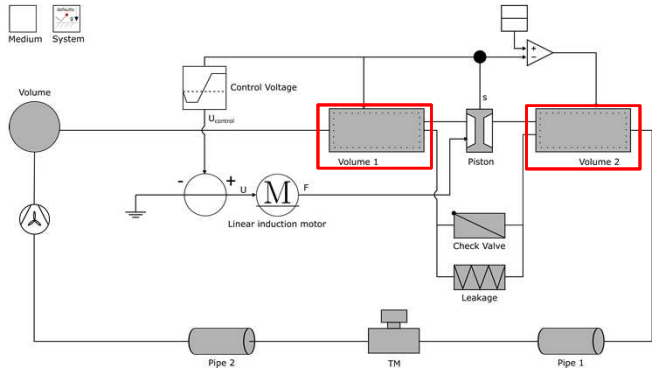
- Inlet pressure: 1 bar
- Inlet temperature: 20 °C
- Volume flow: 50 m³/h – 150 m³/h



Measuring Volumes

- One dimensional flow
- Volume depends on the piston's position
- Finite volume method for spatial discretization
- Heat transfer between piston and volume

- Storage for mass, energy and momentum



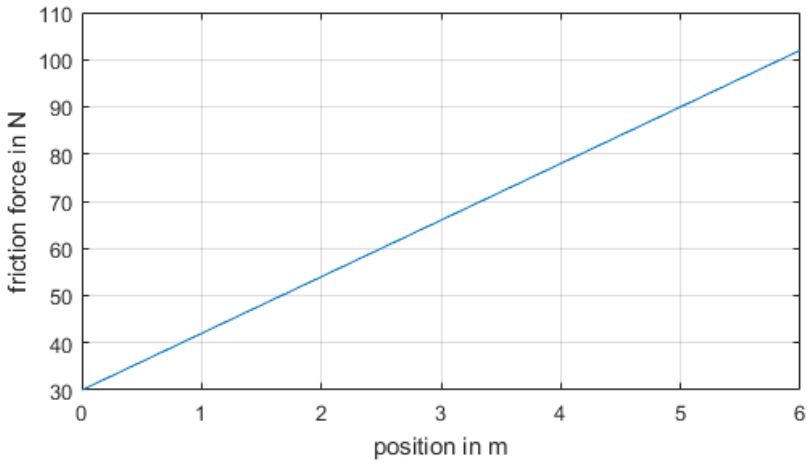
Equation of Motion of Piston

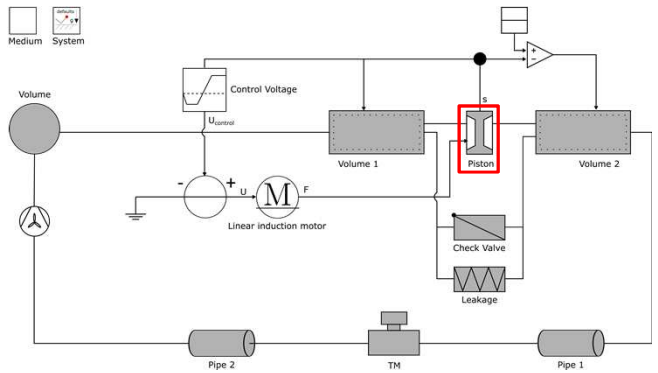
- Uses sliding mass model from MSL
- Friction force includes
  - Piston weight
  - Connection cable weight

$$m_P \ddot{s}_P = p_1 A_P - p_2 A_P - F_{F,P} + F_{LM}$$

$$\text{if } F_{F,P} > |p_1 A_P - p_2 A_P| + |F_{LM}| \text{ then } v_P = 0$$

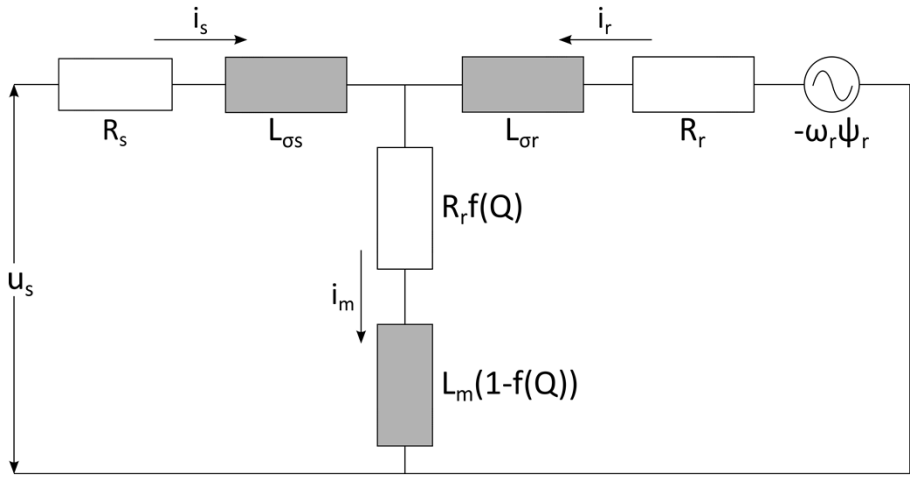
$$F_{F,P} = c_R g m_P + g m_C \frac{s}{l}$$

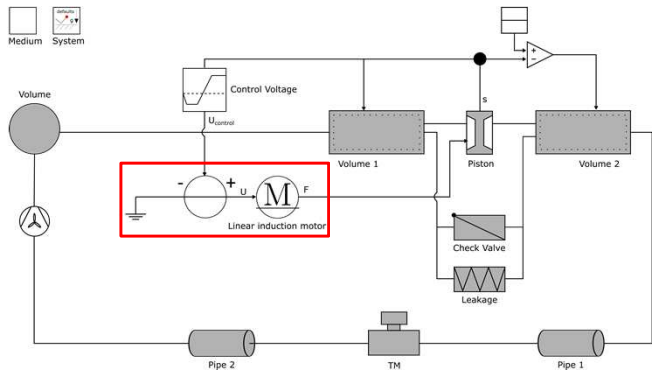




Linear Induction Motor

- Similar space-vector equivalent circuit to rotatory induction motor
- Transversal branch with eddy current resistance and magnetizing inductance
  - Vary with $f(Q) = \frac{1-e^{-Q}}{Q}$ depending on the end effect factor $Q = \frac{\tau_m R_r}{(L_m + L_{\sigma r})v}$
  - End effect factor depends on air-gap thickness, machine speed and inductor length





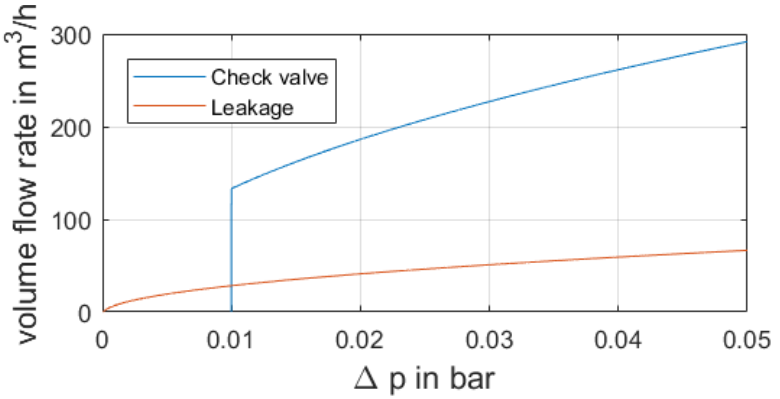
Additional Models

Check valve

- Volume flow rate proportional to pressure drop
- Hysteresis to avoid chattering

Leakage

- Models the mass flow between piston and cylinder
- Volume flow rate proportional to pressure drop

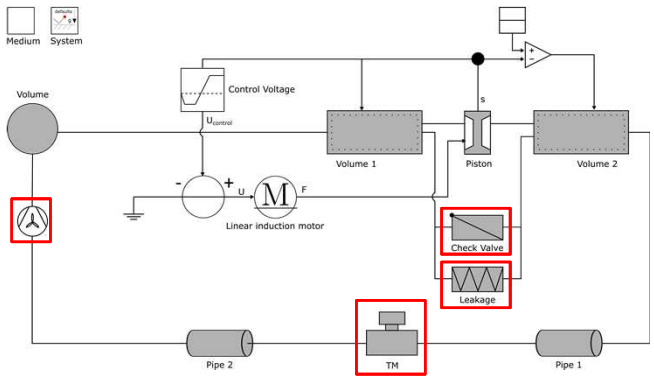


Turbine Meter

- Constant pressure drop coefficient
- Relationship between indicated volume flow rate and real volume flow rate

Fan

- Relationship between volume flow rate and system pressure drop



Validation

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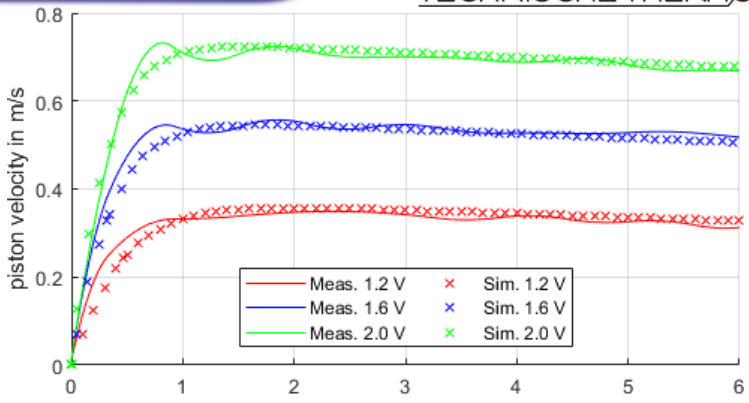
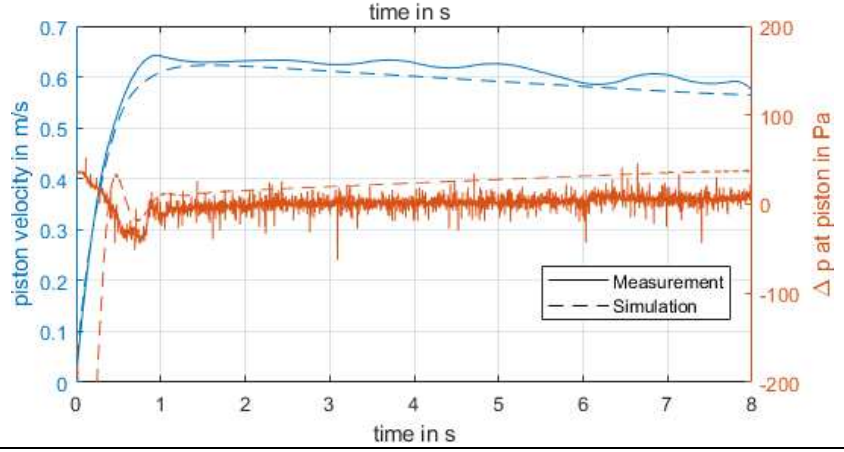
Validation of linear induction motor model

- Good accordance with measurement data



Validation of piston movement and differential pressure

- Similar piston velocity
- Small offset in differential pressure



Optimization of Control Voltage Trajectory

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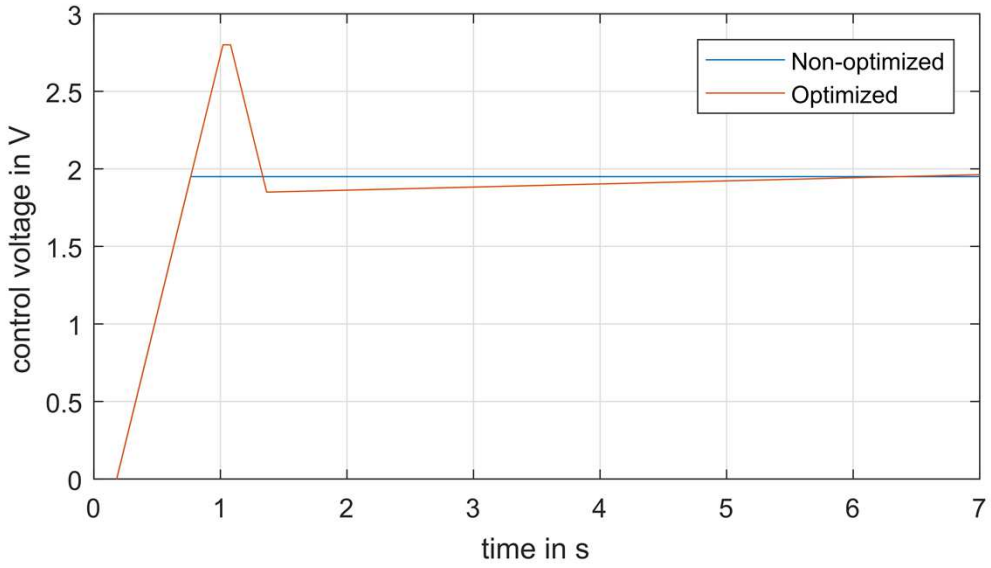
Optimization for maximum calibration time

- Calibration of TM when differential pressure at piston within set limits
- Excessive increase of control voltage at the start
- Optimization parameters
  - Max. control voltage
  - Time at max. control voltage
  - Min. control voltage
  - Increase of control voltage during calibration



Optimization of Control Voltage Trajectory

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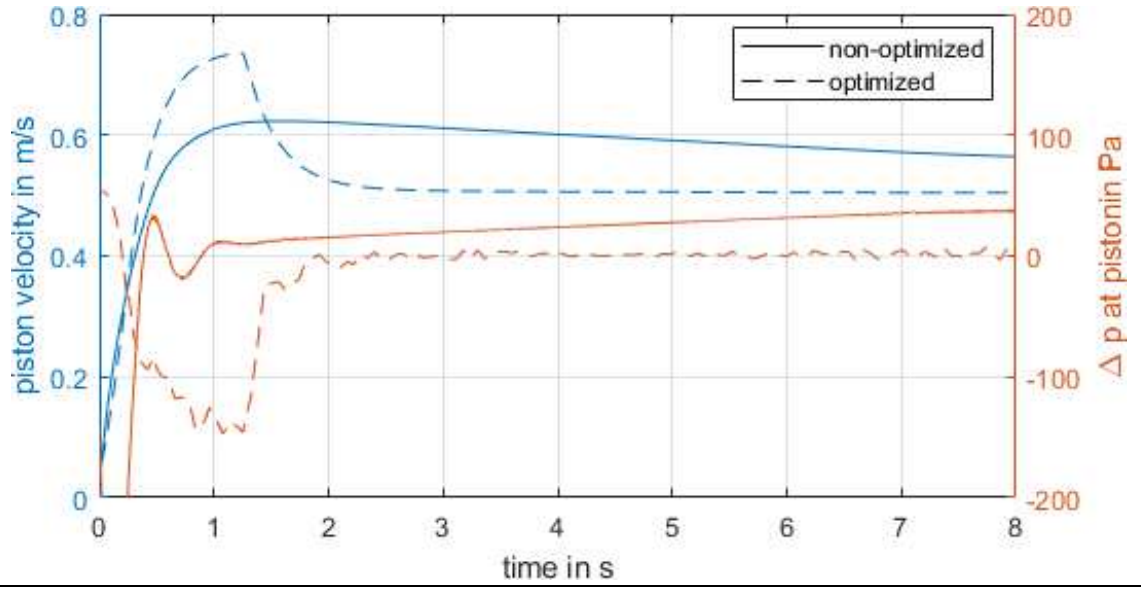
Piston velocity

- Piston velocity earlier equal to air flow velocity
- Piston velocity remains constant
- Zero differential pressure at the piston for long period



Summary & Outlook

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Summary

- Validation of Flow Comparator Model
- Optimization of control voltage for maximum calibration time
  → lasting zero differential pressure at piston and an increase of available calibration time

Outlook

- Implementation of heat transfer in all models
- More detailed optimization of control voltage trajectory
  - Friction force measurement with high accuracy needed
  - Leakage flow needs to be resolved with higher resolution

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Thank you for your attention!

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Backup

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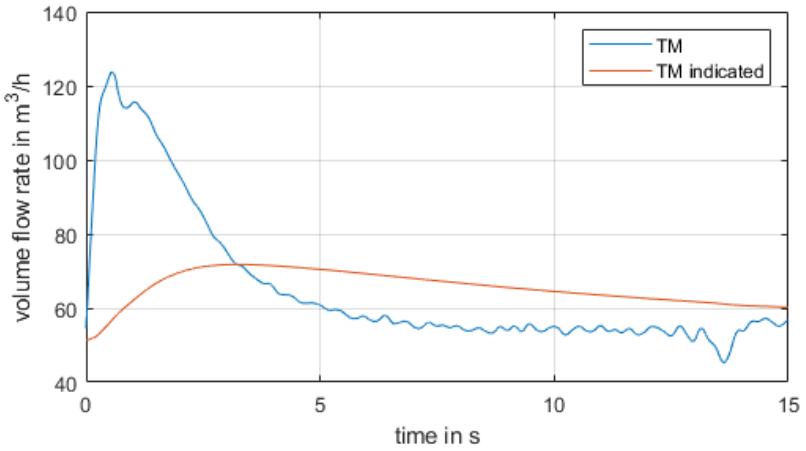
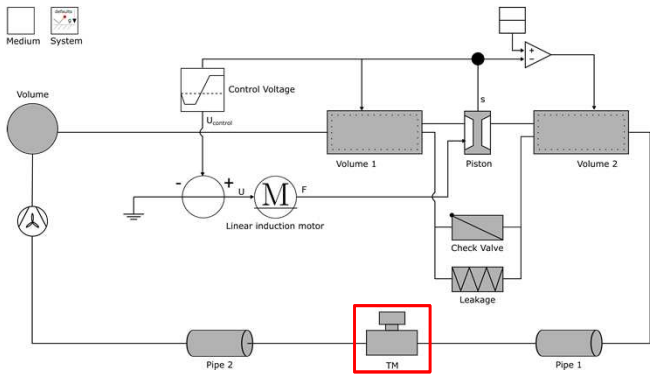
Turbine Meters

- Constant pressure drop coefficient
- Relationship between indicated volume flow rate and real volume flow rate
- Coefficients a, b, A and B based on experiments

$$\dot{V}_{i,rel} - \left(a + bV_{i,rel}\right) = A\rho V^2 - B\rho V V_i$$

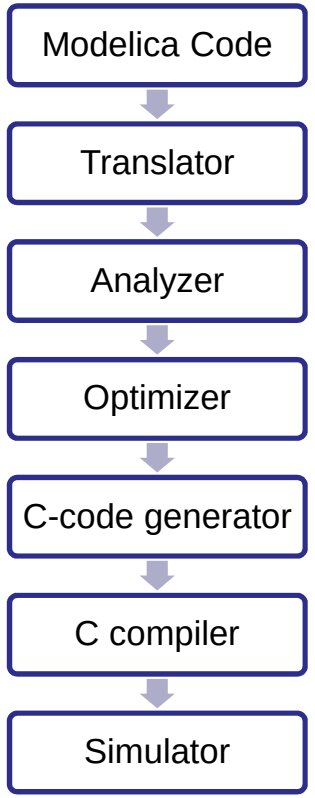
Source: www.vemmtec.de





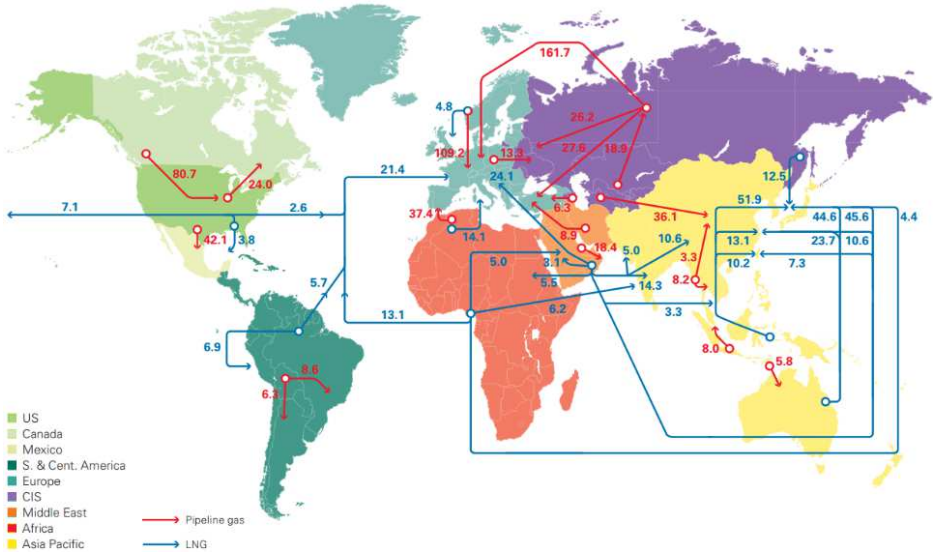
Modelica

- Non-proprietary, object-oriented and equation based language
- Libraries
  - Modelica standard library with 1600 models and 1350 functions
- Simulations envoirments
  - Dymola by Dassault Systemes
  - AMESim by Siemens PLM Software
  - Jmodelica and Openmodelica (open source)
- Used in many different fields
  - Automotive sector (Daimler, BMW, General Motors …)
  - Aviation sector (Airbus, DLR …)
  - Energy sector



Natural Gas Trade Flow

- 3700 bln. m³ natural gas production worldwide in 2017
- Natural Gas is traded between many countries worldwide



Source: BP Statistical Review of World Energy 2018

Measuring principle

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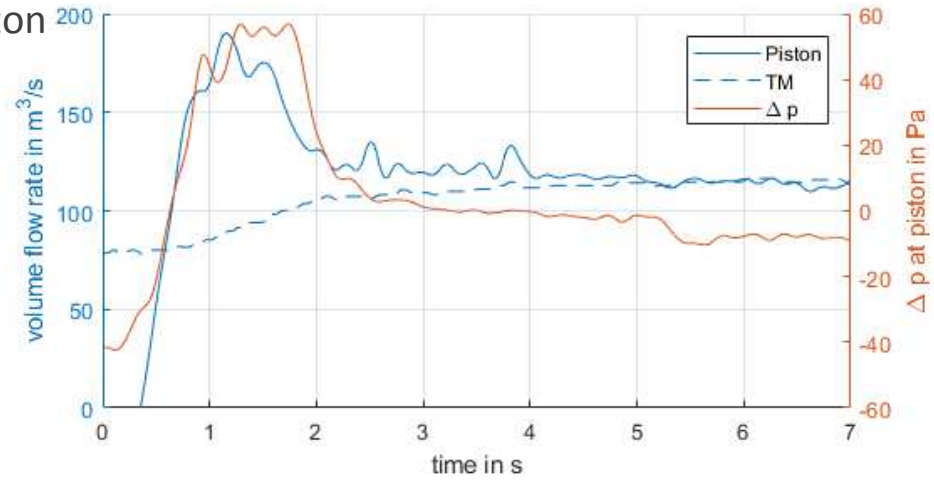
Comparison of fluid state up- and downstream of piston

- No difference when piston moves with fluid velocity



Correction Methods:

- Correlation Leakage – Differential pressure at piston
- Correlation Leakage – Velocity through piston