Physikalisch-Technische Bundesanstalt
Braunschweig and Berlin
National Metrology Institute

Turbine Flow Meter used as Master

Current status of establishing a new method at HDP

21st International EMATEM-Summer School

17./18. September 2025

Kloster Seeon

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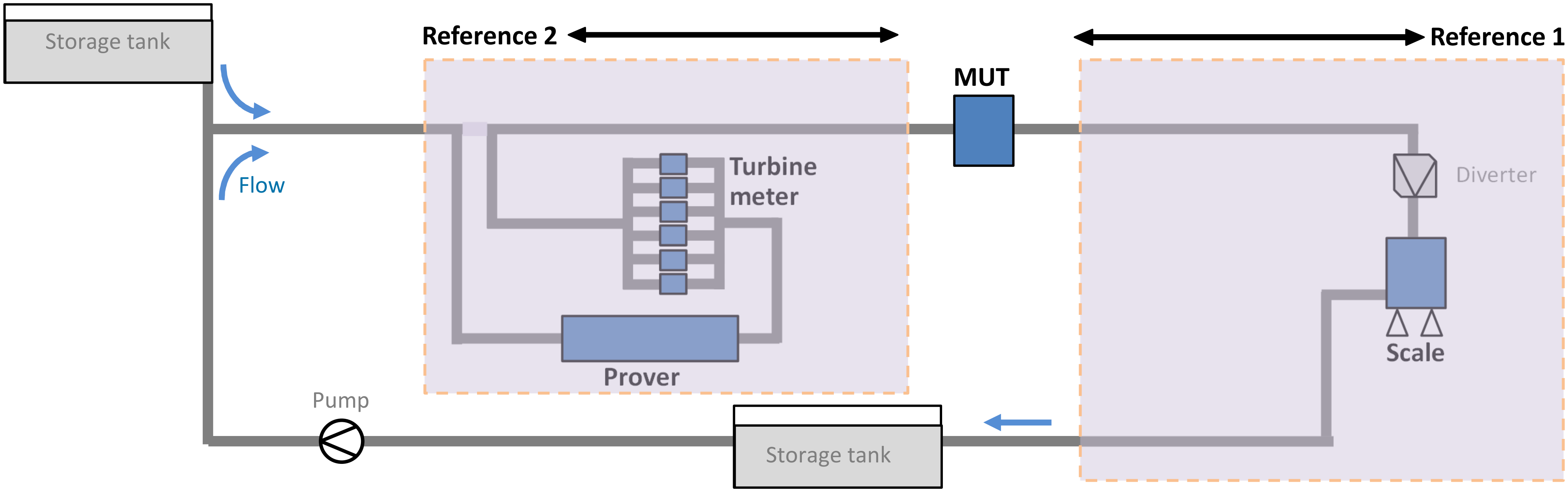
Calibration Capabilities (as original planned)

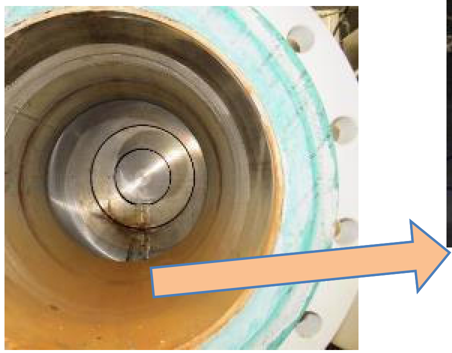
HDP – Calibration capabilities



Damaged Piston Prover

DN: 600 mm (24”)
Flow: 1.6 – 1,600 m^3/h
Volume: 250 L
Fluid: water
Linear encoder

Compact-Pisten-Prover

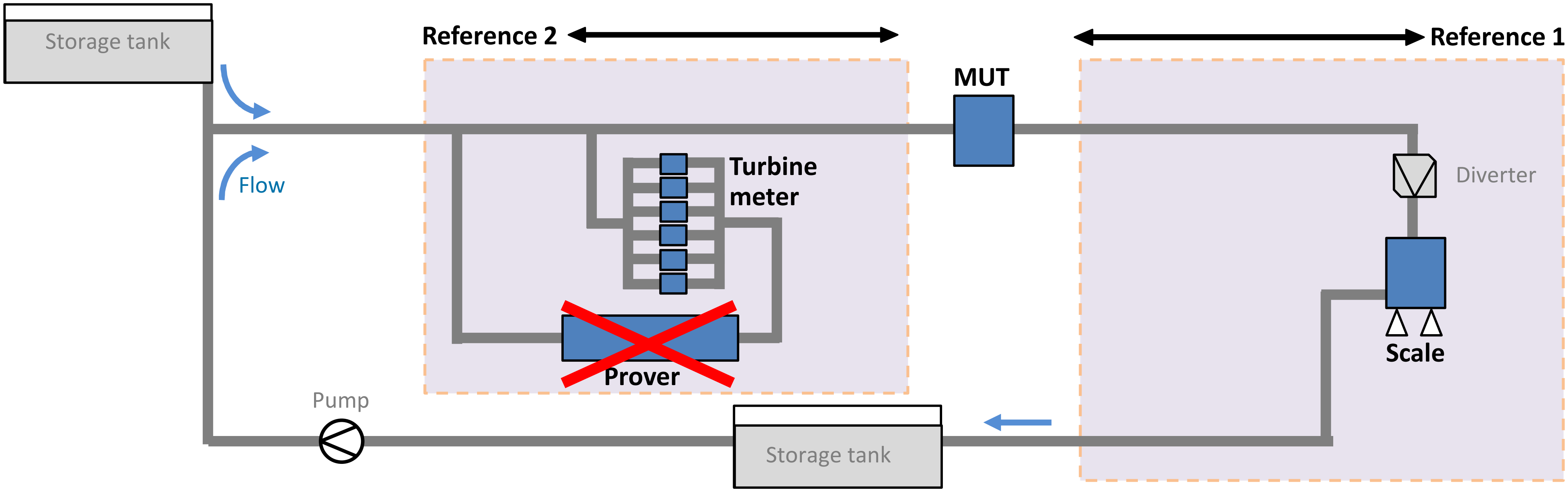


Prover – Inner surface of the cylinder

Prover - positioning rod

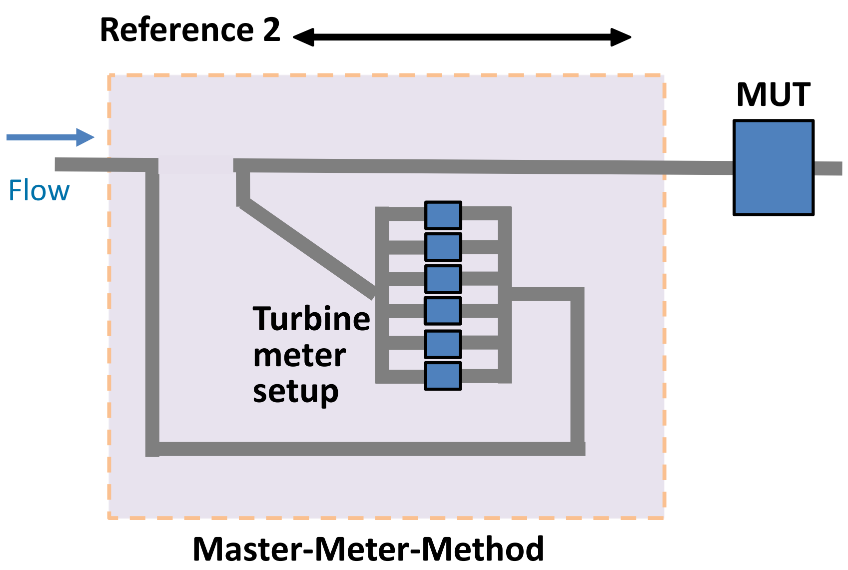
Calibration Capabilities – A new Approach

HDP – Calibration capabilities



Reengineering of Turbine Meter Setup

HDP – New Calibration Capabilities

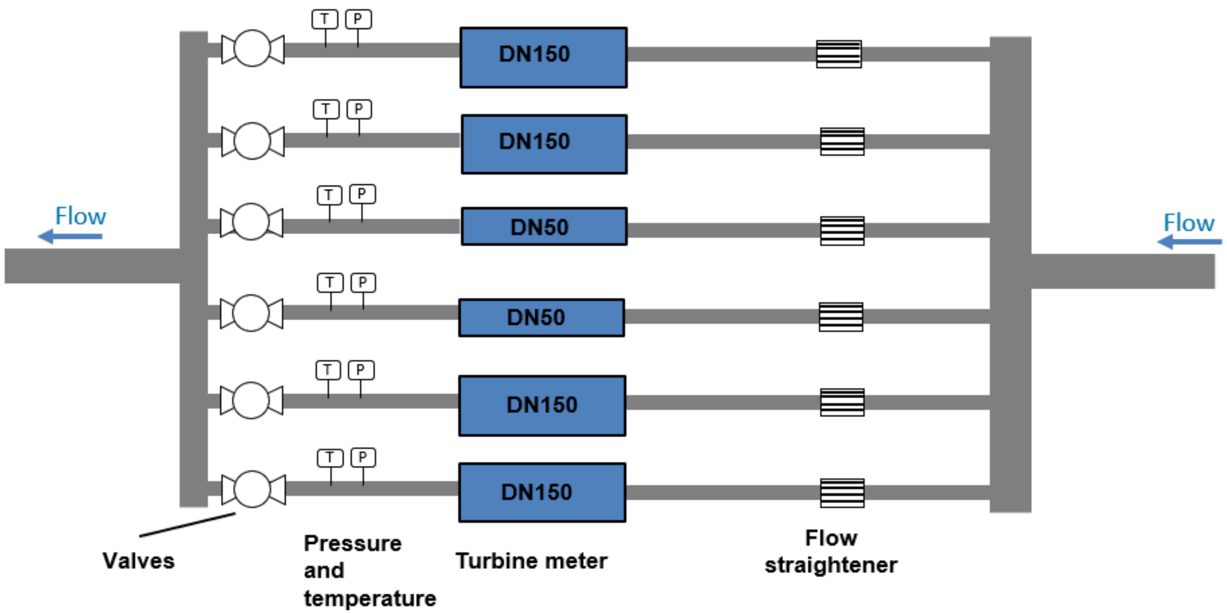


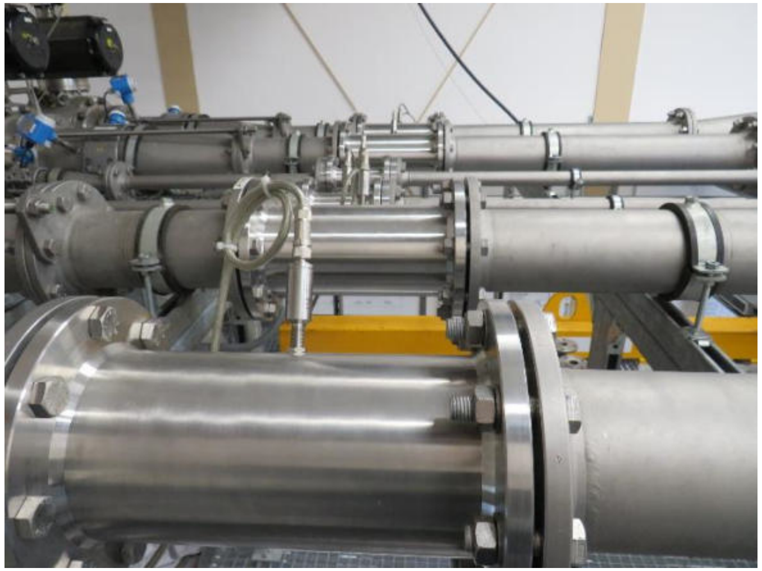
Goals and Specifications

- Less costs and personal resources
- Use of existing infrastructure
- Implementation of Master-Meter-Method
- Using of turbine meters as a working standard – with significantly shorter measurement times

5 single calibrations => at balance system => up to 1,5 h
=> Master Meter Method => 6 min

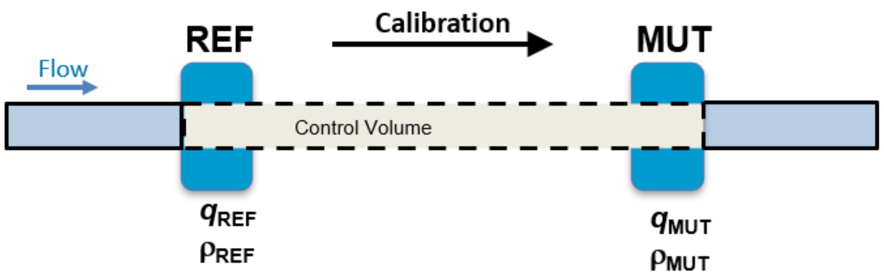
Details of Turbine Meter Setup





Master Meter Method

- **Basic procedure:** Comparison calibration of two output signals from a Reference Meter (REF) and Meter under Test (MUT)
- **Compared output signals:** => pulses => indication of volume/mass
  => electric measurands => indication of flow rate
- **Basic assumption:** Continuity equation is valid between REF and MUT
- **Goal:** Deviation between measured flow of REF and MUT



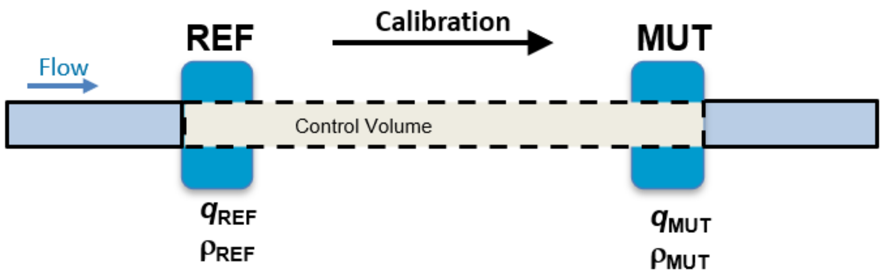
Master Meter Method

- **Benefits:** => Much less complicated and complex (e.g. as the gravimetric method)
  => Lower costs
  => More flexibility, e.g. if an exchange of the reference meter is necessary
  => Easy calibration of the REF (e.g. at higher metrological level)
  => Master Meter Method requires much less calibration time => more calibration in the same time

- **Challenges:** => Larger uncertainty due to secondary standard
  => Search for a suitable meter - **Why turbine meters?** →
  => Uncertainty calculation is still necessary

long term stability
repeatability
pressure loss
no zero setting effect

Uncertainty Calculation



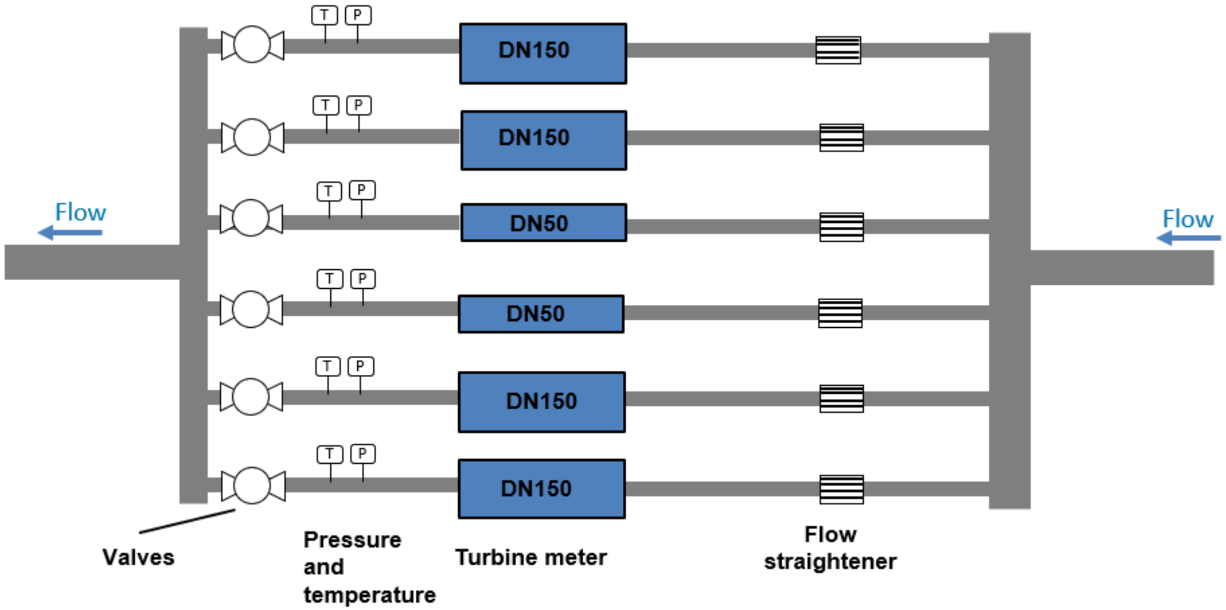
Basic mathematical model

$$E = \frac{\dot{m}_{MUT} - \dot{m}_{REF}}{\dot{m}_{REF}} = \frac{\rho_{MUT} \cdot q_{MUT}}{\rho_{REF} \cdot q_{REF}} - 1$$

Measurement error | **Mass related** | **Volume related**

E – Relative deviation error %
$\dot{m}_{MUT}$ - Mass flow of MUT [kg/h]
$\dot{m}_{REF}$ - Mass flow of REF [kg/h]
ρ_{MUT} - Density at MUT [kg/m³]
ρ_{REF} - Density at REF [kg/m³]
q_{MUT} - Vol. flow of MUT [m³/h]
q_{REF} - Vol. flow of REF [m³/h]

Uncertainty – Combination of Reference Meter



Application of "Staffelmeterverfahren"

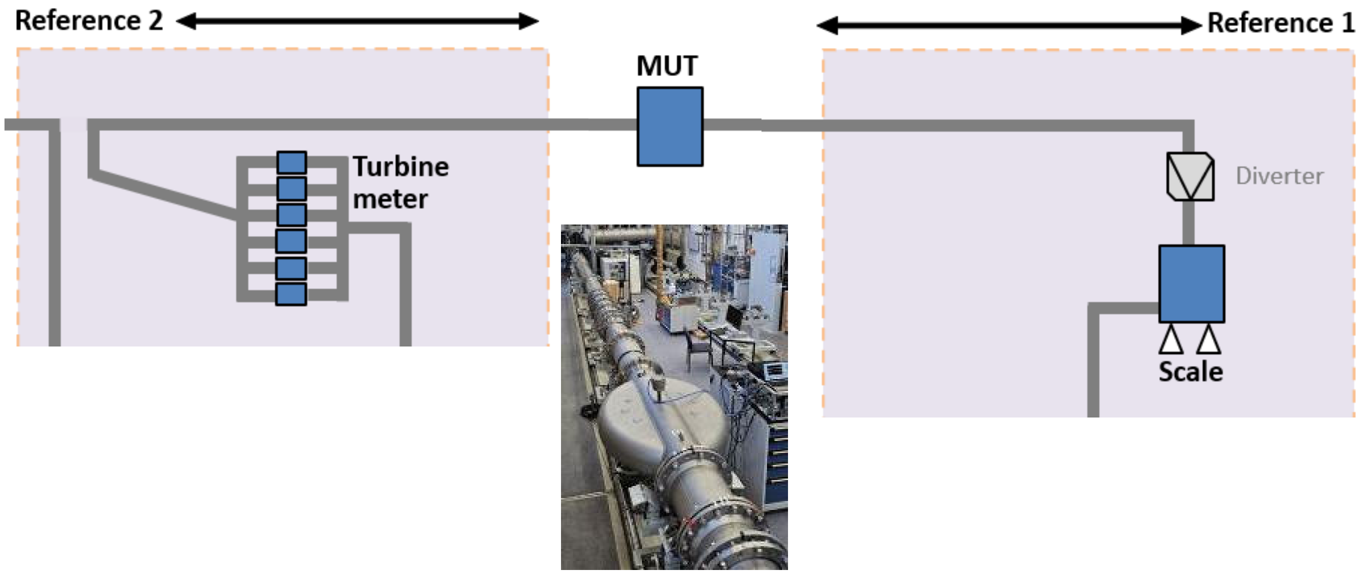
➔ well established in gas flow metering

Calibration of a Coriolis Flow Meter DN400

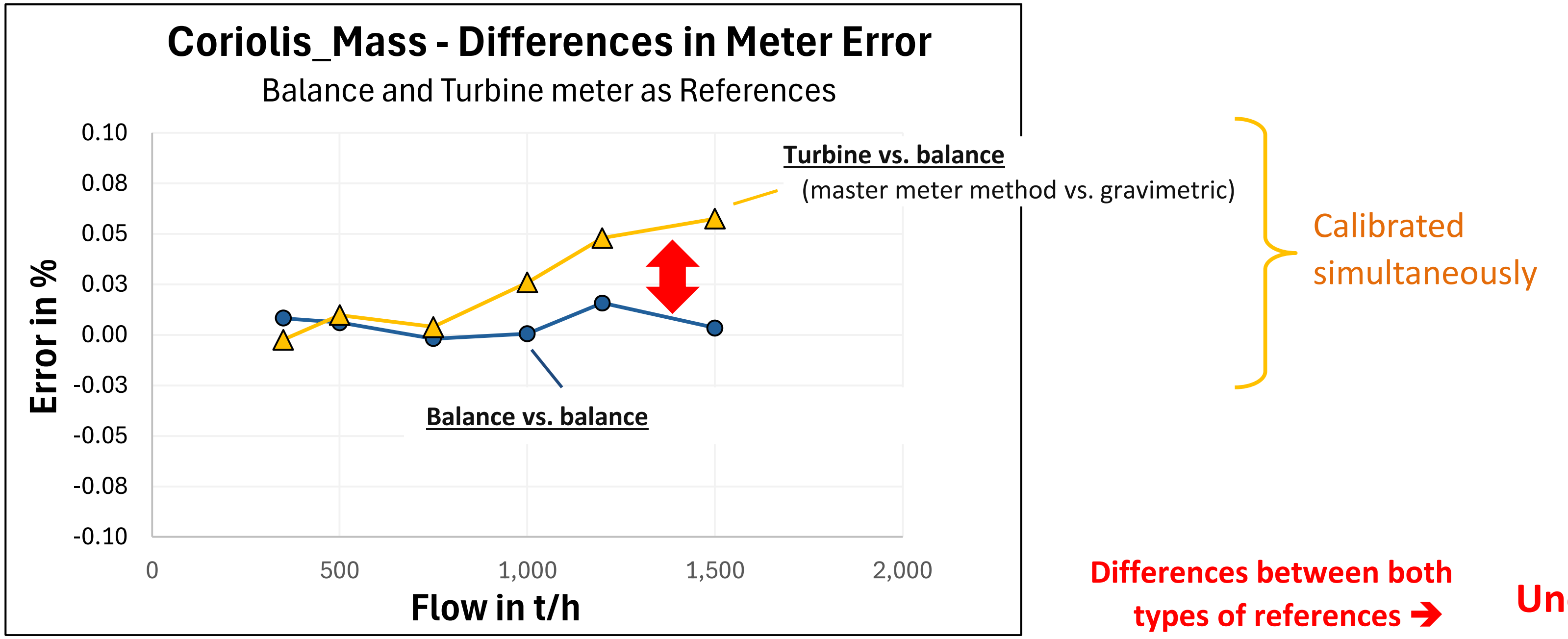
Turbine meter
as Master Meter

Coriolis flow meter DN400
as MUT and best existing device

Gravimetric reference



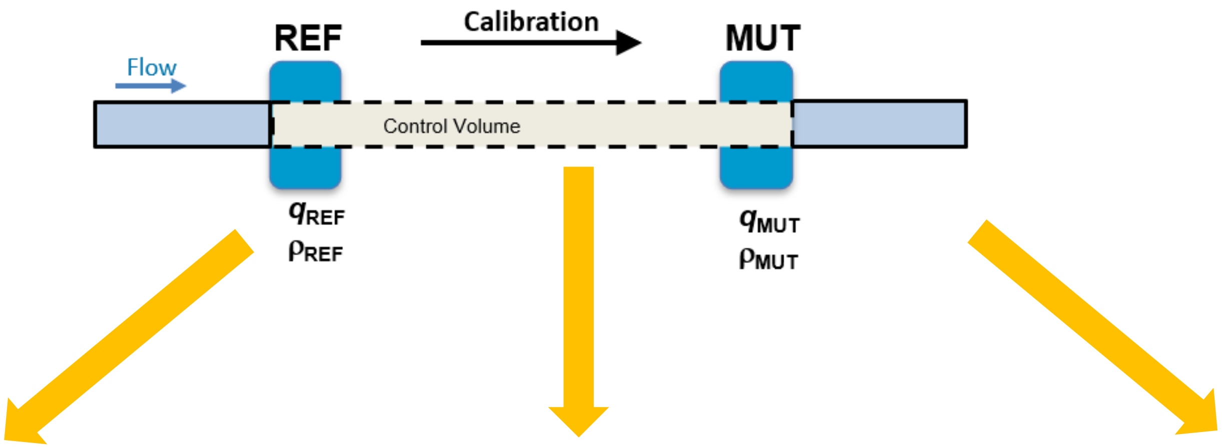
Calibration of a Coriolis Flow Meter DN400



Differences between both types of references ➔ Sources of error?

Uncertainty discussion of Master Meter Method

Uncertainty Input Parameter



Uncertainties of the Reference

- Calibration
- Error of approximation model
- Dependencies on fluid temperature and line pressure
- Long term stability (meter drift)
- Resolution of measurements
- (Zero stability)

Uncertainties of the Process

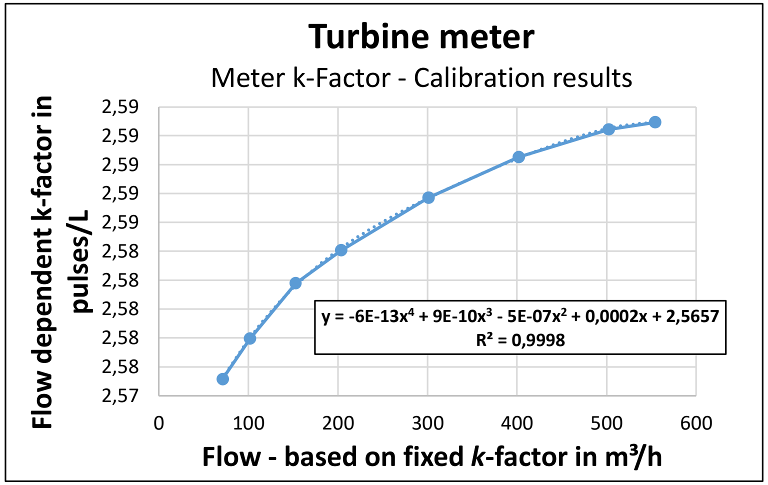
- Flow stability
- Fluid temperature and line pressure
- Density
- Volume of intermediate pipe
- Leakage

Uncertainties of the MUT

- Repeatability
- (if known, also other inputs)

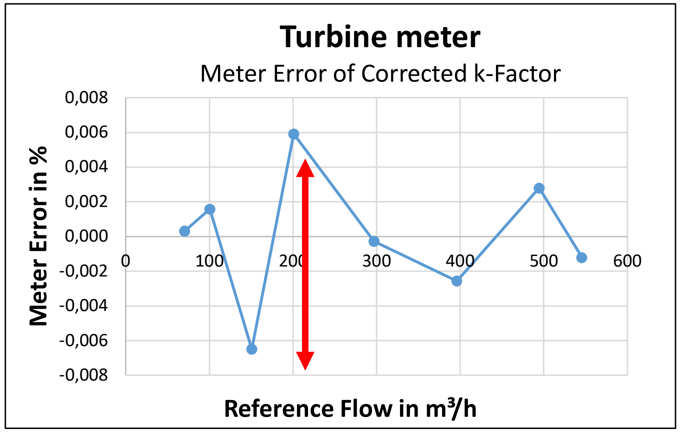
Calibration of a Single Turbine Meter against Gravimetric Standard

- **Goal:** Estimation of flow depended meter *k*-factor => Real flow of turbine meter



- **Correction function of the fixed (original) *k*-Faktor**

- **Quality** of flow depended function via
  => Fitting of function parameter and flow range

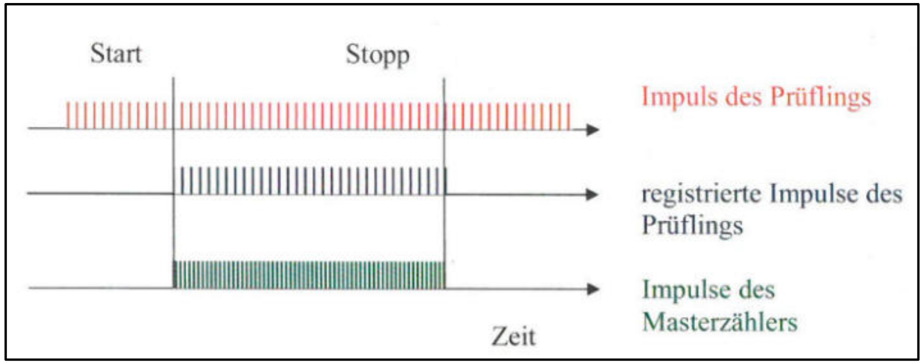


Model error = uncertainty factor

Resolution of Turbine Output vs. Measurement Time

- **Goal:** Determination of minimum measurement time

Best option: Pulse value of master **>** pulse value of MUT



Adunka (2007): Messunsicherheiten – Theorie und Praxis, 3. Auflage

Pulse characteristics of used turbine meter

DN150 => 2,55 pulses/L

DN50 => 63,5 pulses/L

Examples of MUT

DN400 Coriolis flow meter => 15 Pulses/kg

DN250 Coriolis flow meter => 24 Pulses/kg

DN100 Coriolis flow meter => 100 Pulses/kg

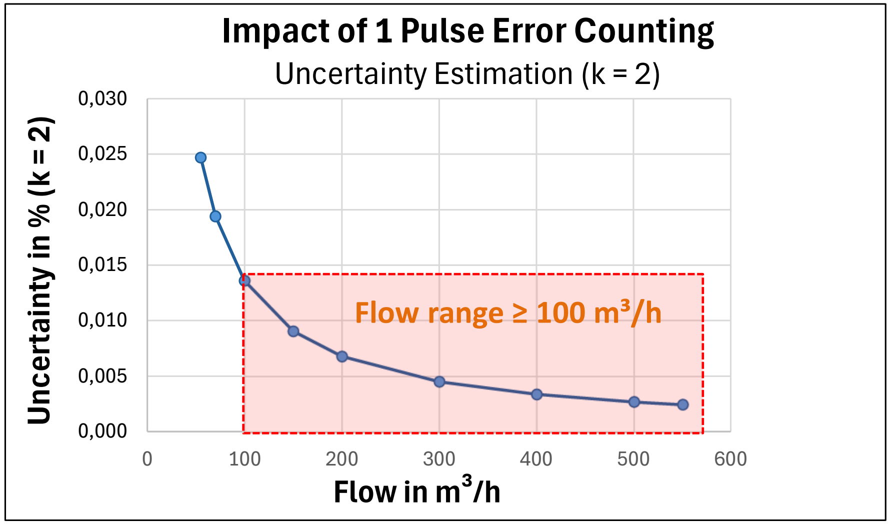
=> Consequences for uncertainty calculation?

Resolution of Turbine Output vs. Measurement Time

- **Goal:** Determination of minimum measurement time

Example for DN150 Turbine meter

DN150				
k-factor	2,550	pulses / L		
	0,392	L / pulse		
Measurement time		60	s	
Flow in m^3/h	55	70	100	150
Volume in L	917	1167	1667	2500
Pulses	2338	2975	4250	6375
+ 1 pulse error				
Volume - change in %				
	0,043	0,034	0,024	0,016
Uncertainty k = 2				
%	0,025	0,019	0,014	0,009



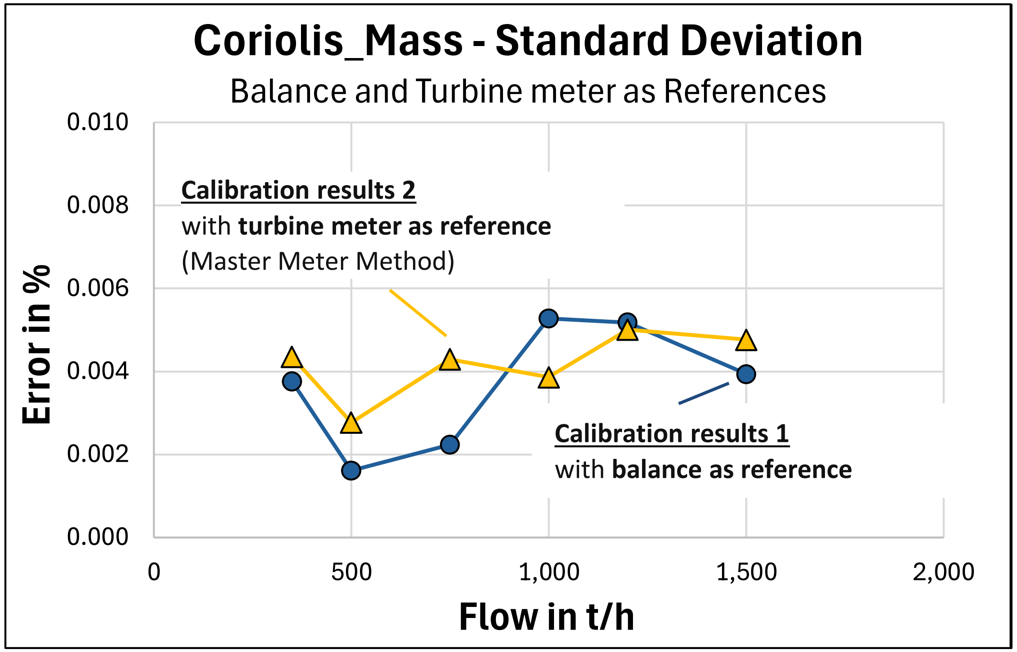
In consequence

=> minimum measurement time 60 s

=> is followed by a max. uncertainty of 0,014 % (k = 2)

Repeatability

- **Goal:** Verification of very low repeatability during calibration



Short time stability of calibrations

=> Standard deviation very low

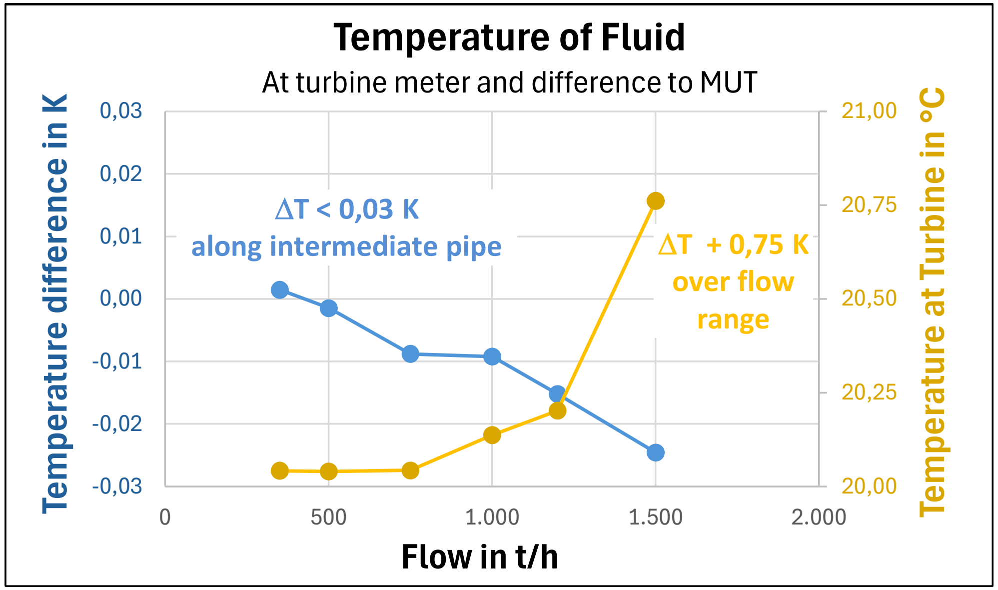
=> no difference between use of both references

In consequence:

=> very low impact on calibration uncertainty

Temperature Effects

- **Important for:** Intermediate pipe and temperature sensitivities of the meter



Temperature gradient along intermediate pipe < 0,03 K

=> very low for 30 m pipe length

=> Chun et al. (2017) recommended < 0,20 K

=> but still to be accounted in uncertainty calculation

Increase of fluid temperature of up to + 0,75 K

=> starting with flow of 1.000 t/h

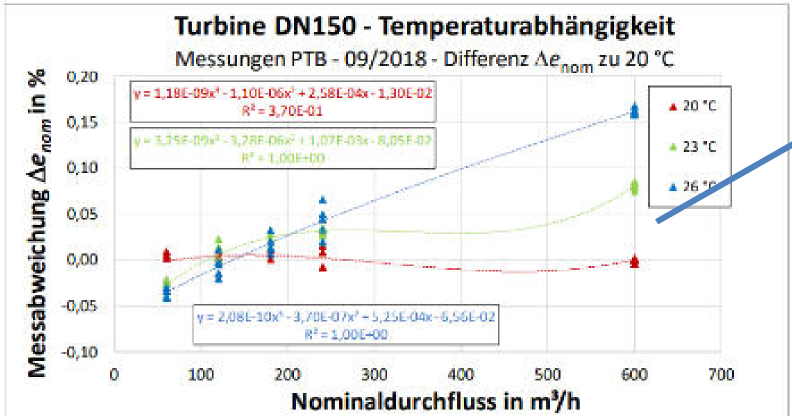
but: calibration of turbine meter at 20 °C

=> Consequences for uncertainty calculation?

Temperature Effects

- **Important for:** Intermediate pipe and temperature sensitivities of the meter

Results of DKD comparison => observed temperature sensitivities of a turbine meter DN150



Frahm (2022): Vergleichsbericht DKD-V 11-3 Ringvergleich Flüssigkeiten – Juni 2017 bis Dezember 2020, DOI: 10.7795/550.20220609

Temperature sensitivity (literature)

=> same type of device (manufacturer, size, flow range)

=> + 0,026 % meter error per 1 K at 600 m³/h

Coriolis calibration - increase of fluid temperature of up to + 0,75 K

=> change in meter error + 0,020 %

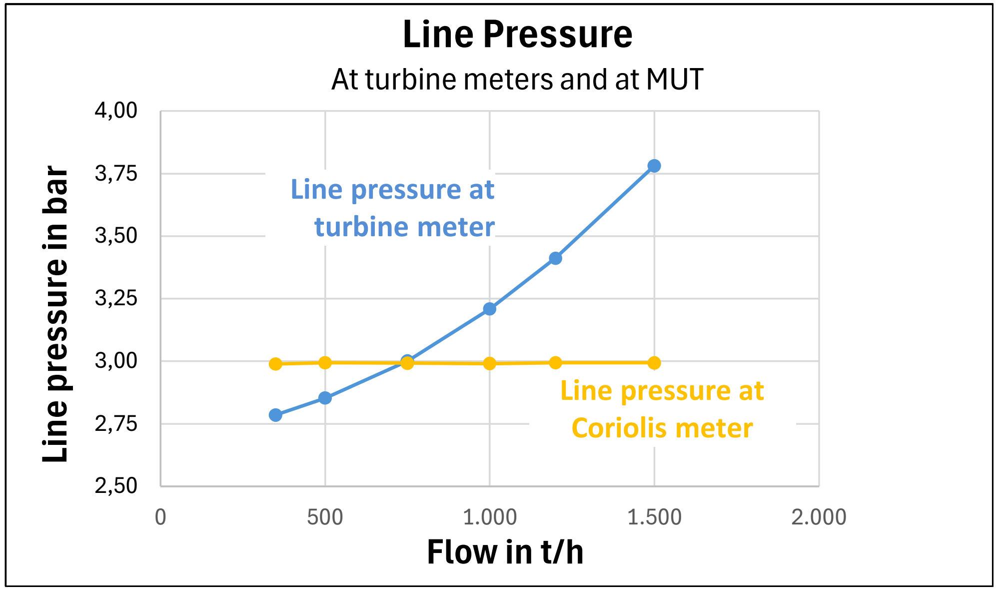
In consequence:

=> calibration as far as possible at 20 °C

=> otherwise, important uncertainty factor

Line Pressure Effects

- **Important for:** Pressure sensitivities of the turbine meter



Line pressure downstream of Coriolis meter

=> control variable

=> constant over full flow scale

Line pressure at turbine meter

=> depends on set pressure at MUT

=> increases with rising flow

=> observed range between 2,4 bar … 3,8 bar

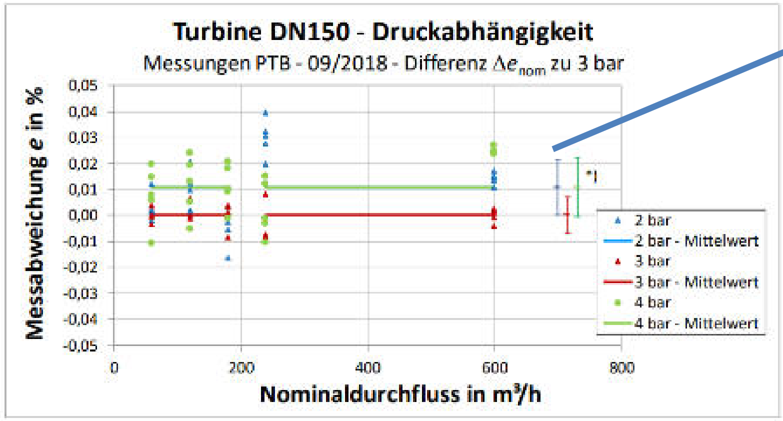
but: calibration of turbine meter at non-constant pressure
=> between 2,7 bar … 3,3 bar

=> consequences for uncertainty calculation?

Line Pressure Effects

- **Important for:** Pressure sensitivities of the turbine meter

Results of DKD comparison => observed pressure sensitivities of a turbine meter DN150



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Pressure sensitivity (literature)

=> same type of device (manufacturer, size, flow range)

=> + 0,025 % meter error per 1 bar at 600 m³/h

Coriolis calibration - increase of line pressure of up to + 1,0 bar

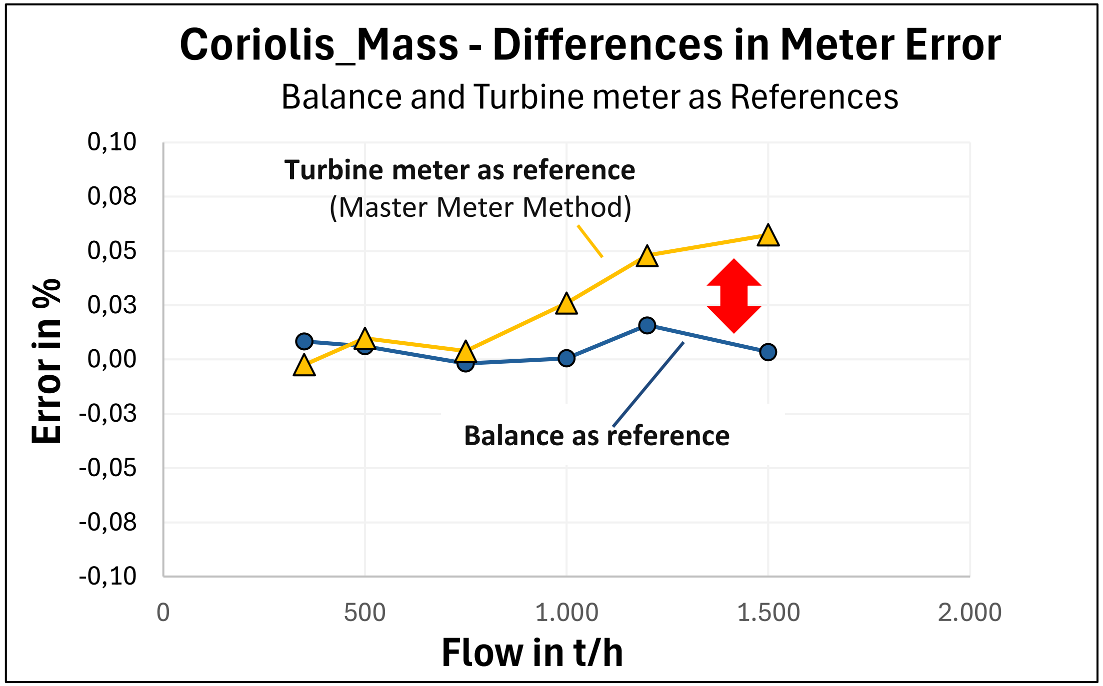
=> change in meter error + 0,025 %

<u>In consequence:</u>

=> a calibration at a constant pressure is not possible

=> introduction of an important uncertainty factor

Summary I



=> **Differences** in calibration mainly caused by pressure dependency of the turbine meter

=> Next steps:
Recalibration of the meter at constant pressure

pressure correction vs. larger uncertainty
???

Summary II

- Mater Meter Method successfully introduced at HDP
- Conditions of turbine meter calibration vs. conditions if used as master meter
- Critical discussion on uncertainty inputs is essential
- **But:** A comparison between methods / facilities gives the most reliable data!

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