EMATEM

European Metrology Association
for Thermal Energy Measurement

International Key Comparison with small Measurement Uncertainty

EMATEM 2018, Grasten, Denmark

EMATEM

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01

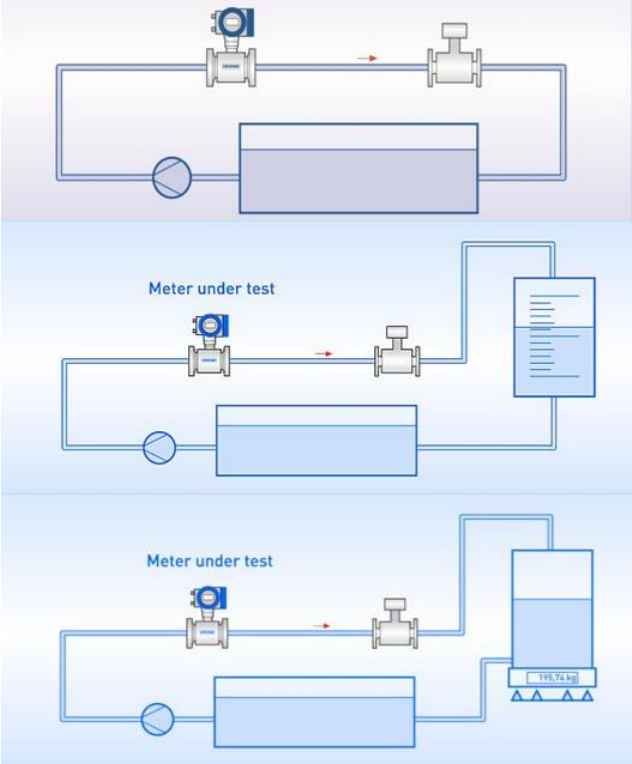
Introduction

International Key Comparison with small Measurement Uncertainty

Introduction

Liquid flow reference calibration technique:

1) Reference flowmeters
2) Gravimetric measuring systems
3) Volumetric measurement systems



International Key Comparison with small Measurement Uncertainty

Introduction

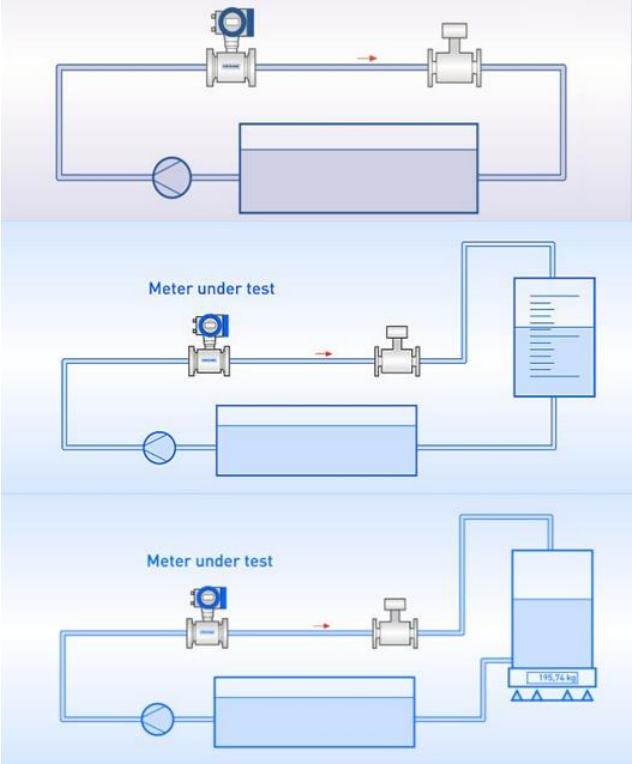
„Quality“ of the systems:

- Measurement uncertainty calculation

Equation for measurement process

$$F_{\mathrm{Pr}} = \frac{V_{\mathrm{Pr.ist}} - V_{\mathrm{Pr.soll}}}{V_{\mathrm{Pr.soll}}} = \frac{\dfrac{I_{\mathrm{Pr}}}{I_{\mathrm{Wert.Pr}}}}{\dfrac{I_{\mathrm{MID/Pr}}}{I_{\mathrm{Wert.Pr}}} \cdot \dfrac{V_{\mathrm{MID.soll}}}{\left(\dfrac{I_{\mathrm{MID}}}{I_{\mathrm{Wert.MID}}}\right)} \cdot \dfrac{\rho_{\mathrm{W.MID}}}{\rho_{\mathrm{W.Pr}}} + \Delta V_{\mathrm{L1}} + \Delta} - 1$$

$$u_{\mathrm{c}}^{2}(y) = \sum_{\mathrm{i}=1}^{\mathrm{n}} \left(\frac{\partial f}{\partial x_{\mathrm{i}}}\right)^{2} u^{2}(x_{\mathrm{i}})$$



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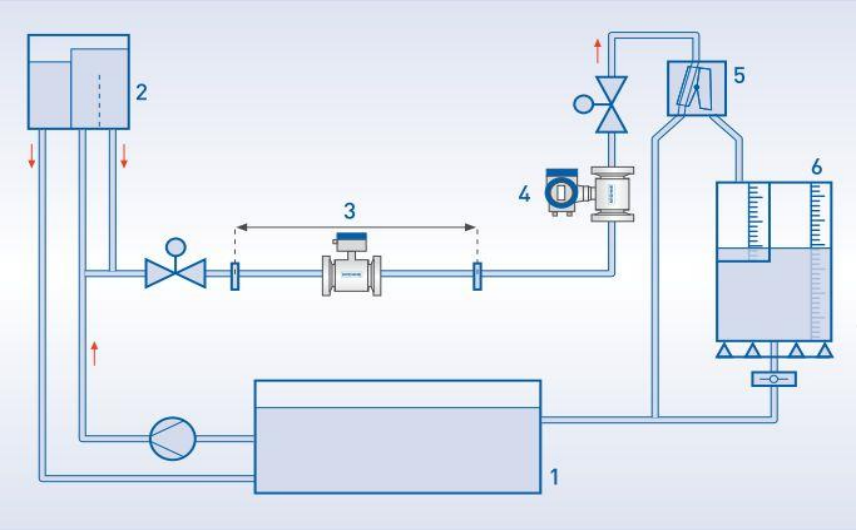
$$u_c^{\,2}(y) = \sum_{i=1}^{n} \left(\frac{\partial f}{\partial x_i}\right)^2 u^2(x_i)$$

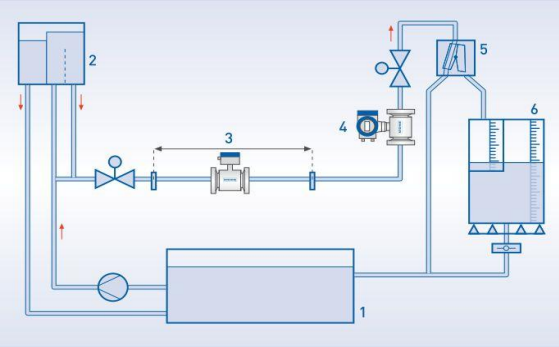
$$\begin{aligned} u_c^{\,2}(V_{\mathrm{MID.soll}}) = & \left(\frac{\partial V_{\mathrm{MID.soll}}}{\partial W_{\mathrm{korr}}}\right)^2 u^2(W_{\mathrm{korr}}) + \left(\frac{\partial V_{\mathrm{MID.soll}}}{\partial V_0}\right)^2 u^2(V_0) + \left(\frac{\partial V_{\mathrm{MID.soll}}}{\partial T_1}\right)^2 u^2(T_1) \\ & + \left(\frac{\partial V_{\mathrm{MID.soll}}}{\partial \Delta V_{\mathrm{R2}}}\right)^2 u^2(\Delta V_{\mathrm{R2}}) + \left(\frac{\partial V_{\mathrm{MID.soll}}}{\partial \Delta V_{\mathrm{L2}}}\right)^2 u^2(\Delta V_{\mathrm{L2}}) + \left(\frac{\partial V_{\mathrm{MID.soll}}}{\partial \Delta V_{\mathrm{U}}}\right)^2 u^2(\Delta V_{\mathrm{U}}) \\ & + \left(\frac{\partial V_{\mathrm{MID.soll}}}{\partial f_2}\right)^2 u^2(f_2) + \left(\frac{\partial V_{\mathrm{MID.soll}}}{\partial \rho_{\mathrm{W.MID}}}\right)^2 u^2(\rho_{\mathrm{W.MID}}) + \left(\frac{\partial V_{\mathrm{MID.soll}}}{\partial W_{\mathrm{a}}}\right)^2 u^2(W_{\mathrm{a}}) \\ & + \left(\frac{\partial V_{\mathrm{MID.soll}}}{\partial T_2}\right)^2 u^2(T_2) + \left(\frac{\partial V_{\mathrm{MID.soll}}}{\partial p}\right)^2 u^2(p) + \left(\frac{\partial V_{\mathrm{MID.soll}}}{\partial \rho_{\mathrm{W2}}}\right)^2 u^2(\rho_{\mathrm{W2}}) + \left(\frac{\partial V_{\mathrm{MID.soll}}}{\partial f_1}\right)^2 u^2(f_1) \end{aligned}$$



International Key Comparison with small Measurement Uncertainty

Introduction

Measurand X_i	Best value x_i	Standard measurement uncertainty (k=1)	Distribution	Sensitivity coefficient	Uncertainty in m³
W_{korr}	20 000 kg	0,130 kg	Normal	$1{,}0\cdot10^{-3}$ m³/kg	$1{,}81\cdot10^{-8}$
V_0	31,94 m³	0,30 m³	Rectangular	0	0
p_{ges}	101 300 Pa	44,05 Pa	Rectangular	$2{,}06\cdot10^{-7}$ m³/Pa	$2{,}74\cdot10^{-11}$
T_1	363,15 K	13,5 mK	Normal	$-8{,}86\cdot10^{-5}$ m³/K	$1{,}43\cdot10^{-12}$
T_2	363,15 K	13,5 mK	Normal	$3{,}11\cdot10^{-5}$ m³/K	$1{,}76\cdot10^{-13}$
f_1	0,700 kg	0,0175 kg	Rectangular	$-5{,}32\cdot10^{-2}$ m³/kg	$2{,}89\cdot10^{-7}$
f_2	0,700 kg	0,0175 kg	Rectangular	$1{,}87\cdot10^{-2}$ m³/kg	$3{,}57\cdot10^{-8}$
ρ_{W2}	965 kg/m³	0,051 kg/m³	Normal	$-6{,}68\cdot10^{-6}$ m⁶/kg	$1{,}13\cdot10^{-13}$
$\rho_{W.MID}$	965 kg/m³	0,051 kg/m³	Normal	$-2{,}14\cdot10^{-2}$ m⁶/kg	$1{,}19\cdot10^{-6}$
W_a	8,376 kg	0,400 kg	Normal	$1{,}00\cdot10^{-3}$ m³/kg	$1{,}16\cdot10^{-7}$
δV_{R2}	0 m³	$3{,}09\cdot10^{-4}$ m³	Normal	1	$9{,}55\cdot10^{-8}$
δV_{L2}	0 m³	$9{,}25\cdot10^{-5}$ m³	Normal	1	$8{,}56\cdot10^{-9}$
δV_U	0 m³	$0{,}636\cdot10^{-3}$ m³	Normal	1	$4{,}04\cdot10^{-7}$
				Combined standard uncertainty (k=1) in m³	0,0021
				Expanded Standard uncertainty (k=2) in m³	0,0042
				Relative expanded uncertainty (k=2)	$3{,}50\cdot10^{-4}$



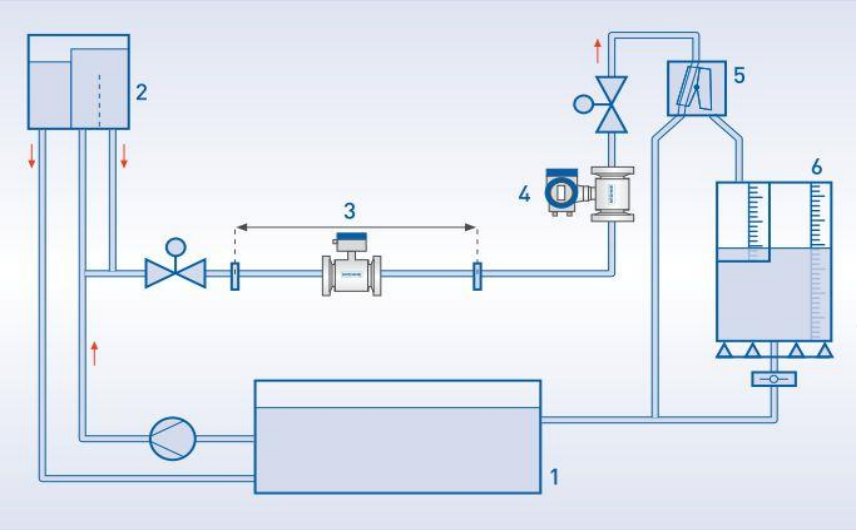
International Key Comparison with small Measurement Uncertainty

Introduction

- Investigation of influence quantities

- Non visible systematic measurement errors of the reference flow calibration standard, software, EMC, pulse counting …

- Relationship between meter under test (MUT) and reference flow calibration standard

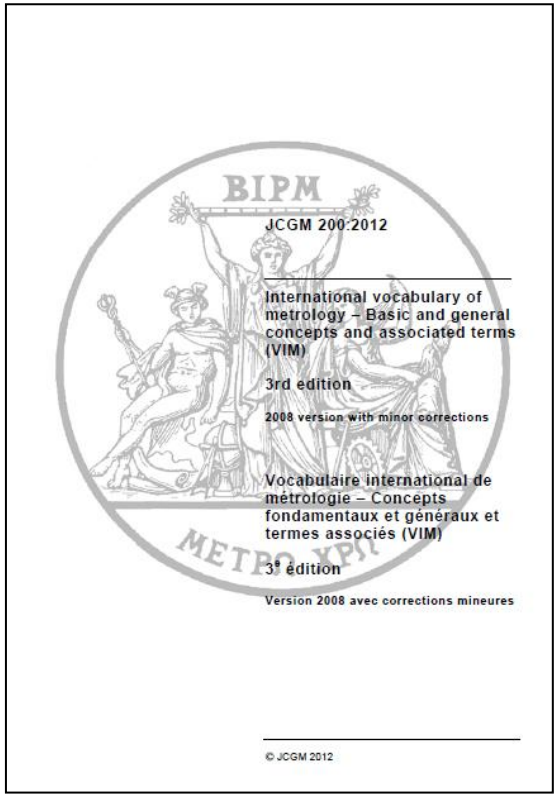


02

Definitions

International Key Comparison with small Measurement Uncertainty

Definitions


BIPM

JCGM 200:2012

International vocabulary of metrology – Basic and general concepts and associated terms (VIM)

3rd edition

2008 version with minor corrections

Vocabulaire international de métrologie – Concepts fondamentaux et généraux et termes associés (VIM)

3e édition

Version 2008 avec corrections mineures

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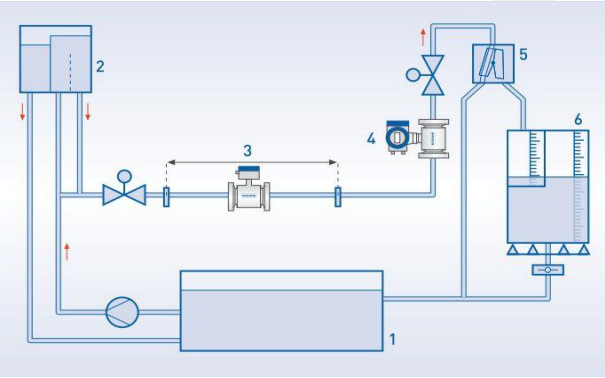
International vocabulary of metrology (VIM)

- Systematic measurement error
- Random measurement error
- Measurement uncertainty
- Conventional true value

-Accuracy
-Repeatability
-Reproducibility
-Trueness



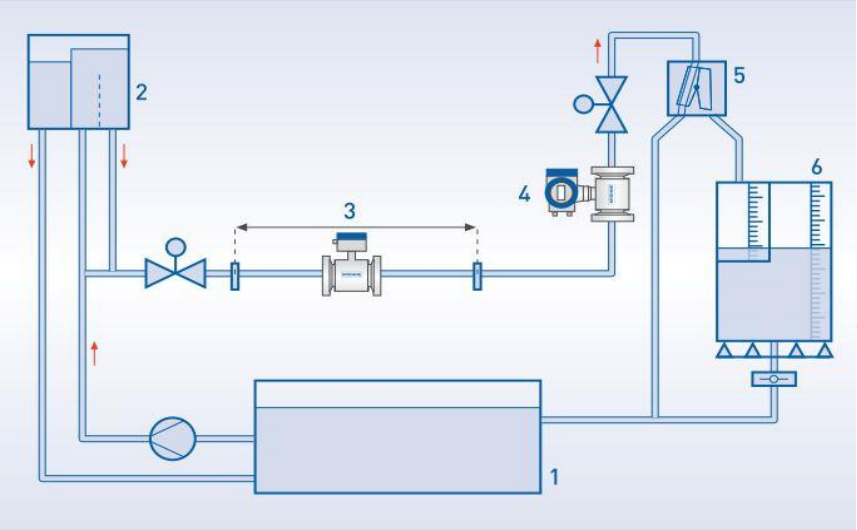
International Key Comparison with small Measurement Uncertainty

Definitions

Intentions

- Investigation of the scale (volume of a flowing liquid)
- Comparison of calibration procedures
- Check of laboratory (people, QM, handling…)
- Investigation of flow meters
- Investiagation of non visible systematic measurement errors

…

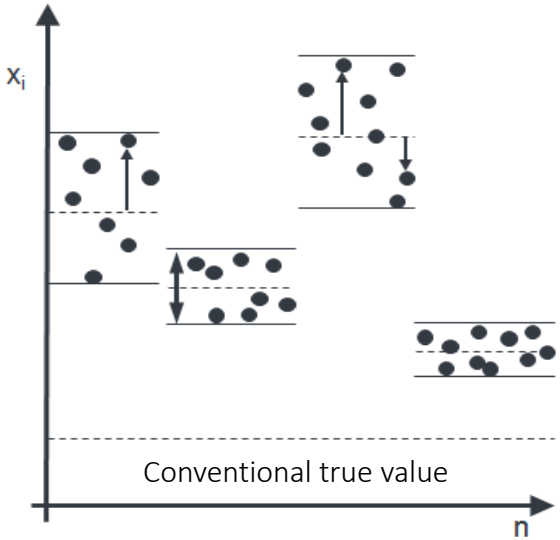


International Key Comparison with small Measurement Uncertainty

Definitions

Intention of **this** comparison:

- High precision inverstigation of the scale (volume of a flowing liquid)
- Best measurement capabilities
- Validation of the measurement data and the calibration process
- Finding and reduction of non visible systematic measurement errors



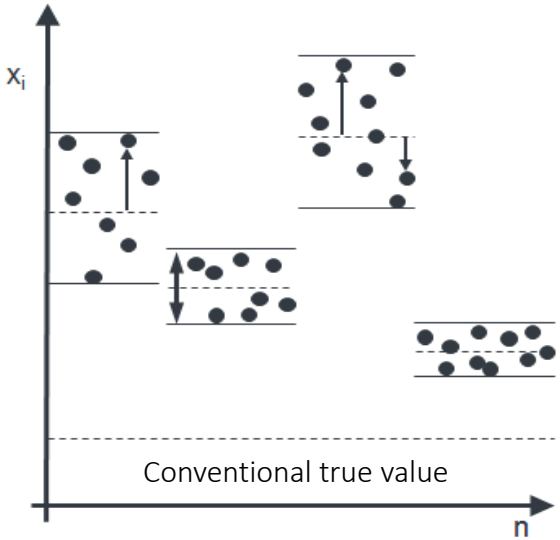



International Key Comparison with small Measurement Uncertainty

Definitions

Requirements:

- High precision reference flowmeter
- Knowledge about influence quantities of liquid flow calibration facilities
- Knowledge about measurement uncertainty calculation
- Professional metrologists at the calibration rig



03

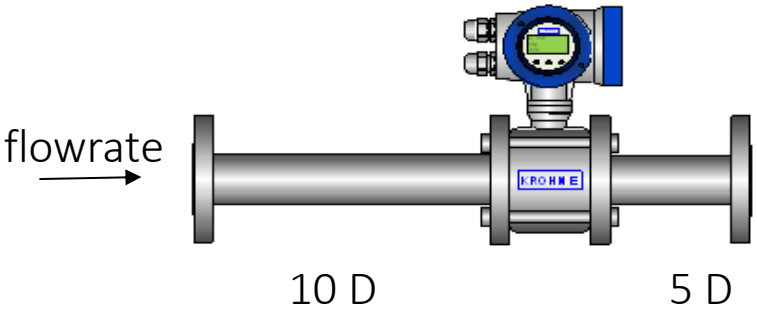
Master meter

International Key Comparison with small Measurement Uncertainty

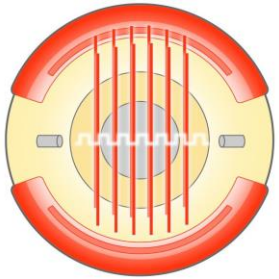
Master meter

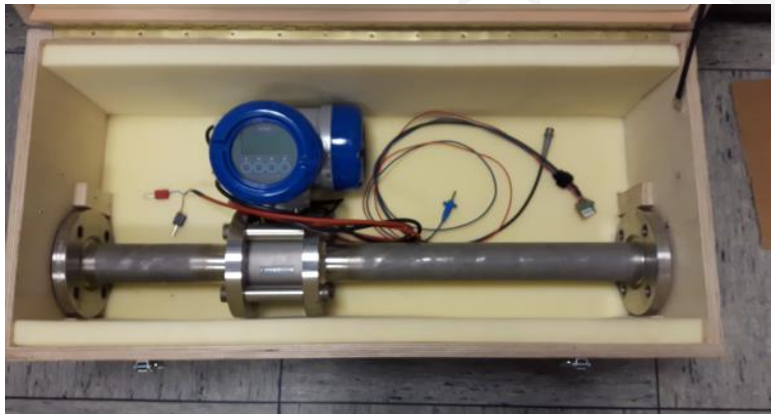
Magnetic Inductive Flowmeter

- DN 50 with special inlet and outlet sections
- 230 V
- Compact version
- Pulse output
- Water 20°C +-5°C
- Flow rates: 10 m³/h … 50 m³/h



Inner geometry





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Master meter - participants

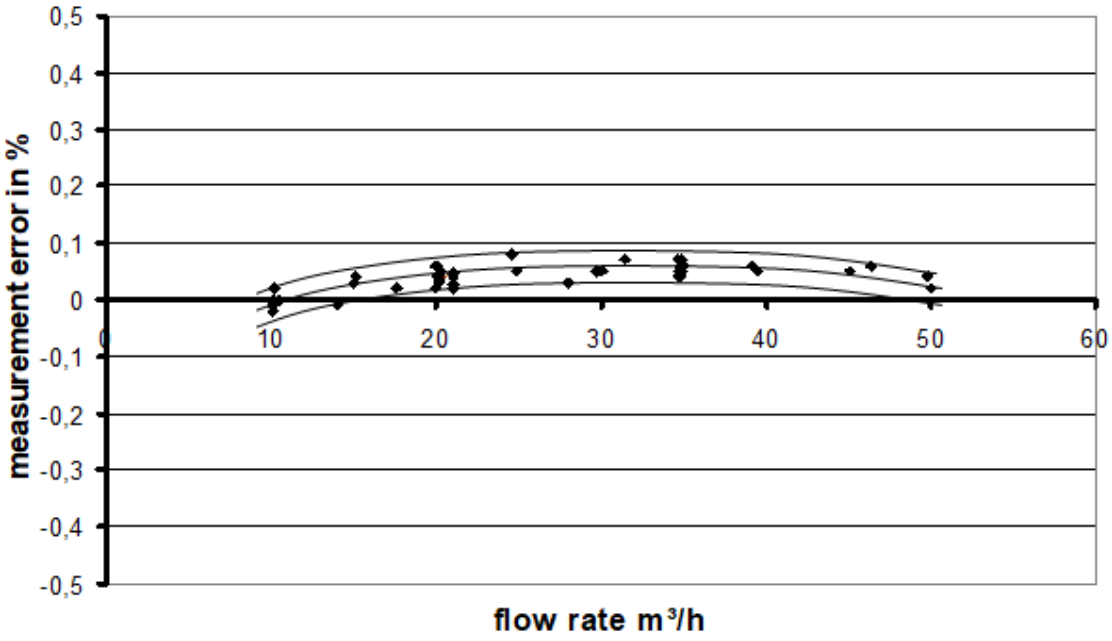
National Metrology Institute	PTB, Braunschweig, Germany	G, D	20°C
Local Authority	Düsseldorf, Germany	V	20°C
KROHNE ALTOMETER	Dordrecht, The Netherlands	V	20°C
Bilfinger Industrial Services (BIS)	Frankfurt, Germany	G	20°C
Allmess	Oldenburg, Germany	G, D	10...80°C
WSG	Essen, Germany	G,D	10...80°C
G flow	Madrid, Spain	V	20°C

G = Gravimetric measurement system
V = Volumetric measurement system
D = Diverter

International Key Comparison with small Measurement Uncertainty

Master meter - results

All measured values are within +- 0,03% from the measured value (min-max)



04

New results

International Key Comparison with small Measurement Uncertainty

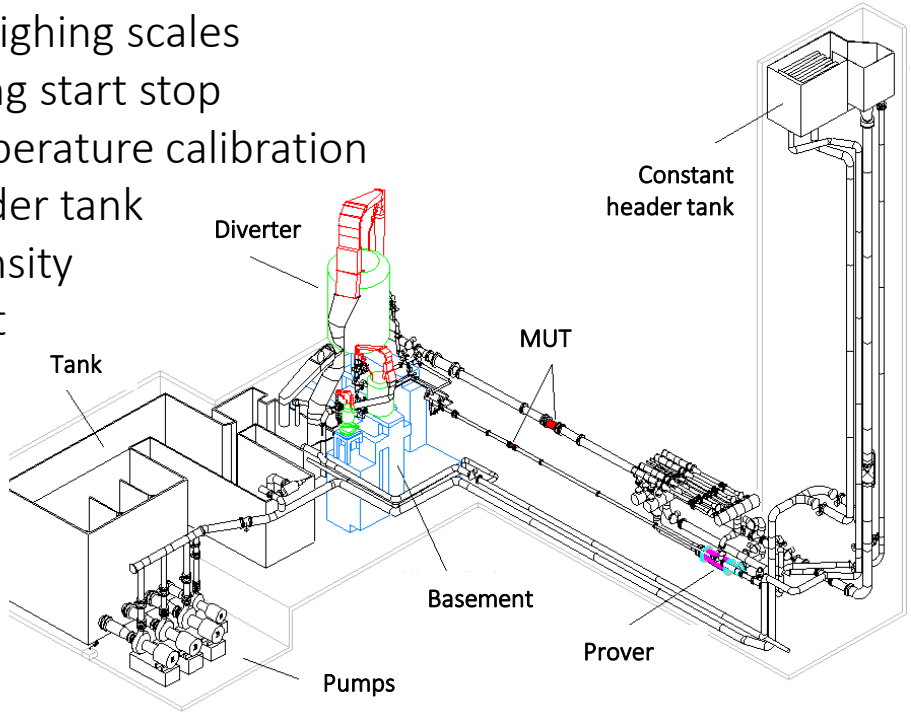
New results

National Metrology Institute	PTB, Braunschweig, Germany
Local Authority	Düsseldorf, Germany
KROHNE ALTOMETER	Dordrecht, The Netherlands
Bilfinger Industrial Services (BIS)	Frankfurt, Germany
Allmess	Oldenburg, Germany
WSG	Essen, Germany
G flow	Madrid, Spain
Gelsenwasser	Gelsenkirchen, Germany

International Key Comparison with small Measurement Uncertainty

New results - PTB Braunschweig 2017, Germany

- 3 different weighing scales
- Standing/Flying start stop
- Different temperature calibration
- Constant header tank
- Reference density measurement
- Uncertainty < 0,02% (k=2)



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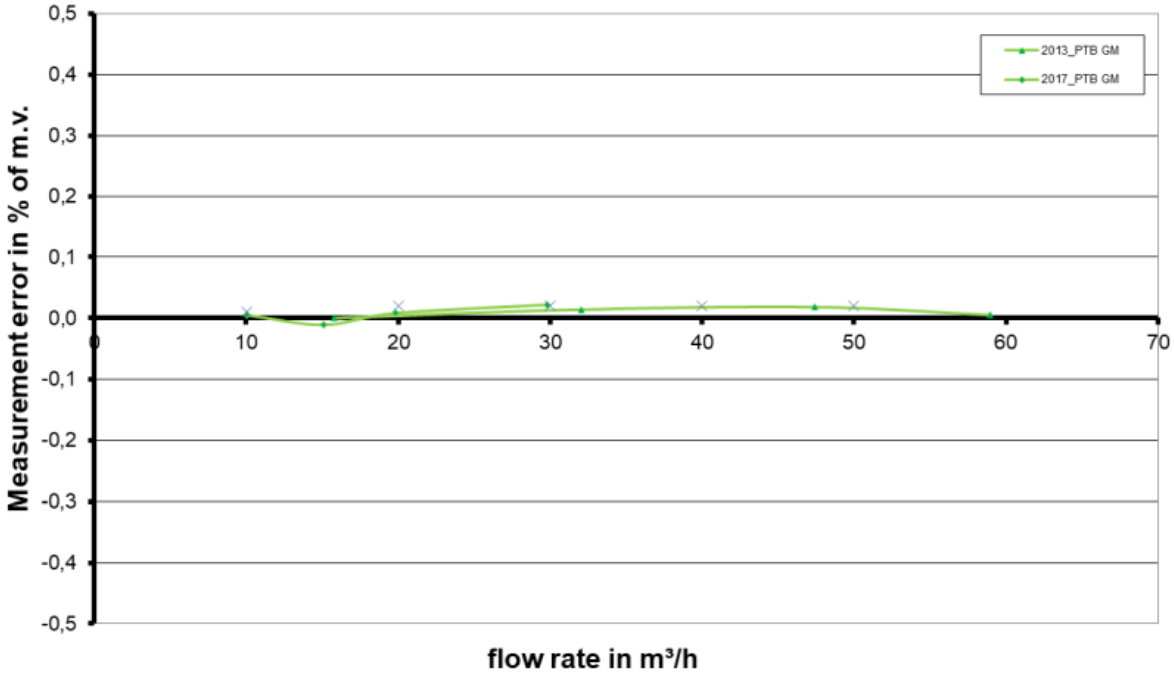
New results - PTB Braunschweig 2017, Germany

- Measurement values identical within the measurement uncertainty
- No drift or other change of calibration rig
- No drift of MUT
- Very good reproducibility



International Key Comparison with small Measurement Uncertainty

New results

National Metrology Institute	PTB, Braunschweig, Germany
Local Authority	Düsseldorf, Germany
KROHNE ALTOMETER	Dordrecht, The Netherlands
Bilfinger Industrial Services (BIS)	Frankfurt, Germany
Allmess	Oldenburg, Germany
WSG	Essen, Germany
G flow	**Madrid, Spain**
Gelsenwasser	Gelsenkirchen, Germany

International Key Comparison with small Measurement Uncertainty

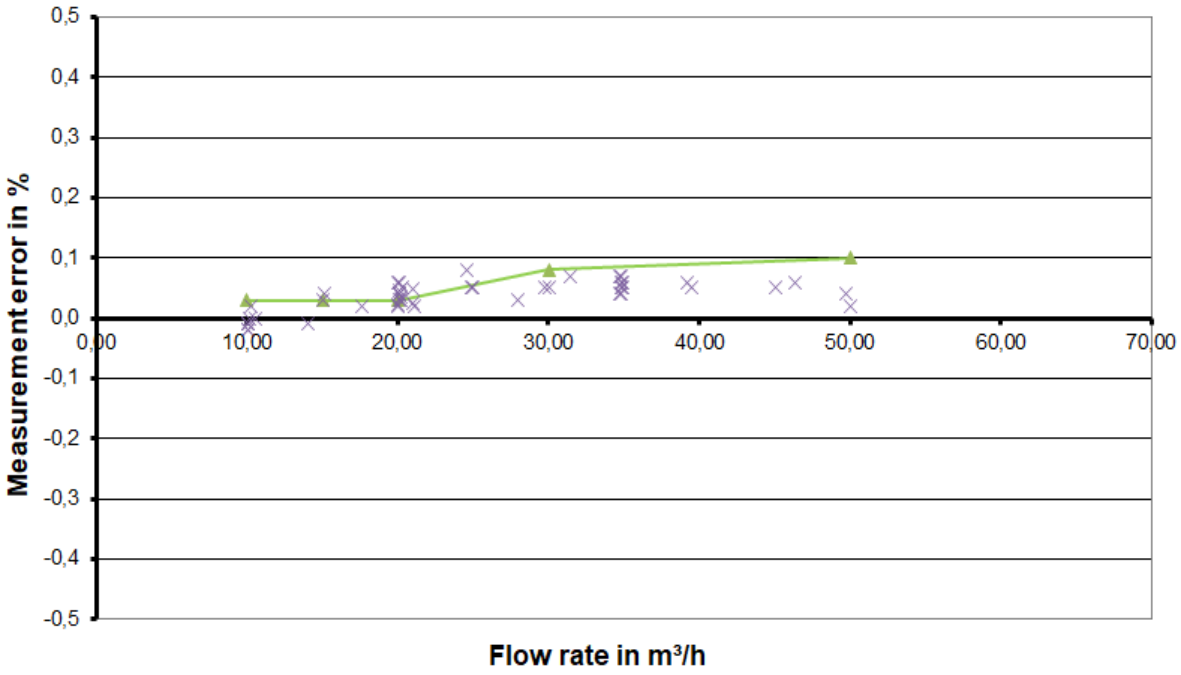
New results – G flow, Madrid, Spain

- Reference volume 1300 l or2600 l
- Standing start stop
- Medium temperature: ambient
- Reference volume for calibration: 2700 l
- Number of repeats: 5

International Key Comparison with small Measurement Uncertainty

New results - PTB Braunschweig 2017, Germany

- Measurement results are within the specified measurement uncertainty
- Very good repeatability
- Small influence at higher flowrates



05

Next steps

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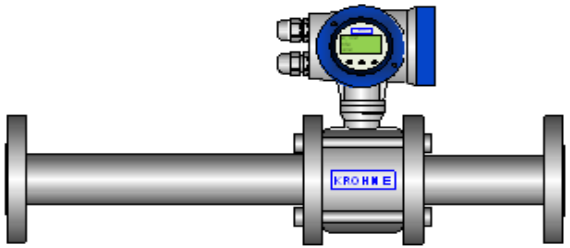
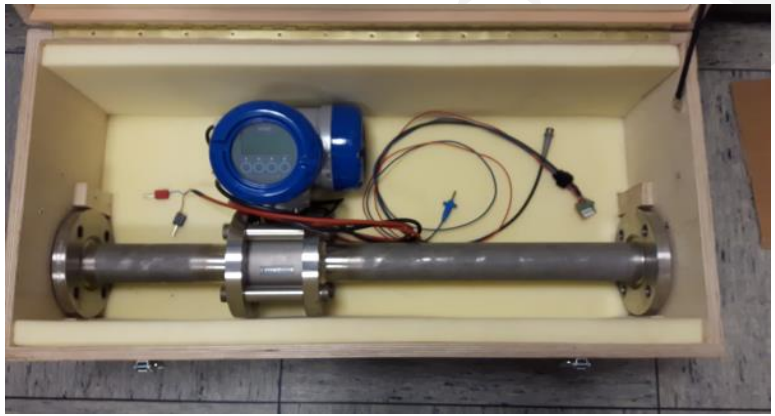
Next steps

- Additional flow meters to select meter and rig influence quantities
- Investigation of lower flowrates
- Investigation of more calibration rigs and new phenomena
- Reduction of measurement uncertainty of calibration rigs





Thank you for your attention!

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