Uncertainty of transfer meter for flow comparisons

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Enrico Frahm, PTB Braunschweig
AG 1.52

Flow comparisons - Introduction

Why flow comparisons?

For Accredited laboratories

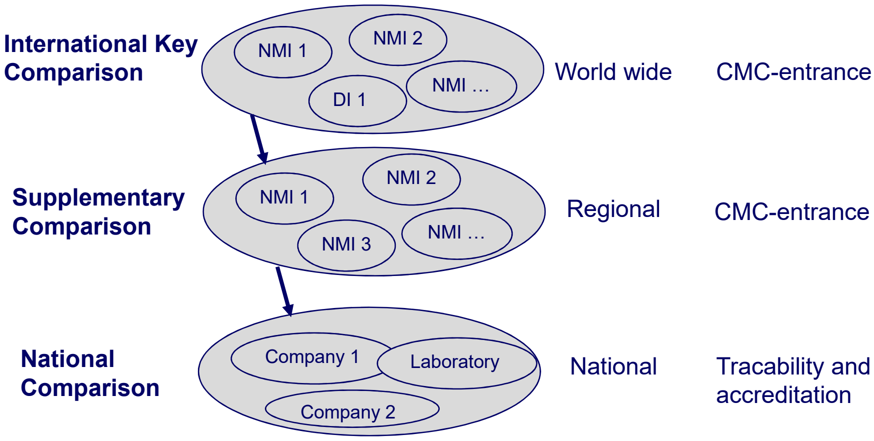
- Confirmation of facility uncertainties
- Traceability to national flow standard

National metrology institutes

- Confirmation of facility uncertainties
- International harmonisation
- Traceability of the unit flow

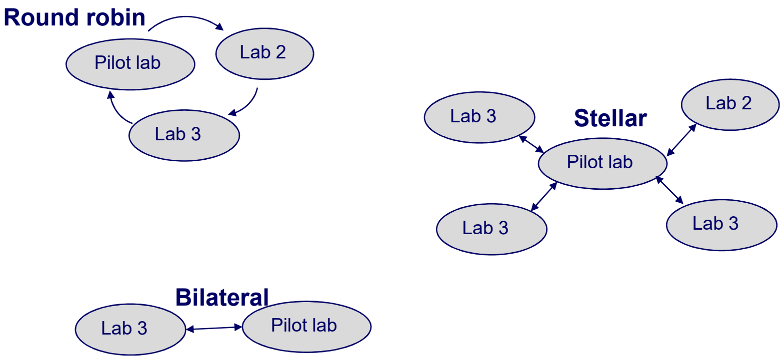
Flow comparisons - Introduction

Levels of flow calibrations (in principle)



Flow comparisons - Introduction

Basic organisation schemes of flow comparisons



Flow comparisons - Introduction

Basic literature

WRIGHT, J. et al. (2016): Transfer standard uncertainty can cause inconclusive inter-laboratory comparisons. In: Metrologia 53 (2016) 1243–1258

BIPM (2014): WGFF Guidelines for CMC Uncertainty and Calibration Report Uncertainty. https://www.bipm.org/utils/en/pdf/ccm-wgff-guidelines.pdf

Cox, M. G., (2002): Evaluation of key comparison data. In: Metrologia, 39, 589-595,2002

BIPM (2013): CCM-WGS, CCM Guidelines for approval and publication of the final reports of key and supplementary comparisons

BIPM (2017): CCEM Guidelines for Planning, Organizing, Conducting and Reporting Key, Supplementary and Pilot Comparisons.

Flow comparisons - Introduction

Flow comparisons - workflow

Objectives of accredited laboratories:

- Confirmation of facility uncertainties
- Traceability to national flow standard

Process:

- Preparation (protocol, manual etc.) and agreement of participants
- Ordering and characterisation of suitable transfer standards
- Calibrations
- Evaluation of the results using E_N-value
- Final report and comparison decision

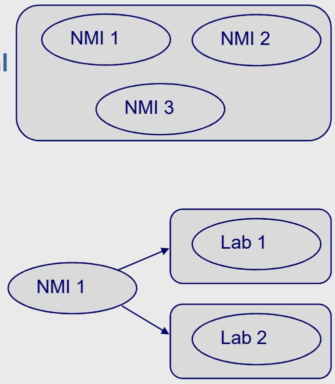
Flow comparisons - Introduction

Evaluation of comparisons

… depending on metrological levels of participants

One (equal) metrological level
(e.g. PTB, VSL, NIST)

Reference lab vs. lower metrological levels



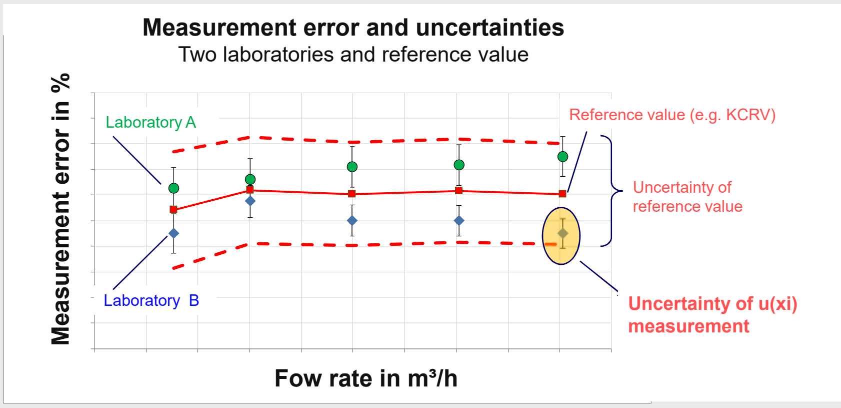
➔ Determination of a *reference value*

➔ *Deviation* to reference laboratory

Flow comparisons - Introduction

Evaluation of comparisons

Analysis of calibration results – using reference value



Evaluation of comparisons

Uncertainty $u(x_i)$ of a measurement – Input parameters

$$u(x_i) = \sqrt[2]{u^2_{Lab,i} + u^2_{Comp}}$$

Laboratory uncertainty

Comparison uncertainty

$$u^2_{Comp} = u^2_{TS} + \frac{s}{\sqrt{n}}$$

Standard uncertainty of measurement

Transfer meter uncertainty

$$u^2_{TS} = u^2_{drift} + u^2_{temp} + u^2_{press} + u^2_{...}$$

Drift Temperature Pressure

Evaluation of calibrations

Quality criteria of evaluation

- Test of normal distribution using **Chi-squared-Test**
- Estimation of **E_N-value**
  and validation of submitted laboratory uncertainty u_{lab}:
  - **En ≤ 1** => u_{lab} accepted (e.g. CMC-value)
  - **En ≤ 1,2** => critical u_{lab}
  - **En > 1,2** => u_{lab} declined
- Relation between lab and transfer meter uncertainty (u_{comp}/u_{base})

$$\frac{u_{comp}}{u_{Lab}} \leq 2.0$$ **=> precondition: u(Comparison) < 2u(facility)**

Flow comparisons - Introduction

Current comparisons of PTB working group 1.52

As pilot laboratory (organising and data analysing)

- *CCM.FF-K1.2015* (water, DN100) = Key Comparison
- *COOMET.M.FF-S2* (water, DN25 + DN 80) = Supplementary Comparison
- *SIM.M.FF-S9* (water, DN 80) = Supplementary Comparison
- *DKD-Ringvergleich Flüssigkeiten* (water + hydrocarbon, DN15/25 DN150)

As a participant

- *CCM.FF-K2.2011* (water + hydrocarbon, DN40)
- *PTB – MIKES* (water, DN100) = Supplementary Comparison
- *ILC 1500-18* manufacturer comparison Italy, Czech Rep. (water, DN 300)

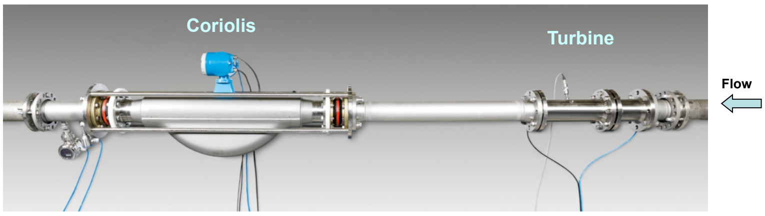
CCM.FF-K1.2015 – Key Comparison

Key comparison CCM.FF-K1.2015 water flow

CCM.FF-K1.2015 – Key Comparison

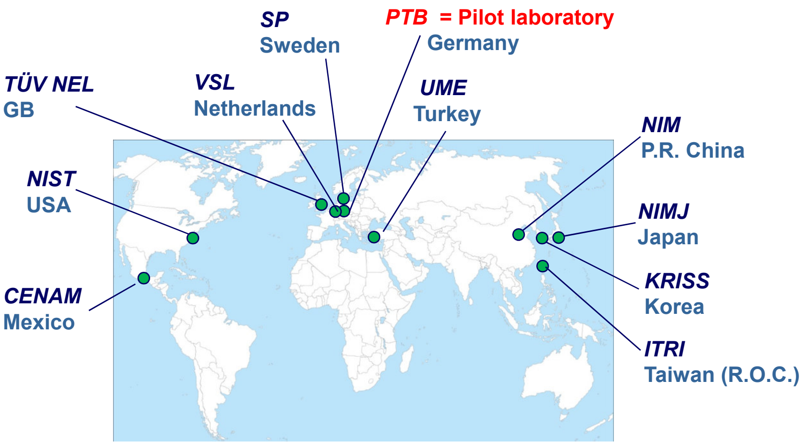
Key comparison CCM.FF-K1.2015 water flow

- **Participants:** 11 NMI`s / DMI`s
- **Conditions:** V = 30 $m^3\ h^{-1}$ … 200 $m^3\ h^{-1}$, T = 20°C, p = 3 bar
- **Measurands:** K-factor (pulses/kg) and (pulses/L)
- **Transfer devices:** Coriolis, Turbine - DN100
- **Calibration period:** 12/2015 – 05/2018



CCM.FF-K1.2015 – Key Comparison

Participants

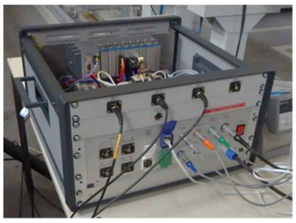


CCM.FF-K1.2015 – Key Comparison

Special data logging system

➔ **High temporal logging of**

- Impulse length of transfer meter
- Fluid properties: density, temperature, pressure
- Difference pressure along turbine meter



CompactRIO-Data logging system

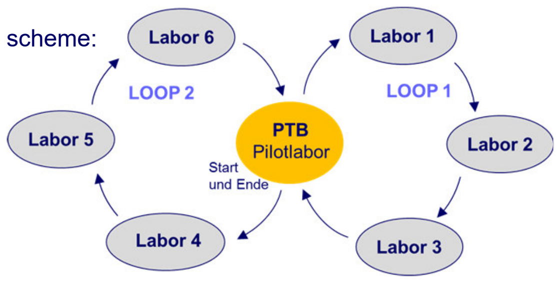
DKD Ringvergleich „Flüssigkeiten“

DKD-Ringvergleich „Flüssigkeiten“

DKD-Ringvergleich „Flüssigkeiten“

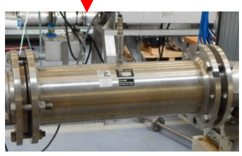
- **Objective:** Verification of accredited laboratory uncertainties
- **Participants:** 6 DAkkS-laboratories
- **Calibration period:** 2017 - 2018

Comparison scheme:



Transfer meter

	Turbine meter DN15	Coriolis meter DN25	MID DN25	Turbine meter DN150
Messbereich	0,08 m³/h - 1,2 m³/h	0,9 t/h - 9,0 t/h	0,9 m³/h - 9,0 m³/h	60 m³/h - 600 m³/h



DKD Ringvergleich „Flüssigkeiten“

Calibration conditions during comparisons

		CCM.FF-K1.2015		DKD	
Line temperature	nominal	20 °C	**Max. deviation to nominal value**	20 °C	**Max. deviation to nominal value**
	Min	11 °C	**8 K**	20 °C	**8 K**
	Max	28 °C		28 °C	
Line pressure	nominal	3 bar		3 bar	
	Min	0,5 bar	**2,5 bar**	2 bar	**1 bar**
	Max	4 bar		3 bar	

➔ Dependency of meter uncertainty?

DKD Ringvergleich „Flüssigkeiten“

Stability of transfer meter - *Characterisation measurements*

- **Strong deviations to nominal calibration** conditions in participated laboratories
- **? Effect to meter uncertainty**
- **Characterisation measurements** at pilot laboratory
- **Observed values:**
  - Fluid temperature
  - Line pressure
  - Reproducibility
  - Repeatability
  - and …
- Objective: Quantification of **meter uncertainty u_{TS}**

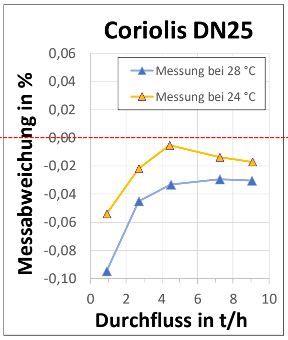
$$u_{TS}^2 = u_{drift}^2 + u_{temp}^2 + u_{press}^2 + u_{...}^2$$

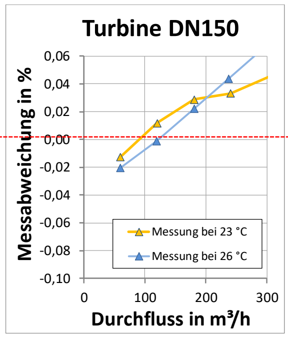
DKD Ringvergleich „Flüssigkeiten“

PTB

Fluid temperature - *PTB-Characterisation measurements*

Deviation of measurement error to 20 °C (for 24 °C and 28 °C)





Deviation temperature PTB => laboratories ΔT_{max} = 8,0 °C

Coriolis (m > 2 t/h) — **Turbine meter**

$\Delta error_{max}$ = 0,045 % — **$\Delta error_{max}$ = 0,044 %**

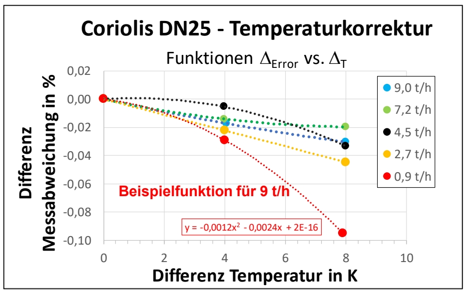
DKD Ringvergleich „Flüssigkeiten“

PTB

Fluid temperature – *Correction function*

=> Objective: Reduction of meter uncertainty

a) Correction based on characterisation measurements



Correlation between Δ_{error} und ΔT

$(e_{Labor} - e_{20°C})$ vs. $(T_{Labor} - T_{20°C})$

➔ **Residuals => u_{Temp}**

b) Correction based on thermal extension coefficient α

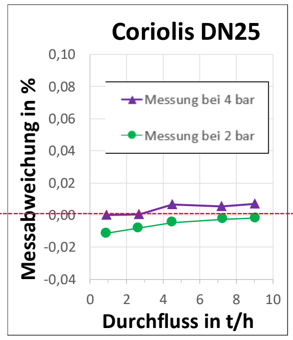
$$K_{\alpha,corr} = K \cdot [1 + 3 \cdot \alpha_{Meter}(T_{Labor} - T_{Nominal})]$$

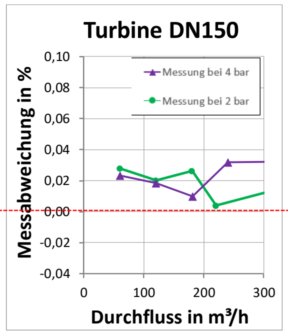
DKD Ringvergleich „Flüssigkeiten“

PTB

Fluid pressure - *PTB-Characterisation measurements*

Deviation of measurement error to 3 bar (for 2 bar and 4 bar)





Deviation of pressure PTB => Labories Δp_{max} = 1,0 bar

Coriolis	Turbine meter	
$\Delta error_{max}$ = 0,010 %	$\Delta error_{max}$ = 0,032 %	=> u_{Press}

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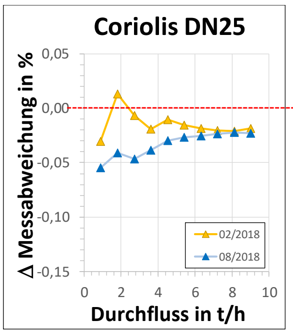
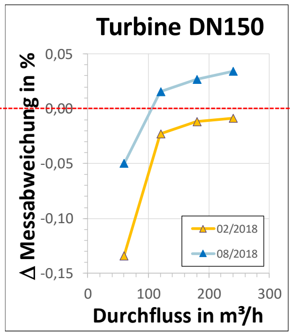
PTB

Drift analysis

Deviation of measurement error between 08/2017 and 10/2018





Max drift 08/2017 => 10/2018

Coriolis	Turbine meter	
$\Delta error_{Drift}$ = 0,055 %	$\Delta error_{Drift}$ = 0,134 %	=> u_{Drift}

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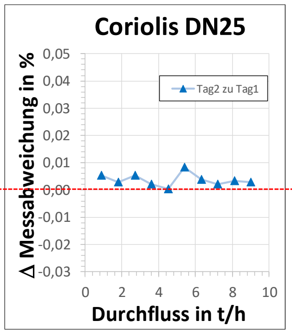
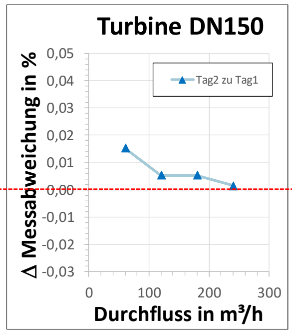
Reproducibility

Deviation of measurement error between two calibration days





Max deviation between two calibration days

Coriolis

$\Delta error_{Reprod}$ = 0,008 %

Turbine meter (V > 2 m³/h)

$\Delta error_{Reprod}$ = 0,015 % **=> u_{Reprod}**

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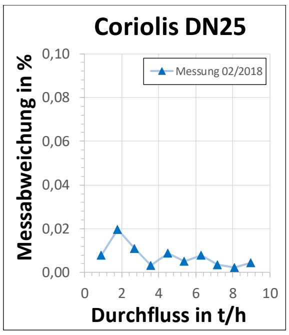
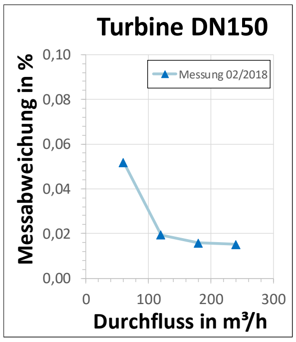
Repeatability

Standard deviation of 5 single calibrations





Max standard dev. of 5 calibrations

Coriolis

$error_{Repeat}$ = 0,02 %

Turbine meter **$u \Rightarrow \frac{s}{\sqrt{n}}$**

$error_{Repeat}$ = 0,051 %

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Transfer meter uncertainty

Meter uncertainty u_{TS} $u_{TS}^2 = u_{drift}^2 + u_{temp}^2 + u_{press}^2 + u_{reprod}^2 + ???$

Uncertainties at 1/3 of flow range

	Turbine DN150 in %	Coriolis DN25 in %
u_{drift}	0,038	0,016
u_{temp}	0,006	0,007
u_{press}	0,009	0,003
u_{reprod}	0,004	0,002
u_{TS}	**0,040**	**0,019**

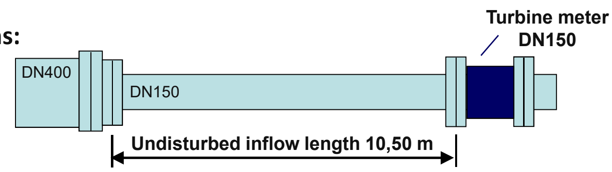
Preliminary results

Consideration of Inflow conditions to transfer meter??

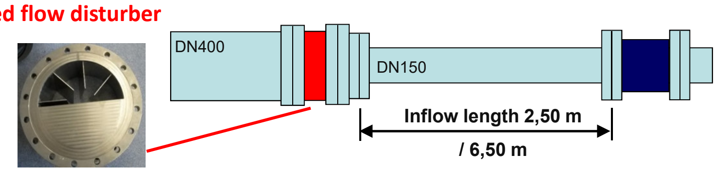
DKD Ringvergleich – Turbine meter DN150

Variation of inflow conditions to transfer meter

PTB- standard conditions:
- Inflow length 10,5 m
- **No** flow disturber



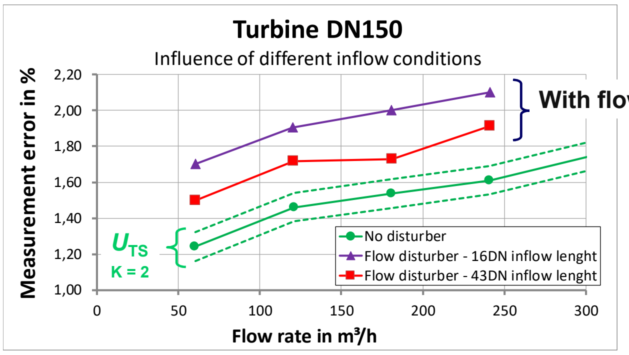
PTB- test (*real*) conditions:
- Inflow length 2,5 m / 6,5 m
- **Combined flow disturber**



DKD Ringvergleich – Turbine meter DN150

PTB

Variation of inflow conditions to transfer meter



With flow disturber

Increasing of meter uncertainty u_{TS}, if inflow conditions are considered => **up to factor 7**

$$u_{TS}^2 = u_{drift}^2 + u_{temp}^2 + u_{press}^2 + u_{reprod}^2 + u_{inflow}^2$$

DKD Ringvergleich – Turbine meter DN150

PTB

Variation of inflow conditions to transfer meter

Quality criteria of comparison evaluation:

Chi-squared-Test, E_N-value and $\mathbf{u_{comp}/u_{labor}}$

↓

Relation between transfer meter uncertainty and lab uncertainty $\frac{u_{TS}}{u_{labor}} \leq 2.0$

Increasing of meter uncertainty u_{TS},
if inflow conditions are considered:

=> Up to factor 7 => u_{TS}(Turbine) = 0,30 % → **A positive confirmation of lab uncertainty is possible only for labs with $u_{lab} \geq$ 0,15 %**

Suitability of this turbine meter as a transfer meter?

Summary

Flow comparisons and transfer meter

- Comparisons are essential for facility uncertainty confirmation
- Very time consuming
- including Technical Protocol
- A suitable transfer meter is required, including characterisation measurements
- Effect of laboratory conditions to calibration results has to be considered (e.g. inflow conditions, ambient conditions)
- A new Key Comparison is coming up soon: for water 200 m^3/h ... 2.500 m^3/h, DN 400

Dr. Enrico Frahm

Physikalisch-Technische Bundesanstalt Braunschweig
Fachbereich 1.5 „Durchfluss“
enrico.frahm@ptb.de