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 m³/h
  → Development of new primary standard with higher volume flow rate

**Source:** www.pigsar.de
Flow Comparator Prototype

Flow sensor

Differential pressure sensor

Stator package

Check valve

Wheels

Cable grommet with strain relief

Differential pressure sensor
Model overview

Medium
System

Volume

Control Voltage

U_{control}

Linear induction motor

Pipe 1

Pipe 2

Volume 1

Volume 2

Piston

Check Valve

Leakage

TM
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:
- $p_{inlet} = \text{const.}$
- $T = \text{const.}$

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

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

if \( F_{F,P} > |p_1 A_P - p_2 A_P| + |F_{LM}| \) 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 \( Q = \frac{\tau_m R_r}{(L_m+L_{or})v} \)
  - 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

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

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

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

#### 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
Thank you for your attention!

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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

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

Source: www.vemmtec.de
Modelica

- Non-proprietary, object-oriented and equation based language

- Libraries
  - Modelica standard library with 1600 models and 1350 functions

- Simulations environments
  - 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

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