Final Report on Supplementary Comparison of National Standards for Liquid Flow **COOMET.M.FF-S2**

(COOMET Project 406/UA/07)

Final Report

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Abstract

A supplementary comparison, COOMET.M.FF-S2, in the area of water flow was organized by the COOMET Technical Committee (TC) 1.4 Flow Measurement and carried out in order to confirm the calibration and measurement capabilities (CMC) of the participating national metrology institutes (NMIs) in the flow ranges from 0.5 m^3/h to 5 m^3/h, and from 20 m^3/h to 100 m^3/h. As a remark, this is the first time a comparison of this type has been done by the COOMET TC Flow Measurement.

This report describes the results from the comparison of water flow facilities between six NMIs: PTB (Braunschweig, Germany), National standards Centre of the Republic of Uzbekistan (Tashkent, Republic of Uzbekistan), LEI (Kaunas, Lithuania), SMU (Bratislava, Slovakia), BelGIM (Minsk, Belarus), VNIIR (Kazan, Russia).

In this instance, the PTB was designated as the pilot lab of this comparison test, due to the low measurement uncertainty of its water flow primary standard, in comparison to all participants, and because of its experience in leading and participating in previous international flow comparisons.

In order to cover a large flowrate range, two transfer standard packages were delivered to all involved NMIs of the inter-laboratory comparison. The following flowmeters were used: for low flowrate range with a nominal diameter of 25 mm - a turbine meter and an electromagnetic flowmeter, and, respectively, for large flow rates with a nominal diameter of 80 mm – two turbine meters. All the calibrations were made during March 2009 until May 2012.

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1 Introduction

The comparison was carried out in accordance with its Technical Protocol, which specified the procedures to be followed in the comparison, and had been prepared in accordance with the Guidelines for CIPM Key Comparisons [1] and regulations for comparison of measurement standards from the national metrological institutes of COOMET R/GM/11:2010 [2] by the PTB and approved by the participants.

The main objective of this comparison is to give opportunity to the participating laboratories to support their uncertainty statements made in their CMC Tables. In this instance, the PTB, which has well-established measurement capabilities in the actual flowrate range (supported by a prior key comparison, e.g.CCM.FF-K1) was chosen as a Pilot Laboratory.

Because of the large flowrate range covered by the comparison from 0.5 m^3/h up to 100 m^3/h, it was necessary to split the measurements into a small flowrate range (0.5 m^3/h up to 5 m^3/h - nominal diameter of the equipment DN25 mm) and a large flowrate range (20 m^3/h up to 100 m^3/h - nominal diameter of the equipment DN80 mm) using different types and sizes of the corresponding transfer standards.

The type of measurement principle employed in the primary standards was the so called gravimetric method, except the Uzbek NMI, which holds a volumetric reference for the realization of the flow unit.

The K-factors of the transfer standards, separated by specified flowrates, were reported by the participants. Additionally, the laboratories notified their uncertainty budgets. The analysis of the reported results were carried out, in accordance to the methods specified by Cox and the COOMET recommendations [3, 4]. The reference utilized in order to write this Draft B report were based in the CIPM and COOMET documents mentioned above.

2 Participants and Organization

2.1 Participants

The participating laboratories in order of testing schedule were PTB (Braunschweig, Germany), National Standards Centre of the Republic of Uzbekistan (Tashkent, Uzbekistan), LEI (Kaunas, Lithuania), SMU (Bratislava, Slovakia), BelGIM (Minsk, Belarus), VNIIR (Kazan, Russia).

The general description of the participants' facilities and their uncertainty budgets can be found in Appendix A.

2.2 Chronology and problems during comparison

Because of the large flowrate range covered by the comparison (0.5 m³/h up to 100 m³/h), the measurements were split into a large flowrate range from 20 m³/h to 100 m³/h (nominal diameter of the equipment DN 80) and in a smaller flowrate range from 0.5 m³/h and 5 m³/h (nominal diameter of the equipment DN 25). For each flowrate range, a standard package was used consisting of two transfer meters connected in series.
The comparison was conducted by circulating the transfer standard packages among the participants, according to Fig. 1. Each NMI was responsible for the customs clearance and delivery of the transfer standards to the next NMI. The pilot laboratory performed three measurement cycles of transfer standards (Table 1).

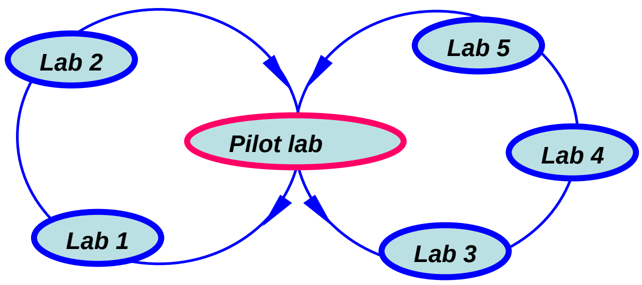


Fig. 1 Circulation scheme of the transfer standard packages

During the comparison, series of issues occurred which delayed the comparison tests by nearly two more years. As examples, during comparion VNIIR completely reconstructed its water flow standard facility. Additionally, the comparison time was extended by several problems concerning to customs clearance. Some of the participant laboratories had problems with the temporary import of the transfer standards, whereby the pilot lab had to intervene in some cases, in order to prove the ownership of the transfer package, and thus getting the equipment released.
For these reasons, the pilot lab had to re-arrange the round robin schedule and to move VNIIR to the end of the time schedule. Because of the first delays, the intermediate check at PTB could be carried out only ten months after starting the comparison, in July 2010. After the second circle, the standard packages returned to PTB in January 2012. Because at that time the PTB's water test facility was under systematic service, the final measurements could be carried out only in May 2012.
All changes in the time schedule had been discussed and agreed during the regular meetings of COOMET TK 1.4 in 2010 and 2011. Table 1 gives the final testing order, types of primary standards used, and the uncertainty of the facilities. The given uncertainties of Table 1 are standard values (k = 1).

Table 1: Schedule and facilities used during the comparison

№	NMI, country	Place of he comparison	Date of the measurement	Type of primary standard	Standard uncertainty (*k*=1) in %	Responsible person
1	PTB, Germany , initial investigation	Bundesallee 100, D-38116 Braunschweig, Germany	12.-17.03.2009	Gravimetric	0.01 (for large flowrates) 0.05 (for small flowrates)	I. Marfenko
2	National standards Centre of the Republic of Uzbekistan	Farobi str. 333[a], 700049, Tashkent, Republic of Uzbekistan	10.-11.02.2010	Volumetric tank	0.15	M. Kaumov
3	LEI, Lithuania	3 Breslaujos str., LT-44403 Kaunas, Lithuania	26.-27.04.2010	Gravimetric	0.04	G. Zigmantas
4	PTB, Germany, intermediate check	Bundesallee 100, D-38116 Braunschweig, Germany	07.-14.07.2010	Gravimetric	0.01 0.05	I. Marfenko
5	SMU, Slovakia	Karloveská 63, 842 55 Bratislava, Slovak Republic	29.11.-03.12.2010	Gravimetric	0.04	M. Benkova
6	BelGIM, Belarus	Starovilensky trakt 93, 220053, Minsk, Republic of Belarus	11.-16.03.2011	Gravimetric	0.04	V. Gulyuk
7	VNIIR, Russia	2nd Azinskaya str., 7a, 420029, Kazan, Russia	10.-30.06.2011	Gravimetric	0.02	G. Reut
8	PTB, Germany, final investigation	Bundesallee 100, D-38116 Braunschweig, Germany	07.-16.05.2012	Gravimetric	0.01 0.05	G. Wendt

The completeness and state of the transfer standards were controlled and documented with the arrival and departure protocols.

Lithuania reported traces of rust in both DN80 turbines, but after a thorough cleaning of the flowmeters with distilled water, and a pre test, it was confirmed that the equipment was not damaged, and thereafter LEI successfully tested the package. It was assumed that the presence of rust was caused by the previous measurements at NMI (Uzbekistan), wherein its facility used non-stainles steel pipelines in the test section area.

The second change to the schedule occurred if SMU reported that the signal converter of the DN25 electromagnetic flowmeter was damaged. In order to solve this problem, the pilot lab sent a new signal converter to SMU. Because a signal converter can be combined with any measuring sensor without affecting meter performance, testing was continued. The comparison was delayed for another three months.

3 Procedures and calculations – general description

3.1 Measurement provedures

The measurement procedure of the comparison was designed to practice a standard calibration at the participation laboratories - routine calibration methods, personnel, instruments, software, etc. to calibrate the TS according to the same procedure at the specified test conditions:

- water temperature: (20 ± 5)°C, as near to 20°C as possible
- ambient temperature range: 15 °C to 25 °C
- ambient relative humidity range: 45 % to 75 %
- ambient atmospheric pressure range: 86 kPa to 106 kPa (0.86 bar to 1.06 bar)
- working fluid: potable water.

The calibrations were measured at the flow rates of Table 2. Each flow rate consists 5 repeated measurements.

Table 2: Flowrates of the comparison

	Flowrate range 0.5 … 5 m³/h	Flowrate range 20 … 100 m³/h
Q_1	0.5	20
Q_2	1	30
Q_3	2	40
Q_4	3	60
Q_5	5	80
Q_6		100

In order to quantify aspects like reproducibility under turn-off-turn-on and take-out-put-back conditions, a measurement procedure for small flow rates (*Fig. 3*), respectively, for high flow rates (see *Fig. 4* and *Fig. 5*) was designed. A detailed description of the procedures are given in the Technical Protocol of the comparison (Appendix B). According to these procedures, each of the two flowmeters of each standard package was tested in two differerent positions (upstream and downstream) at different flows and different days.

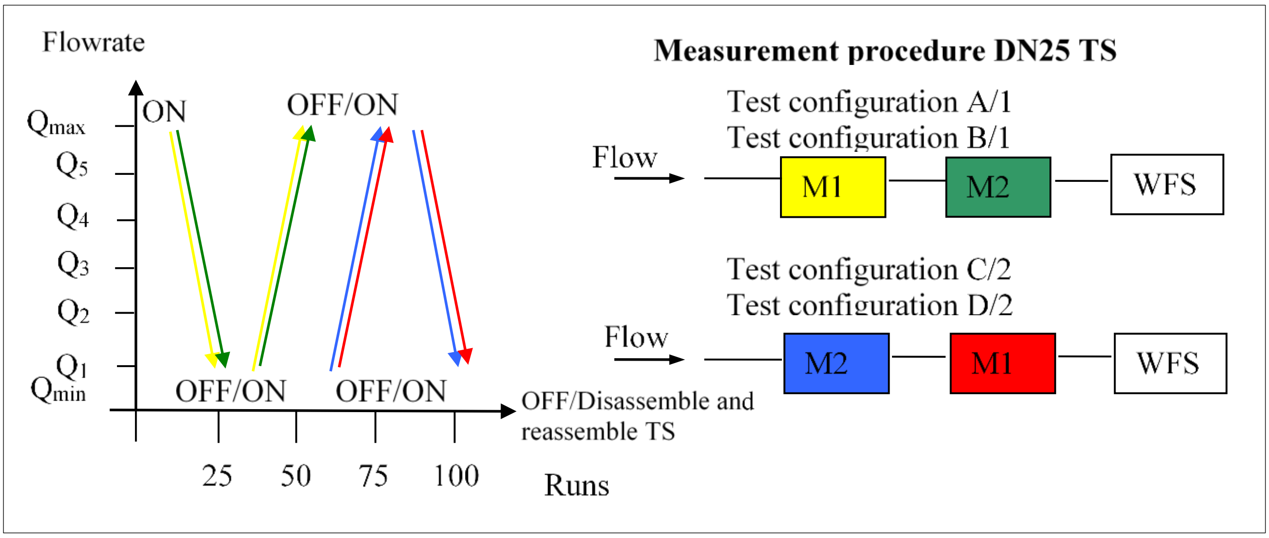


Fig. 2 Measurement procedure A1/B1and C2/D2 for DN25 transfer standards

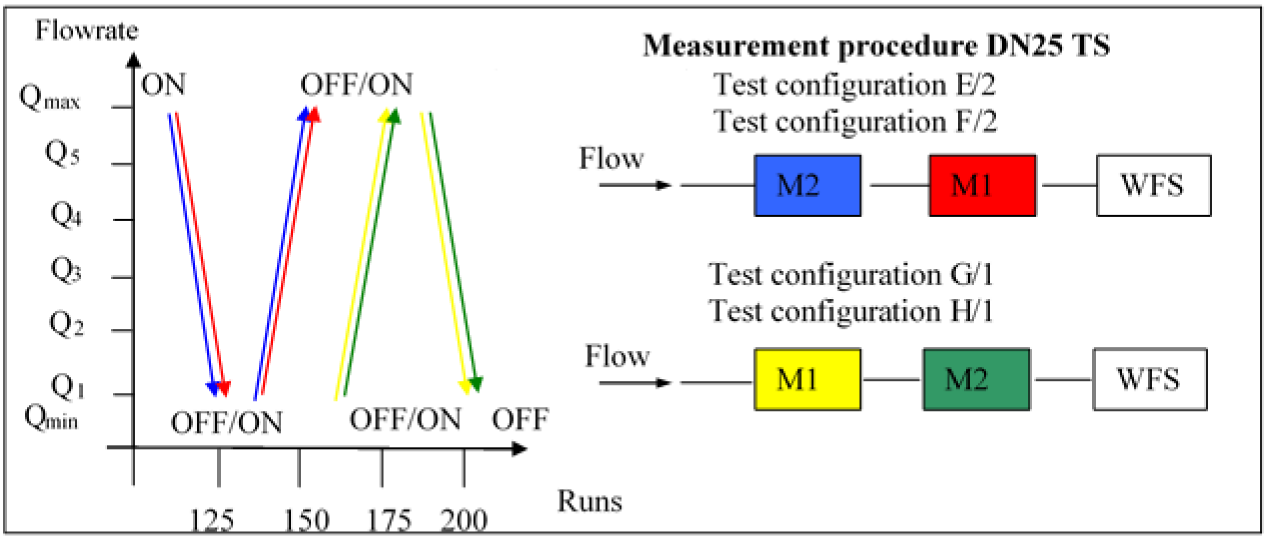


Fig. 3 Measurement procedure E2/F2 and G1/H1 for DN25 transfer standards

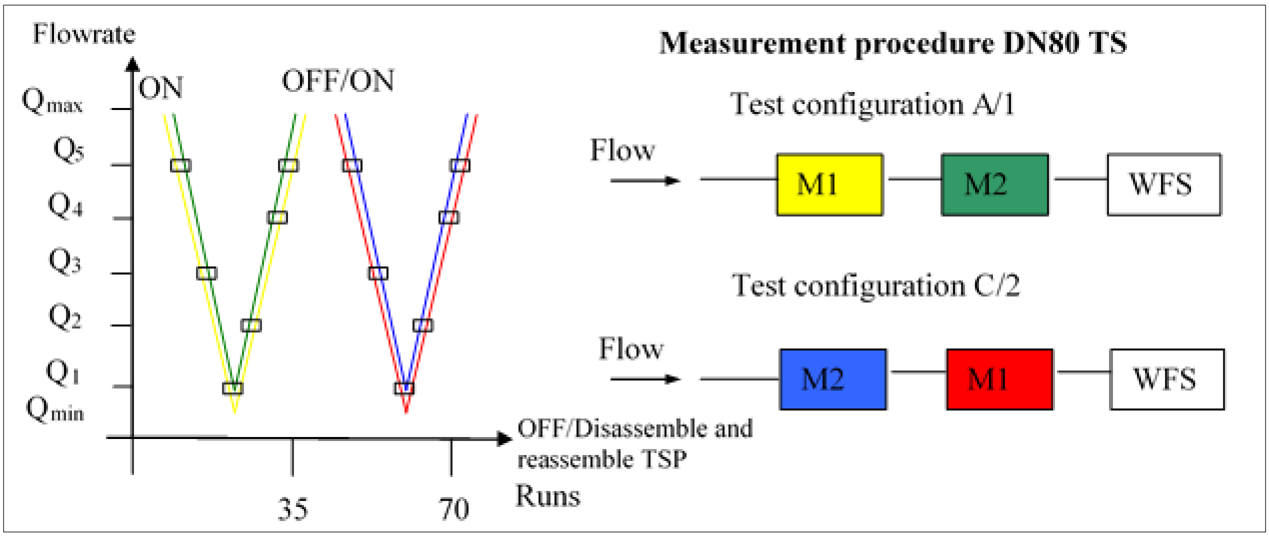


Fig. 4: Measurement procedure A1and C2 for DN80 transfer standards

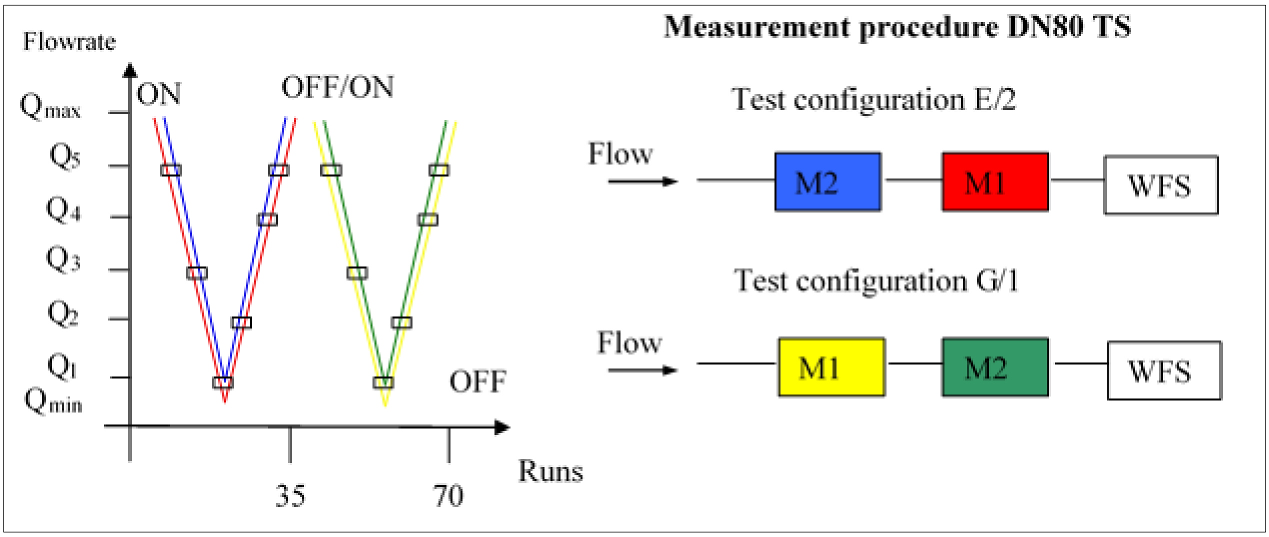


Fig. 5: Measurement procedure E2 and G1 for DN80 transfer standards

3.2 Basic calcultions

The K-factor (in pulses/m^3) was calculated for every test point (flowrates according to Table 2), based on at least 5 repeated runs for each test configuration (Fig. 5):

$$K_i = \frac{N_{i,pulses}}{V_{ref}} \qquad (3.1)$$

where K_i - caluculated K-factor of the transfermeter in pulses/m³
$N_{i,pulses}$ - number of pulses, which are read from the transfer flowmeter
V_{ref} - volume, which is measured by the reference standard, in m^3

The relative measurement error e_i (in %) was calculated for each K_i:

$$e_i = \frac{K_i - K_{nom}}{K_{nom}} \cdot 100 \qquad (3.2)$$

where K_{nom} - nominal K-factor of the transfer meter, in pulses/m^3

The quantity used to compare the participants' results is the mean value of the relative error e_r (in %) at each test point (flowrate):

$$e_r = \frac{\sum_{i=1}^{n}(e_i)}{n} \qquad (3.3)$$

where n - number of measurements at the corresponding test point.

The repeatability of this value (type A uncertainty) is:

$$u_{repeat}(e_r) = \sqrt{\frac{\sum_{i=1}^{n}(e_i - \overline{e})^2}{n \cdot (n-1)}} \qquad (3.4)$$

where n - number of measurements at corresponding test point and configuration

3.3 Uncertainty of the transfer standard

In accordiance to the WGFF recommendation for comparison calculations (proposed by J. Wright, B. Mickan, M. Benkova, February 7, 2014), the standard uncertainty u_{TS} of the transfer meter is the root-sum-of-squares (RSS) of several transfer meter characteristics: calibration drift (and its associated instrumentation) during comparison, temperature sensitivities, pressure sensitivities, property sensitivities, and other components:

$$u_{\text{TS}} = \sqrt{u_{\text{drift}}^2 + u_{\text{T}}^2 + u_{\text{P}}^2 + u_{\text{prop}}^2 + \cdots} \qquad (3.5)$$

where u_{TS} - combined standard uncertainty of the transfer meter in %
u_{T} - standard uncertainty of the transfer meter caused by temperature effects in %
u_{P} - standard uncertainty of the transfer meter caused by fluid pressure effects in %
u_{prop} - standard uncertainty of the transfer meter caused by additional effects in %

all values of u are given for k = 1

The uncertainty due to calibration drift u_{drift} is normally quantified by performing repeated calibrations in the Pilot lab using the same reference standard before, during, and after the comparison. For this report a rectangular distribution was applied to the observed range at pilot laboratory of the calibration data during comparison $(e_{r,max} - e_{r,min})$:

$$u_{drift} = \frac{e_{r,max} - e_{r,min}}{2 \cdot \sqrt{3}} \qquad (3.6)$$

where $e_{r,max}$ - maximum observed relative measurement error at pilot laboratory in %
$e_{r,min}$ - minimum observed relative measurement error at pilot laboratory in %

For this comparison , influences of temperature, pressure or fluid properties can be neglected because of the documented stability of these parameters at the Hydrodynamic Test Field of PTB used for the measurements. But, the day-to-day reproducibility of the transfer standards is included because of possible instabilities of the meter during measurements:

$$u_{TS}(e_r) = \sqrt{u_{drift}^2 + u_{reprod}^2} \qquad (3.7)$$

where u_{reprod} - standard uncertainty of the transfer meter caused by temperature effects in %

3.4 Temperature correction

Because the K-factor depends on an actual diameter, the defined pipe diameter at 20 °C must be corrected for temperature expansion for each flow tested. This temperature correction reflects, to some degree, the geometrical temperature changes of the meter under test. The correction was carried out based on the thermal coefficient of expansion of the meter material:

$$K_{M0} = K_M \cdot [1 + 3 \cdot \alpha_M \cdot (T_M - T_0)] \qquad (3.8)$$

where K_{M0} and K_M meter factor at reference (20 °C) and metering conditions, respectively, in pulses/m^3,
T_{M0} and T_M temperature of the flowmeter at reference (20 °C) and metering conditions, respectively, in °C,
α_M linear expansion coefficient for the material of the flowmeter body, in °C^{-1}.

3.5 Uncertainty of the reported value

In general and in accordance to the WGFF recommendation for comparison calculations (proposed by J. Wright, B. Mickan, M. Benkova, February 7, 2014), the combined standard uncertainty of measurement at the individual participating laboratories $u(e_{r,i})$ includes the uncertainty of the participant's flow reference $u_{lab}(e_{r,i})$ and the comparison uncertainty u_{comp}. The value of u_{comp} consists the following components: uncertainty introduced by the transfer standard $u_{TS}(e_r)$ - according to equation (3.5) - and the repeatability of the reported value at each test point $u_{repeat}(e_{ri})$ - according to equation (3.5):

$$u(e_{r,i}) = \sqrt{u_{lab}^2(e_{r,i}) + u_{comp}^2(e_{r,i})} = \sqrt{u_{lab}^2(e_{r,i}) + u_{TS}^2(e_r) + u_{repeat}^2(e_{r,i})} \qquad (3.9)$$

3.6 Determination of the suplementary comparison value and its uncertainty

To determine the reference value of this suplementary comparison (SCRV), the weighted mean equation (3.10) was selected using the inverses of the squares of the associated standard uncertainties as the weights [4] in accordance with the instructions given by the BIPM:

$$e_{r,SCRV} = \frac{\frac{e_{r,1}}{u^2(e_{r,1})} + \frac{e_{r,2}}{u^2(e_{r,2})} + \cdots + \frac{e_{r,i}}{u^2(e_{r,i})}}{\frac{1}{u^2(e_{r,1})} + \frac{1}{u^2(e_{r,2})} + \cdots + \frac{1}{u^2(e_{r,i})}} \tag{3.10}$$

where $e_{r,1}$, $e_{r,2}$, ..., $e_{r,i}$ — error values, which were measured in the participating independent laboratories 1, 2, ..., i based on equation (3.3)

$u(e_{r,1})$, $u(e_{r,2})$, ..., $u(e_{r,i})$ — combined standard uncertainties connected with the values of errors, which were measured in the independent laboratories 1,2, ..., i, based on equation (3.9)

SCRV was determined for each flow rate separately.

To calculate the standard deviation $u(e_{r,SCRV})$ associated with the supplementary comparison reference value $e_{r,SCRV}$ equation (3.11) was used [4]:

$$u^2(e_{rSCRV}) = \frac{1}{\frac{1}{u^2(e_{r,1})} + \frac{1}{u^2(e_{r,2})} + \cdots + \frac{1}{u^2(e_{r,i})}} \tag{3.11}$$

The obtained expanded uncertainty of the reference value is

$$U\left(e_{r,SCRV}\right) = k \cdot u\left(e_{r,SCRV}\right) = 2 \cdot u\left(e_{r,SCRV}\right) \tag{3.12}$$

3.7 Consistency test of results - Chi-Square Test

To identify eventual inconsistent results, a chi-square test was applied to all i calibration results [4].

$$\chi^2_{obs} = \frac{(e_{r,1} - e_{r,SCRV})^2}{u^2(e_{r,1})} + \frac{(e_{r,2} - e_{r,SCRV})^2}{u^2(e_{r,2})} + \cdots + \frac{(e_{r,i} - e_{r,SCRV})^2}{u^2(e_{r,i})} \tag{3.13}$$

The degrees of freedom ν in this case was determined according to the equation:

$$\nu = i - 1 \tag{3.14}$$

where i is the number of the evaluated laboratories.

The theoretical value can be found with the excel-function *CHIINV*(0.05;6), where 0.05 gives the significance level of 5 % and 6 the actual degree of freedom (if all participants contribute to the SCRV). The participating labs must correspond to the following condition

$$CHINV(0.05;\nu) > \chi^2_{obs} \tag{3.15}$$

As practiced in [Benkova 2011], if such condition is not fulfilled, the reference value is calculated without the data of the lab which has the highest value of the parameter χ. This procedure was repeated until the condition of equation (3.15) was satisfied.

3.8 The determination of the differences "Lab to SCRV" and "Lab to Lab"

The most important outcome of the comparison is the closeness of each result to the reference value SCRV. Two measures can be used to characterize the results - the difference d_i between the laboratory value and the SCRV and, respectively, the degree of equivalence E_i.
The difference d_i of each comparison result to the reference value calculates in accordance with equation (3.16):

$$d_i = e_{r,i} - e_{r,SCRV} \tag{3.16}$$

Calculating the corresponding uncertainties of these differences, it should be taken into account, that the standard uncertainty of measurement, which is got from the interferences at SCRV determination between two dependent inputs, is created by the square sum of the standard uncertainties corresponding to the individual contributed quantities minus the double number of their covariance.

3.8.1 Differences to the SCRV

The value of covariance is identical to the value of measurement uncertainty related to SCRV for the independent participating labs which took part in the SCRV determination. The standard uncertainty $u(d_i)$ was calculated according to equation (3.17).

$$u(d_i) = \sqrt{u^2(e_{r,i}) + u^2(e_{r,SCRV}) - 2 \cdot u^2(e_{r,SCRV})} = \sqrt{u^2(e_{r,i}) - u^2(e_{r,SCRV})} \tag{3.17}$$

Participating labs, which were excluded from the SCRV determination, do not have any interference. In that case the value of $u(d_i)$ was calculated according to equation (3.18).

$$u(d_i) = \sqrt{u^2(e_{ri}) + u^2(e_{rSCRV})} \tag{3.18}$$

3.8.2 Lab to Lab Differences

All of the participants in this comparison have independent traceability chains. There is no covariance between the results of two independent laboratories *i* and *j* and the uncertainty of the difference between two labs is:

$$u(d_{ij}) = \sqrt{u^2(e_{ri}) + u^2(e_{rj})} \tag{3.19}$$

Equations (3.17) to (3.19) use the standard uncertainties. The expanded uncertainties *U(di)* and *U(dij)* are determined by using a coverage factor of 2 to obtain an approximately 95 % confidence level value:

$$U(d_i) = k \cdot u(d_i) = 2 \cdot u(d_i) \tag{3.20}$$

Note: According to the 14th CCM meeting (February, 2013) pair-wise degrees of equivalence should no longer be published in the KCDB. Information on pair-wise degrees of equivalence published in KC reports should be limited to the equations needed to calculate them, with the addition of any information on correlations that may be necessary to estimate them more accurately.

3.9 Calculation of the degree of equivalence $E_{N,i}$

The basis for the estimation of the laboratory's successful participation in the comparison is the standardized degree of equivalence (DoE) $E_{N,i}$. It was calculated according to equation (3.21).

$$E_{N,i} = \left| \frac{d_i}{U(d_i)} \right| \quad (3.21)$$

The standardized degree of equivalence to the SCRV is determined for the results of each lab according to the following evaluation (WGFF Comparison Calculations; Wright, Mickan, Benkova for the Working Group for Fluid Flow; February 7, 2014):

- the results of the lab are **acceptable (satisfactory)** if $E_{N,i} \leq 1$
- the results of the lab are **non-acceptable (unsatisfactory)** if $E_{N,i} > 1.2$
  such an estimation indicates a serious problems of the lab which must be analysed and removed for proper functioning of the lab
- the so-called **warning level** is established for values in the interval $1 < E_{N,i} \leq 1.2$
  which signals to the participating lab on the drawbacks of less serious character, but it is the cause for taking corrective measures

4 Transfer standards

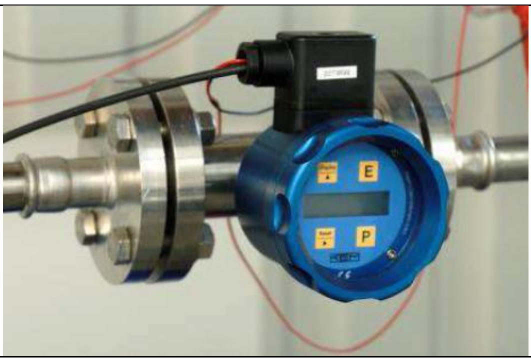
4.1 DN25 Transfer Package

4.1.1 Description of the transfer package

The DN25 transfer package used for the flowrate range from 0.0 m^3/h to 5 m^3/h is described in detail in the Technical Protocol of the comparison, together with packing-unpacking, installation procedure and very specific instructions on how to operate the transfer standard. It consists of turbine and electromagnetic flowmeters, put in series with dedicated pressure and temperature instrumentation, three associated pipeworks and data acquisition system. The data acquisition system was used only to monitor the collecting flow signals from flow meters as well as pressure and temperature transmitters of the transfer standard.

Some of the specifications of the flowmeters are summarized in Table 3.

Table 3: Specifications of the flowmeters DN25 transfer standards[1]

	
Meter M1	**Meter M2**
Turbine flowmeter DN 25	Electromagnetic flowmeter DN 25
Type: HM 13/25 F PN40 (VTM-B.D.K.S.K)	Type: IFS5000Mod/6
Serial number № 01671417	Serial number № A08 28679
Flow range: (0.51 to 5.1) m^3/h	Flow range: (0.5 to 5.0) m^3/h

The total lengh of the transfer standard is 1.745 m. The installation setup and geometry of the DN25 transfer standard is given in Fig. 6 and Fig. 7.

[1] Certain commercial equipment, instruments, or materials are identified in this paper to foster understanding. Such identification does not imply recommendation or endorsement, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

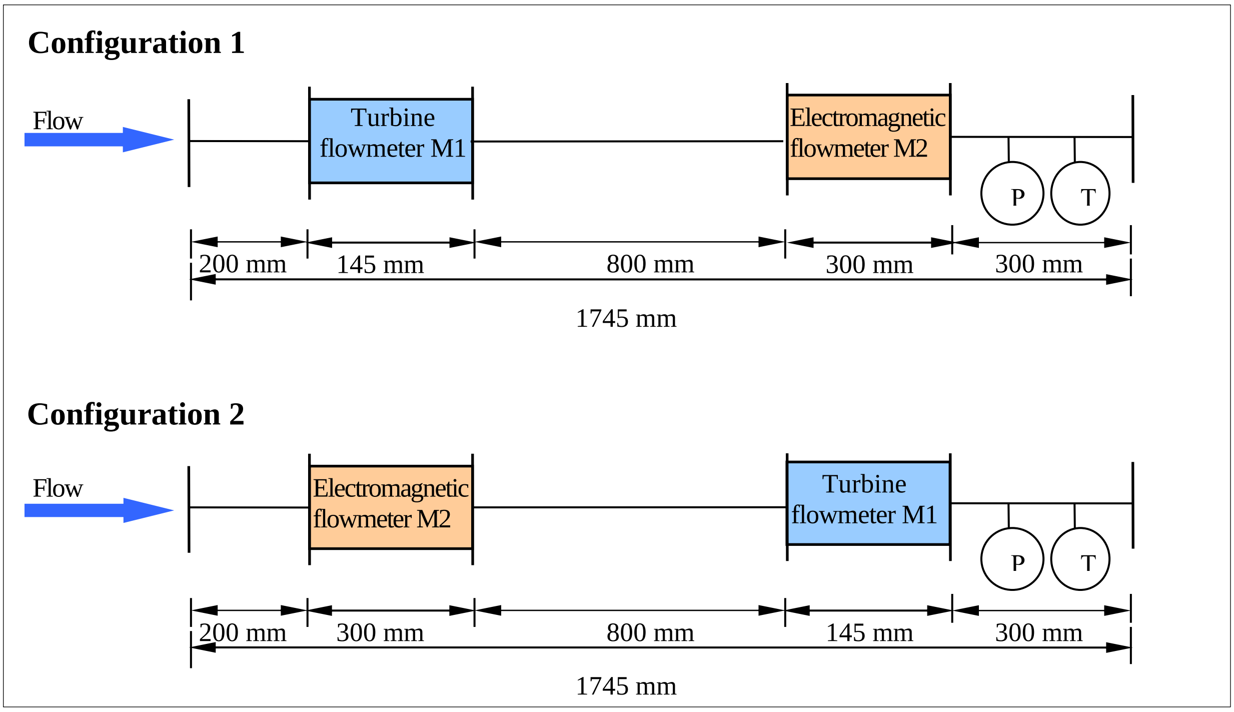


Fig. 6: Measurement configurations for the DN25 transfer standard

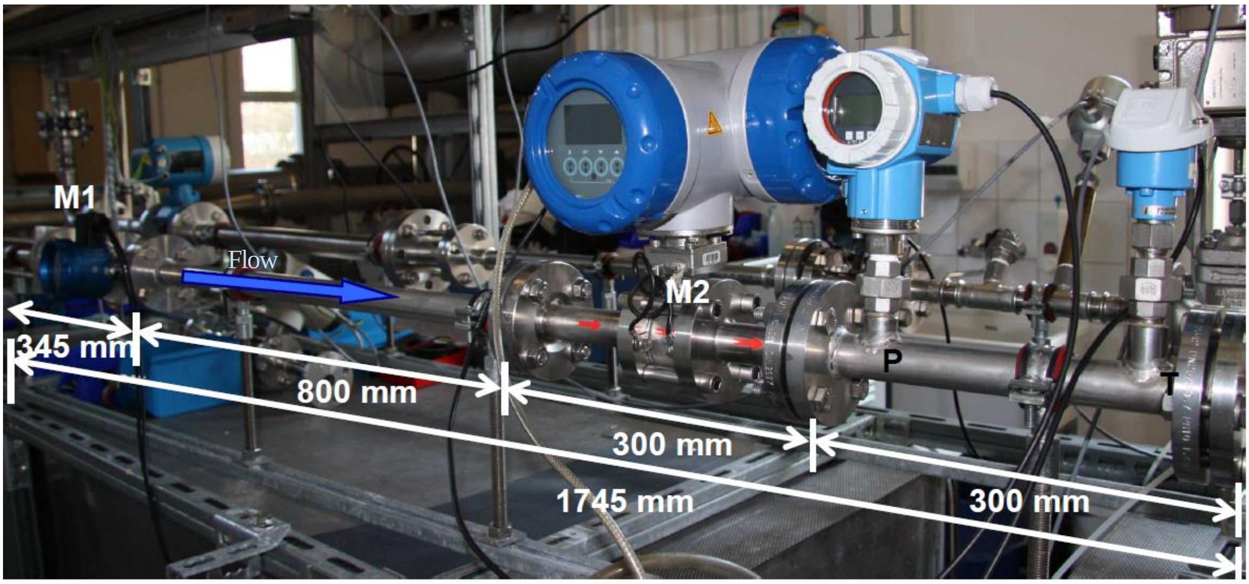


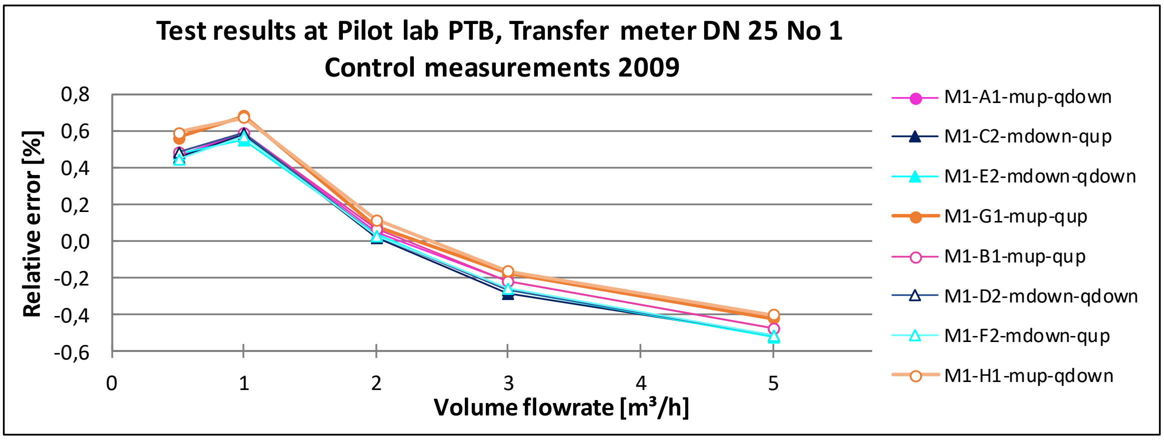
Fig. 7: Photograph of the installed DN25 transfer standards

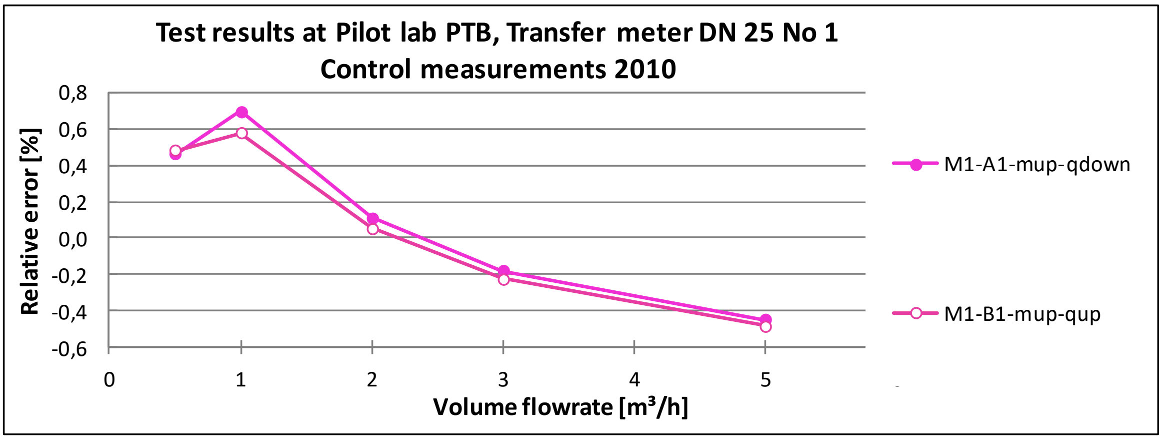
4.1.2 Measurements results of pilot laboratory

PTB as pilot laboratory performed measurements at the beginning (2009) and at the end of the comparison (2012). In 2010 control measurements had been carried out to check the correct functioning of the transfer standard meters.

- **Transfer turbine flowmeter DN 25 (meter M1)**

The complete set of the pilot lab's results for the turbine flowmeter is shown in the Fig. 8. The results were calculated based on equation (3.3).





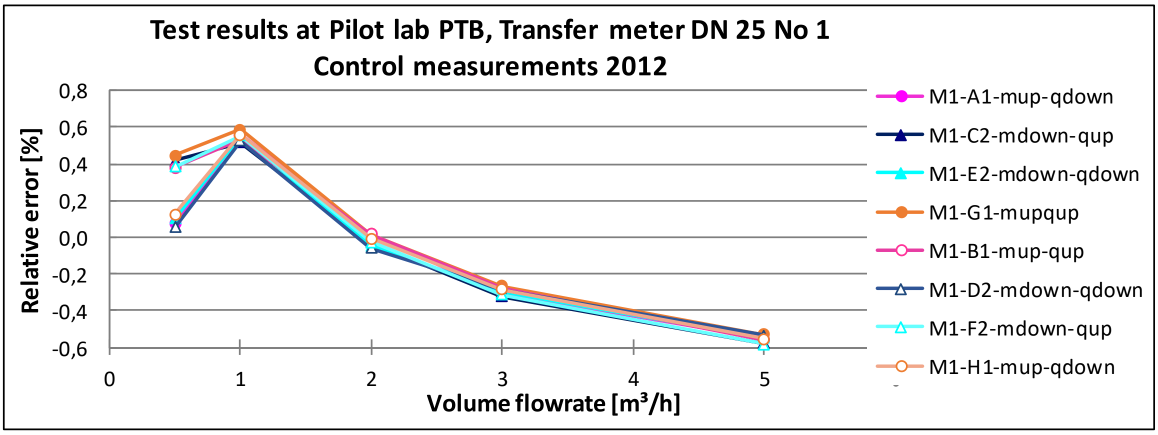


Fig. 8: Measurement error of transfer meter 1 (turbine meter DN25) - calibrated at PTB during the years of 2009, 2010 and 2012
with: M1 - Meter 1 (Turbine flow meter DN25)
mup - flowmeter in upstream position   mdown - flowmeter in downstream position
qup - increasing flowrate   qdown - decreasing flowrate

Fig. 9 respresents the deviations of the errors at each test flowrate from the corresponding average value of all measurements at pilot lab PTB.

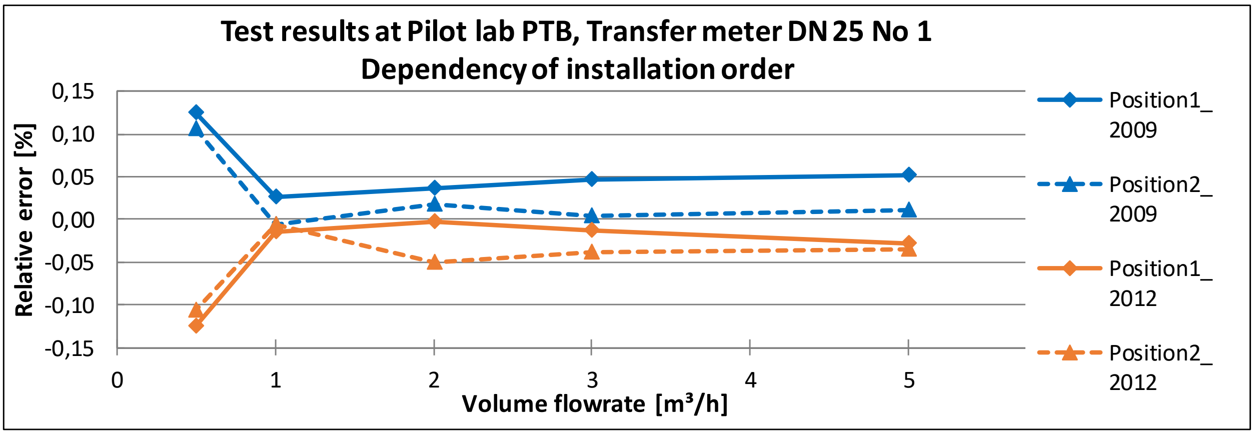


Fig. 9: Turbine flowmeter M1 – Deviation to mean of measurement errors in dependency of installation order (upstream - position 1, downstream - position 2) for comparable measurement conditions (e.g. day 1 to day 3, given as A1/B1 to E2/F2) (see Fig. 2 to Fig. 5)

For the turbine flowmeter, a significant influence of the flowmeters' position on the measurement errors was detected. The second meter of the package, the electromagnetic flowmeter, does not have any moving parts or changes of the flow channel. Therefore it represents only an extension of the straight inlet pipe for the turbine flowmeter in the case that it is installed in front of it and should not have a significant influence on the turbine flowmeter. Behind that background the observerd influences of meter position to measurement errors can be interpreted as a facility induced installation effect. This effect will be considered by the discussions to the drift uncertainties (Kapitel…).

4.1.3 Transfer standard uncertainties for DN25

In accordance with chapter 4.1.2, calibration curves of transfer flowmeter M1 were obtained in the pilot laboratory PTB before (2009) and after the comparison (2012) as shown in Fig. 10. The results of the measurements are summarized in Table 4.

Table 4: Turbine flowmeter M1 - measurement errors of the calibration periods at PTB in 2009 and 2012. The errors are representing mean values, caluculated by using all measured data of different calibration variations for each flowrate.

Flowrate in m³/h	**e_r March, 2009** in %	**e_r August, 2012** in %	**abs($e_{r,2009} - e_{r,2012}$)** in %
5	-0,481	-0,555	0,074
3	-0,234	-0,292	0,058
2	0,051	-0,015	0,066
1	0,599	0,547	0,052

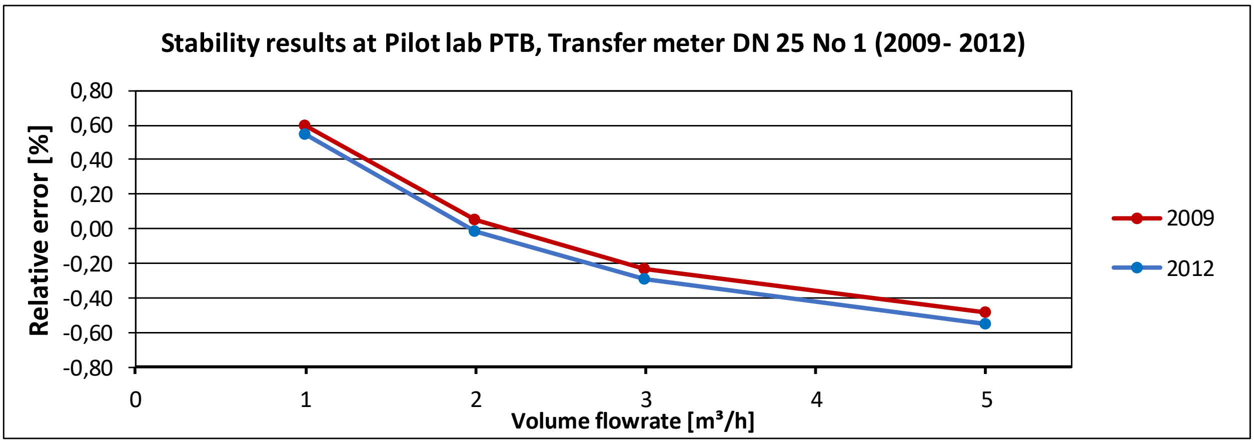


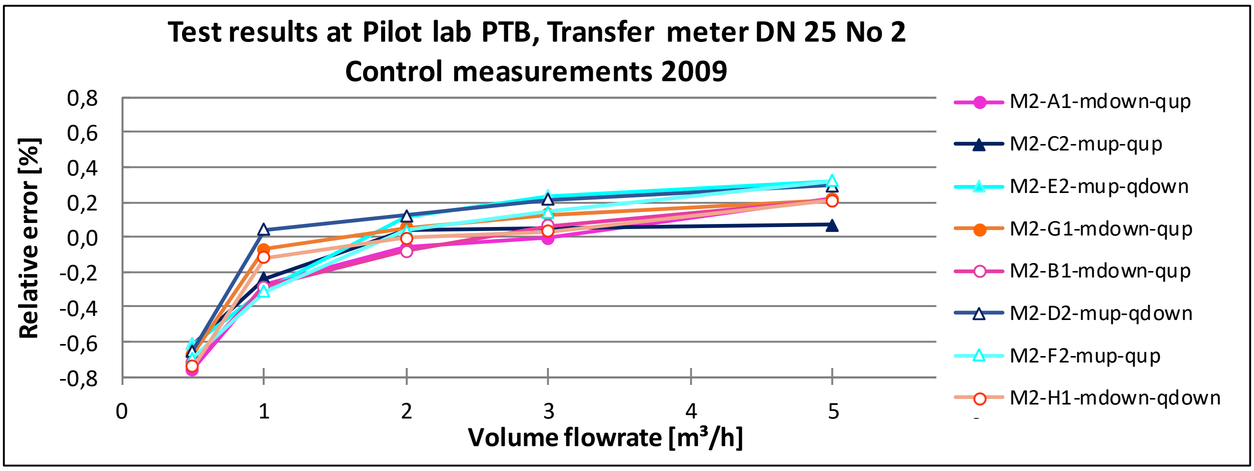
Fig. 10: Turbine flowmeter M1 - Stability during calibration period between 2009 and 2012 at pilot laboratory - The measurement errors are representing mean values, caluculated by using all measured data of different calibration variations for each flowrate.

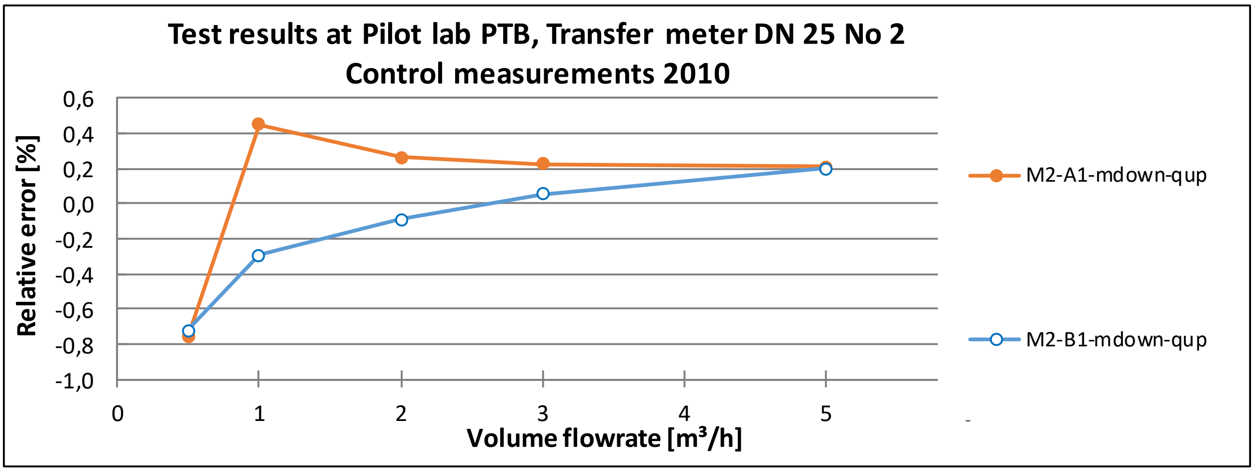
In accordance to Table 4 and equation (3.6) $\max(e_{r,2009} - e_{r,2012}) = 0{,}074\ \%$, leads to $u_{drift} = 0{,}021\ \%$. Since the values of u_{drift} are essentially constant over all relevant flow rates, this amount of u_{drift} was used for all flow rates. The uncertainty for reproducibility was calculated to $u_{reprod} = 0{,}005\%$ which is also valid for all flow rates.

Combining the uncertainties due to transfer standard calibration stability and instabilities of the meter during measurements by root-sum-of-squares leads to a transfer standard uncertainty of $u_{TS} = 0{,}022\%$.

- **Transfer electromagnetic flowmeter DN 25 (meter M2)**

The complete set of the pilot lab's test results for the turbine flowmeter is shown in the *Fig. 11*. The results were calculated in accordance to equation (3.3).





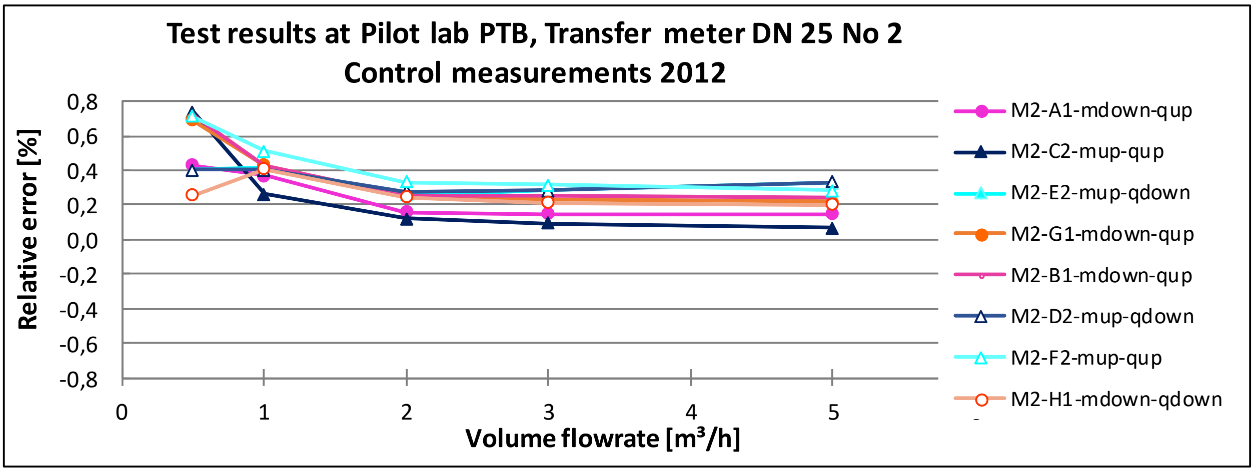


Fig. 11: Electromagnetic flowmeter M2 DN 25 - Measurement errors of the calibrations at PTB
with: M2 - Meter 2 (Electromagnetic flowmeter DN 25)
mup - flowmeter in upstream position   mdown - flowmeter in downstream position
qup - increasing flowrate   qdown - decreasing flowrate

The deviations of the errors at each test flowrate from the corresponding average value of all measurements at Pilot lab PTB at that flowrate are presented in Fig. 12.

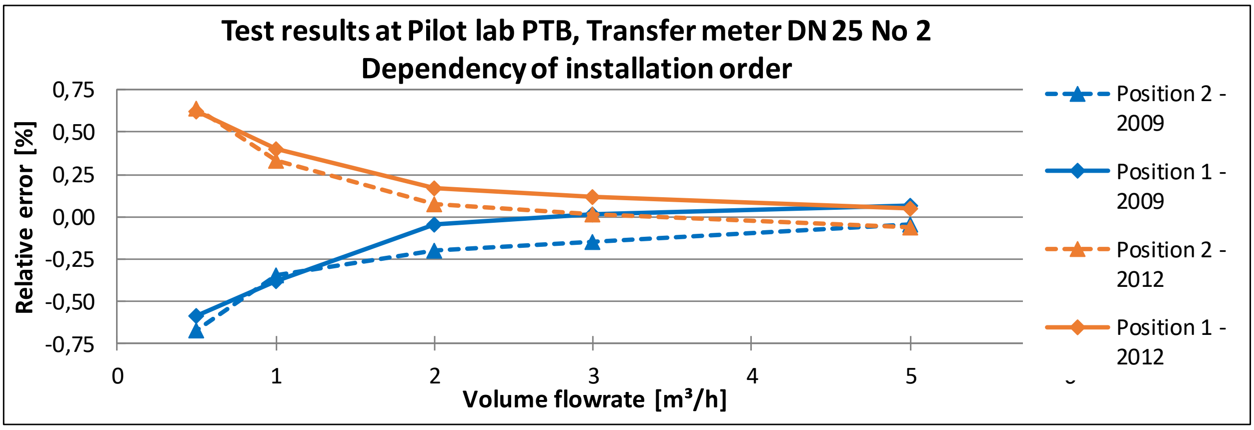


Fig. 12: Electromagnetic flowmeter M2 – Deviation to mean of measurement errors in dependency of installation order (upstream - position 1, downstream - position 2) for comparable measurement conditions (e.g. day 1 to day 3, given as A1/B1 to E2/F2)

The transfer electromagnetic flowmeter significantly changed its behaviour during the comparisons, in particular the error curve did not move parallel but changed its trend. As the results of the other labs show, this reversal happened several times.

As already reported in chapter 1, in Slovakia it was impossible to get signals from the electromagnetic flowmeter. The signal converter was changed, but the situation did not improve. Therefore it was decided to continue the measurements in accordance with the agreed measurement procedure, e.g. to use and install the electromagnetic flowmeter in the required manner, but completely exclude its results from the calculation of the comparison parameters.

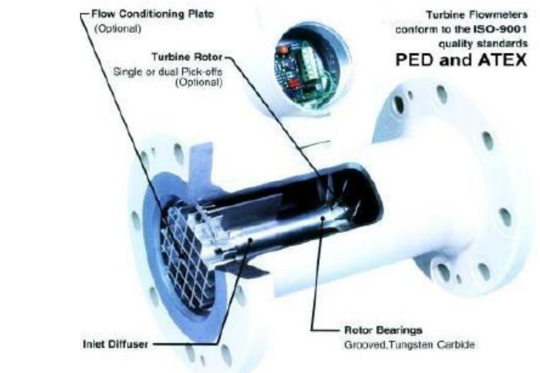
4.2 DN80 Transfer Package

4.2.1 Description of the transfer package

The DN 80 transfer package used for the flowrate range from 20 m³/h to 100 m³/h is described in detail in the Technical Protocol (Appendix B) of the comparison together with packing-unpacking, installation procedure and very specific instructions on how to operate this transfer standard. It consists of two turbine flowmeters put in series with dedicated pressure and temperature instrumentation, three associated pipeworks and data acquisition system. By checking the agreement of the two flowmeters in series, it is possible to obtain another measurement of the uncertainty introduced by the transfer standard.

The data acquisition system included in the transfer standard was only used to monitor the results by collecting flow signals from flow meters as well as pressure and temperature transmitters of the transfer standard. Some of the specifications of the flowmeters are summarized in Table 5.

Table 5: Specifications of the transfer standard flowmeters for DN80[2]



Turbine flowmeter M1, DN 80	Turbine flowmeter M2, DN 80
Type: MEYERINCK-Parity DN 80/PN 16	Type: MEYERINCK-Parity DN 80/PN 16
Serial number № 1695	Serial number № 1697
Flow range: (10 to 160) m^3/h	Flow range: (10 to 160) m^3/h

The basic arrangement and geometry of the DN80 transfer standards is shown in Fig. 13. The total length is 1.80 m. Fig. 14 shows the DN80 transfer standards instaled in calibration line.

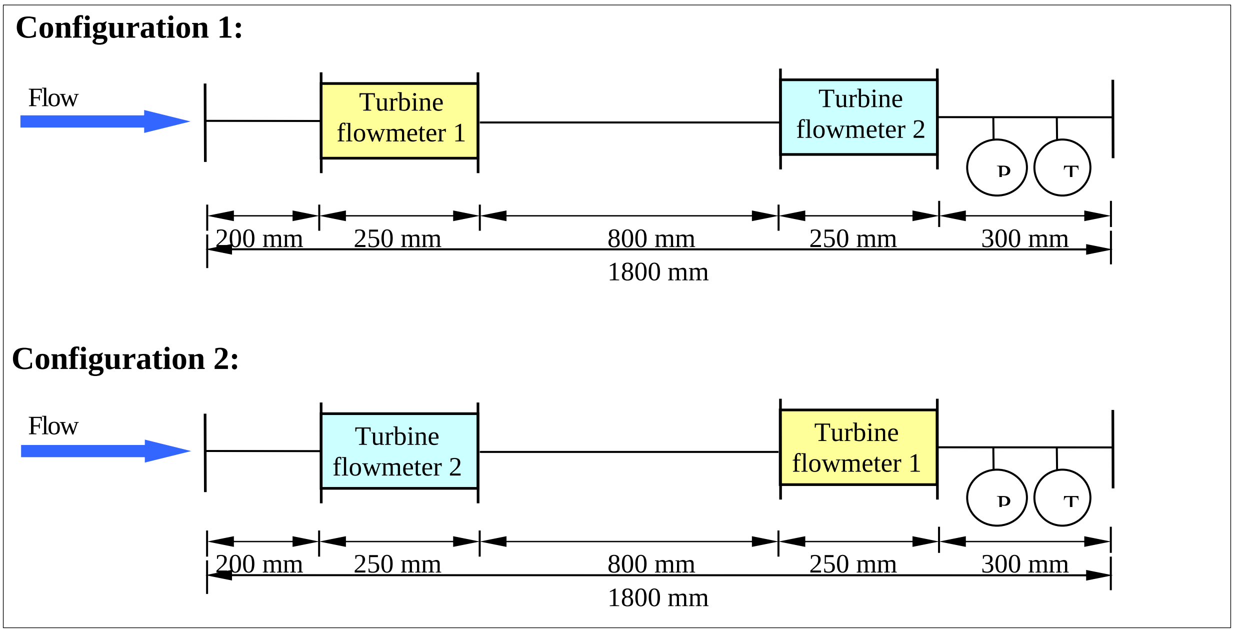


Fig. 13: Measurement configurations 1 and 2 for the DN80 transfer standards

[2] Certain commercial equipment, instruments, or materials are identified in this paper to foster understanding. Such identification does not imply recommendation or endorsement, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

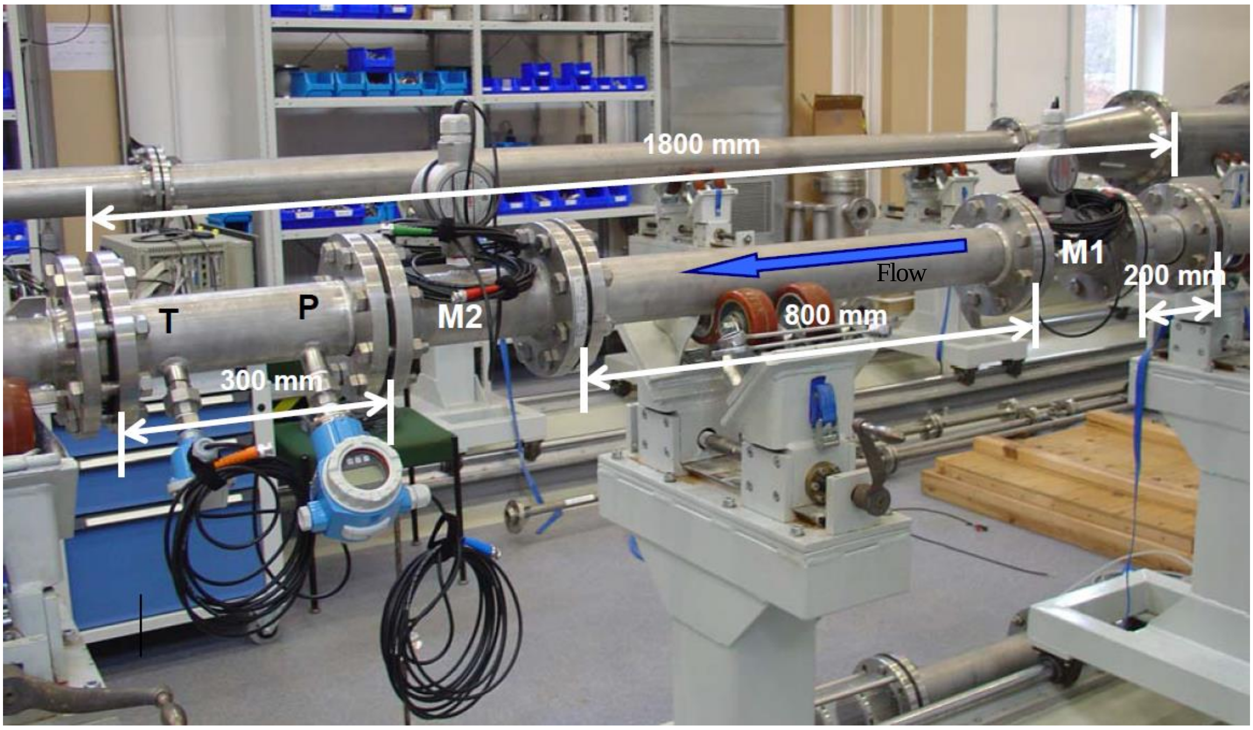


Fig. 14: DN80 transfer standards installed in calibration line at PTB

4.2.2 Measurement results at pilot laboratory

PTB as pilot laboratory performed measurements at the beginning (2009), in the middle (2010), and at the end of the comparison (2012). The complete sets of the test results, calculated in accordance to equations (3.1) to (3.2), are shown in Fig. 15 for the transfer turbine flowmeter No 1 and in Fig. 16 for transfer turbine flowmeter No 2.

Fig. 17 and *Fig. 18* respresent the deviations of the errors measured from the corresponding average values separated for the two positions of turbine flowmeter (upstream and downstream) within the transfer package for meter No 1 and meter No 2, respectively.

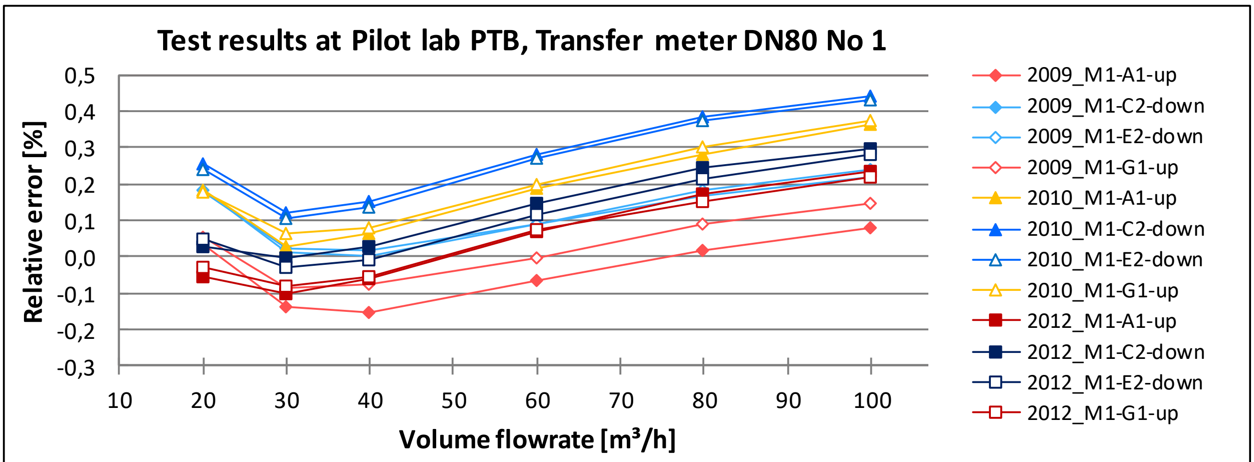


Fig. 15: Turbine flowmeter DN 80 M1 – Mesurement error of the calibrations at PTB
with: M1 - Meter 1 (Turbine flowmeter DN 80)
up - flowmeter in upstream position
up - increasing flowrate

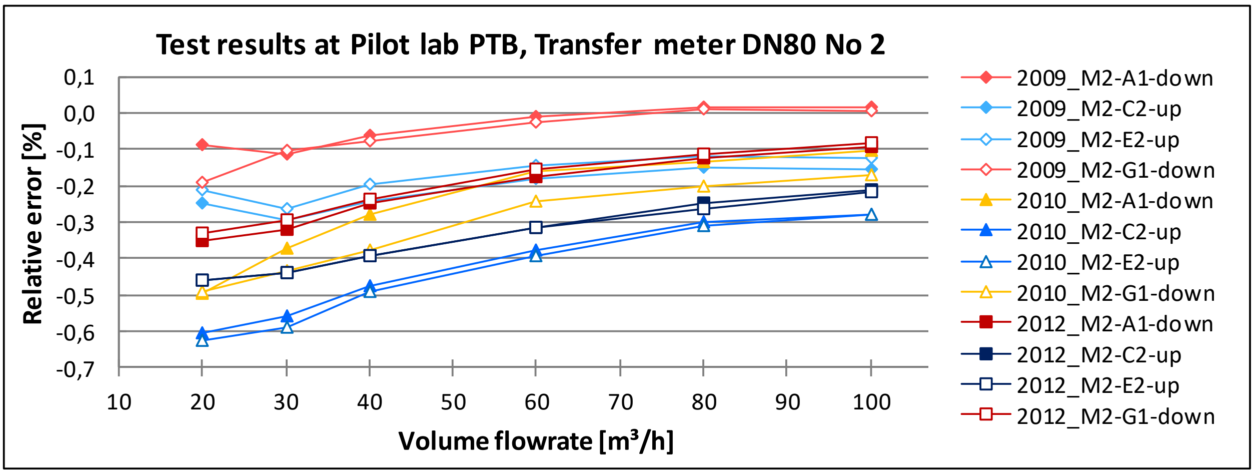


Fig. 16: Turbine flowmeter DN 80 M2 – Measurement error of calaibrations at PTB
with: M2 - Meter 2 (Turbine flowmeter DN 80)
up - flowmeter in upstream position
up - increasing flowrate

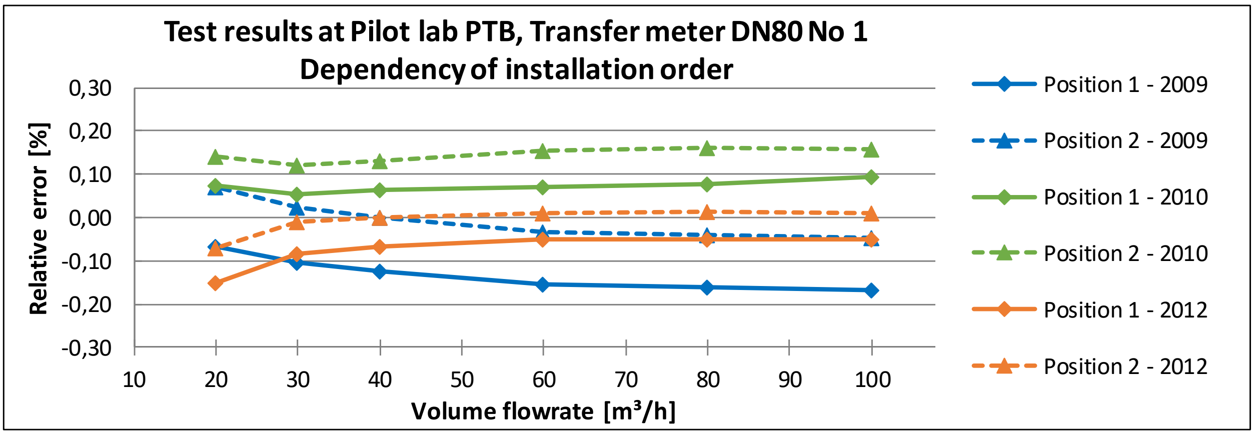


Fig. 17: Turbine flowmeter M1 – Deviation to mean of measurement errors in dependency of installation order (upstream - position 1, downstream - position 2) for comparable measurement conditions (e.g. day 1/4 to day 2/3, given as A1/G1 to C2/E2

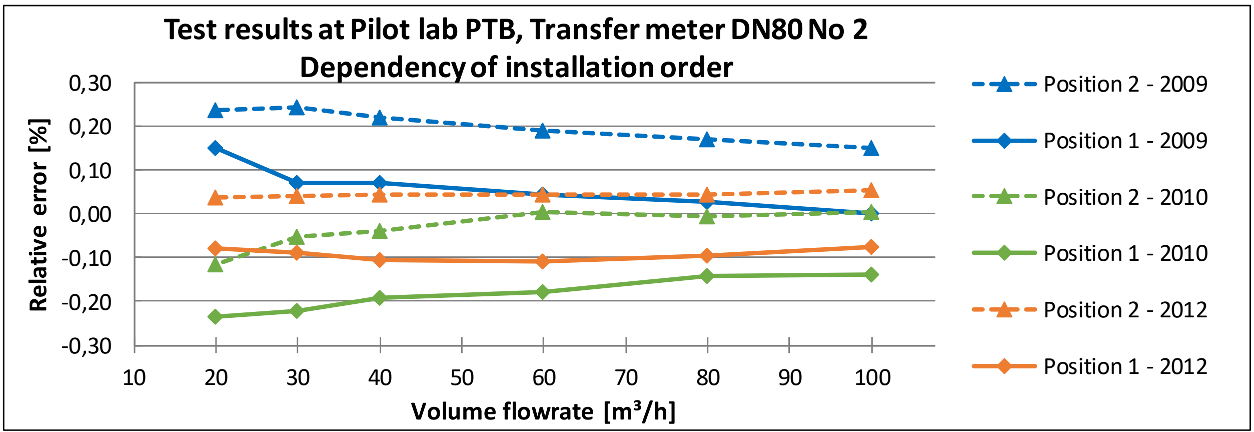


Fig. 18: Turbine flowmeter M2 – Deviation to mean of measurement errors in dependency of installation order (upstream - position 1, downstream - position 2) for comparable measurement conditions (e.g. day 1/4 to day 2/3, given as A1/G1 to C2/E2)

The diagrams show very large spreads of the indications of both transfer flowmeters – up to 0.33 % for meter No 1 and up to 0.50 % for meter No 2 whereas the expanded uncertainty of the Pilot lab's facility amounts to 0.02 %. The changes are parallel, but in different directions for both flowmeters – for meter No 1, the deviations e_r increase during the first circle and decrease during the second. For meter No 2, the deviations e_r move in the opposite direction (decrease during the first circle and increase during the second one). Such a measuring behaviour of the meters is a clear sign for insufficient long-term stability of the meters themselves but not of the facility of the Pilot lab.

Taking into account the small uncertainties of the flow facilities of the participating NMIs, it was necessary to analyse the results very carefully to find out the transfer standard configuration with the best and stablest behaviour.

In the result of intensive discussions of Draft A of this Report at a workshop held by the pilot lab (23 October, 2012, at PTB Braunschweig), it was agreed between the participants to use only the results of transfer flowmeter No. 1 in downstream position, because this configuration gives the best consistency of the evaluated labs.

4.2.3 Transfer standard uncertainty for DN80 - Meter 1

A calibration curves of transfer flowmeter No 1 was obtained at three times in the pilot laboratory PTB before (2009), during (2010), and immediately after the comparison (2012). The results of the measurements are summarized in Table 6:

Table 6: Turbine flowmeter M1 - Measurement errors of the transfer standard obtained at various times at PTB. The errors are representing mean values, caluculated by using all measured data of different calibration variations for each flowrate.

Flowrate in m³/h	e_r March, 2009 in %	e_r July, 2010 in %	e_r May, 2012 in %	abs($e_{r,Max} - e_{r,Min}$) in %
100	0,1714	0,4032	0,2594	0,2318
80	0,1205	0,3366	0,1949	0,2161
60	0,0340	0,2367	0,1046	0,2027
40	-0,0531	0,1093	-0,0276	0,1624
30	-0,0461	0,0808	-0,0516	0,1323
20	0,1160	0,2155	-0,0003	0,2158

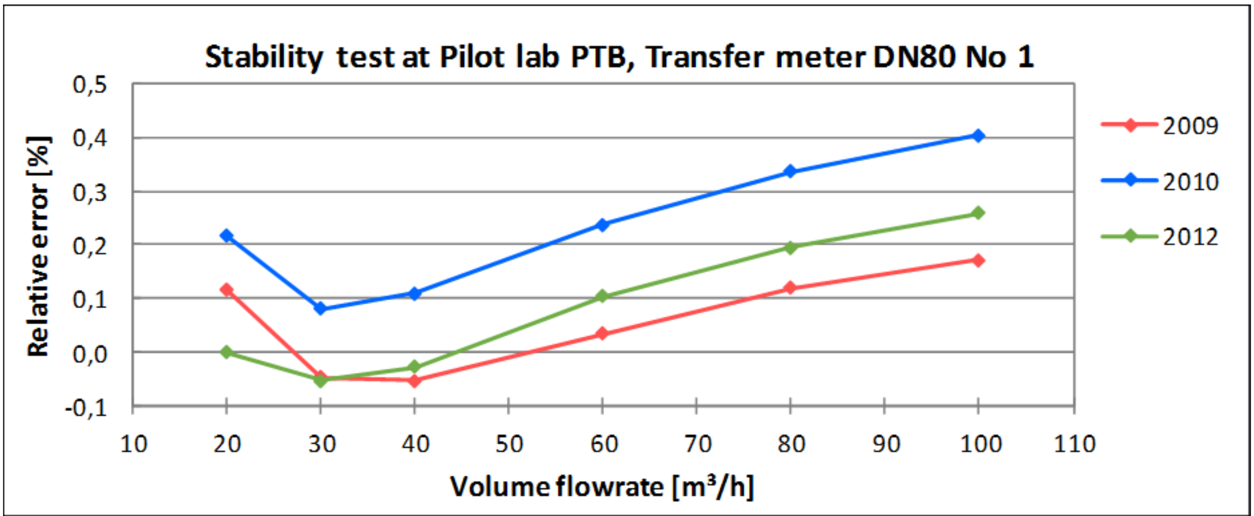


Fig. 19: Turbine flowmeter M1 - Stability of the transfer standard

In accordance with Fig. 19 and equations (3.6): $\varepsilon_{max} - \varepsilon_{min} = 0{,}23\%$, leading to $u_{drift} = 0{,}067\%$. Since the values of u_{drift} are essentially constant over all relevant flow rates, we used only one value. The uncertainty for reproducibility was calculated with $u_{reprod} = 0{,}008\%$ which is also valid for all flow rates.

Combining the uncertainties due to transfer standard calibration stability and instabilities of the meter during measurements by root-sum-of-squares leads to a transfer standard uncertainty of $u_{TS} = 0{,}067\%$.

5 Evaluation of the results

As already mentioned above, it was agreed to use for both setups (DN25 and DN80) only the results of transfer flowmeter No. 1 for each flowrate range in downstream position (Day #2), because this configuration gives the best consistency of the evaluated labs. That means, for evaluating DN25 data set, calibration program C2/D2 was analysed, respectively for DN80, calibration program C2.

5.1 DN25 Transfer Package

5.1.1 Laboratory results

All data collected from the participating laboratories are summarized in the following Table 7 and Fig. 20.

Table 7: Relative errors $e_{r,i}$ (%) of the transfer standard obtained by the participating laboratories (Meter M1 DN25)

Flow rate in m³/h	**Germany PTB 2012** in %	**Belarus BelGIM 2011** in %	**Lithuania LEI 2010** in %	**Russia VNIIR 2011** in %	**Slovakia SMU 2010** in %	**Uzbekistan UzStandard 2010** in %
5	-0,557	-0,662	-0,607	-0,709	-0,537	-0,529
3	-0,306	-0,401	-0,354	-0,387	-0,220	-0,200
2	-0,044	-0,147	-0,066	-0,123	0,010	0,130
1	0,520	0,473	0,477	0,452	0,610	-

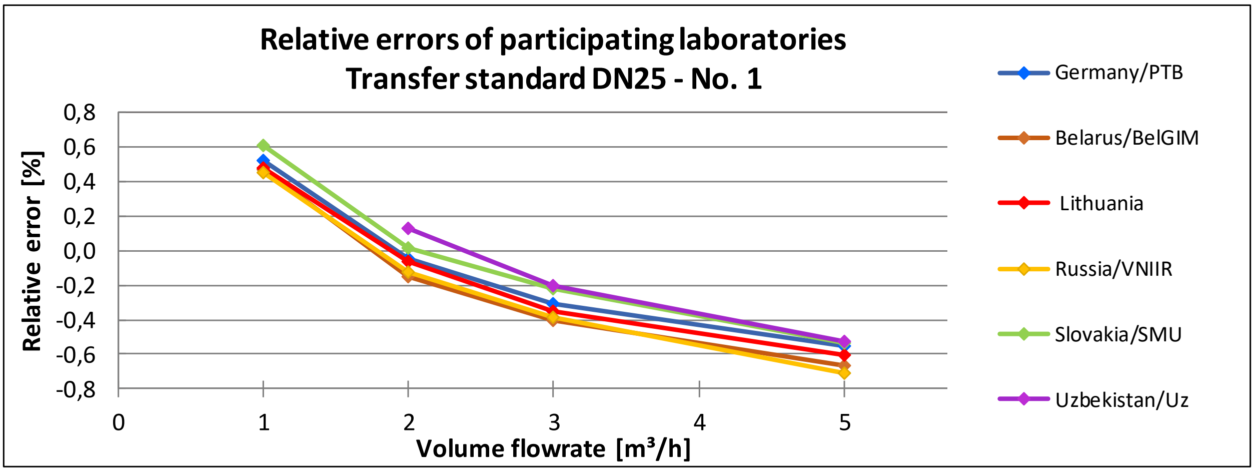


Fig. 20: Relative error $e_{r,i}$ of participating laboratories (Meter M1 DN25)

5.1.2 The SCRV and its uncertainty

The weighted mean e_{rSCRV} and its uncertainty $u(e_{rSCRV})$ was calculated based on the data from all of the laboratories. The results of $\frac{(e_{ri}-e_{rSCRV})^2}{u^2(e_{ri})}$ and consistency check are summarized in , respectively in Table 9.

Table 8: Results of $\frac{(e_{ri}-e_{rSCRV})^2}{u^2(e_{ri})}$ for each participating laboratories (Meter M1 DN25)

Flow rate in m³/h	**Germany PTB 2012**	**Belarus BelGIM 2011**	**Lithuania LEI 2010**	**Russia VNIIR 2011**	**Slovakia SMU 2010**	**Uzbekistan UzStandard 2010**
5	2,106	0,265	0,434	5,883	4,669	0,499
3	0,488	1,368	0,043	2,051	7,223	0,911
2	0,569	1,608	0,172	1,584	3,022	2,013
1	0,220	0,182	0,143	1,959	6,441	-

Table 9: Results of the chi-squared test at each flow of 1st calculation round

Flowrate in m³/h	**1. round**		
	χ^2_{obs}	$\chi^2(\nu)$	**Results of the chi-squared test**
5	13,86	11,07	failed
3	12,08	11,07	failed
2	10,38	11,07	passed
1	8,94	9,49	passed

Based on the results of the highest value of $\frac{(e_{ri}-e_{rSCRV})^2}{u^2(e_{ri})}$, Russia (5 m³/h) und Slovakia (3 m³/h) in Table 8, were excluded for the next round of evaluation and the new reference value of e_{rSCRV}. The new standard uncertainty of the reference value $u(e_{rSCRV})$ and the chi-squared value χ^2_{obs} were recalculated, but without the values of the excluded laboratory. The revised results are given in Table 10 and Table 11.

Table 10: Results of 2nd calculation round for the chi-squared test at each flow without the values of the excluded laboratory

Flowrate in m³/h	**2. round**		
	χ^2_{obs}	$\chi^2(\nu)$	**Results of the chi-squared test**
5	4,16	9,49	passed
3	3,47	9,49	passed
2	10,38	11,07	passed
1	8,95	9,49	passed

Table 11: Suplementary comparison reference values (SCRVs)

Flowrate in m³/h	e_{rSCRV} in %	$u(e_{rSCRV})$ in %
5	-0,590	0,024
3	-0,369	0,020
2	-0,085	0,019
1	0,494	0,019

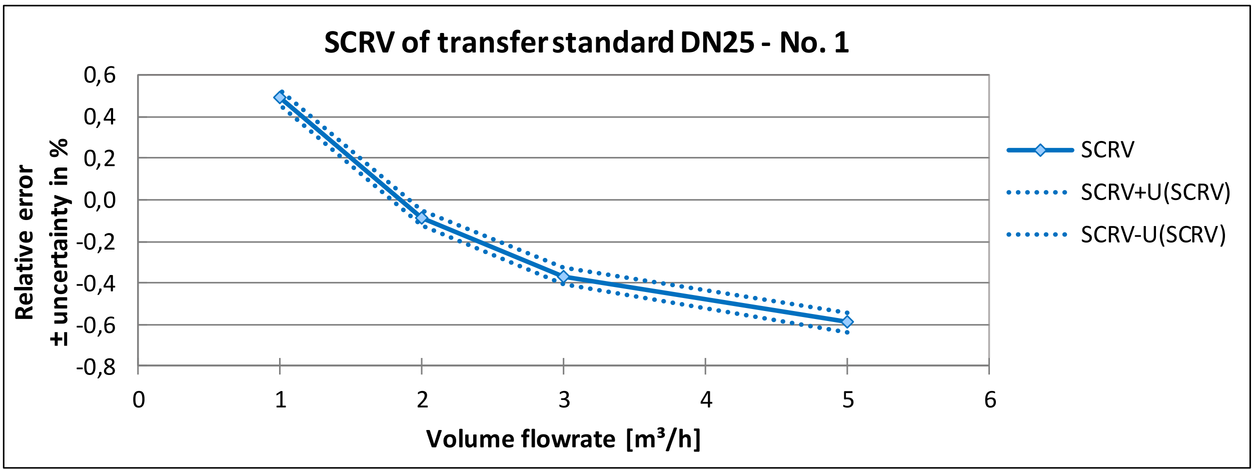


Fig. 21: Suplementary comparison reference value and it`s expanded uncertainty U(SCRV)

5.1.3 Summary

The degree of equivalence with the SCRV (En_i) is a measure of result agreement of each participating laboratory to the SCRV. The "lab to SCRV" values are summarized in
Fig. 22, the equivalence degrees of En_i in Table 12. All marked values of Table 12 did not confirm to the discussions of the Chi²-test (section 5.1.2). This values were excluded from the calculation of all other not marked En-values.

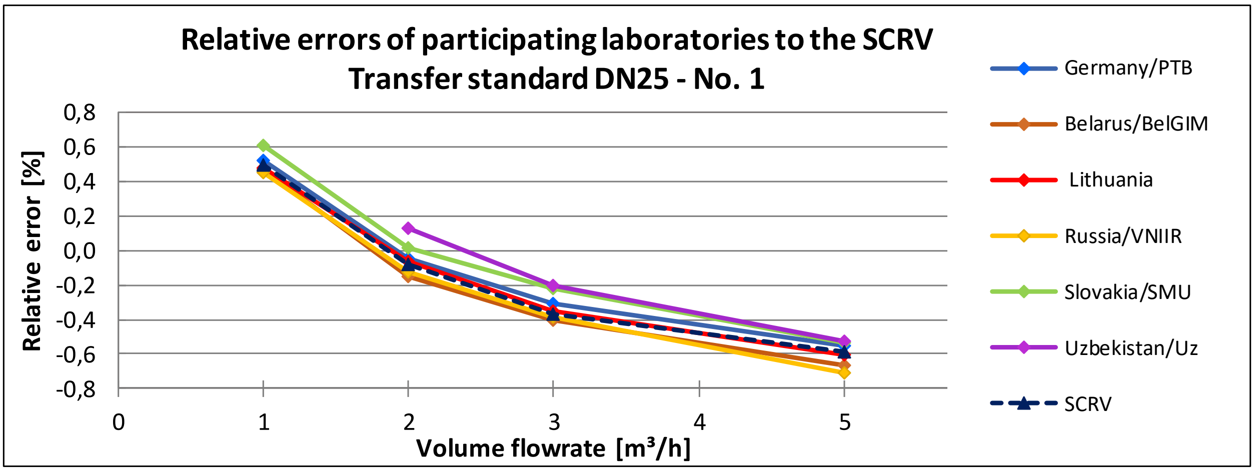


Fig. 22: Relationship of lab results to the SCRV

*Table 12: Degree of Equivalence (E_n) to SCRV of all participated laboratories. The *-marked values do not contribute to the discussions of Chi²-test. This values were excluded from the caluculations of the other not marked E_N-values.*

Flow in m³/h	**Germany** **PTB** **2012**	**Belarus** **BelGIM** **2011**	**Lithuania** **LEI** **2010**	**Russia** **VNIIR** **2011**	**Slovakia** **SMU** **2010**	**Uzbekistan** **UzStandard** **2010**
5	0,334	-0,849	-0,215	-1,557*	0,671	0,203
3	0,611	-0,372	0,177	-0,429	1,467*	0,561
2	0,401	-0,688	0,228	-0,810	0,944	0,715
1	0,250	-0,233	-0,206	-0,899	1,392*	-

5.1.4 Test on conclusivity of the comparioson results

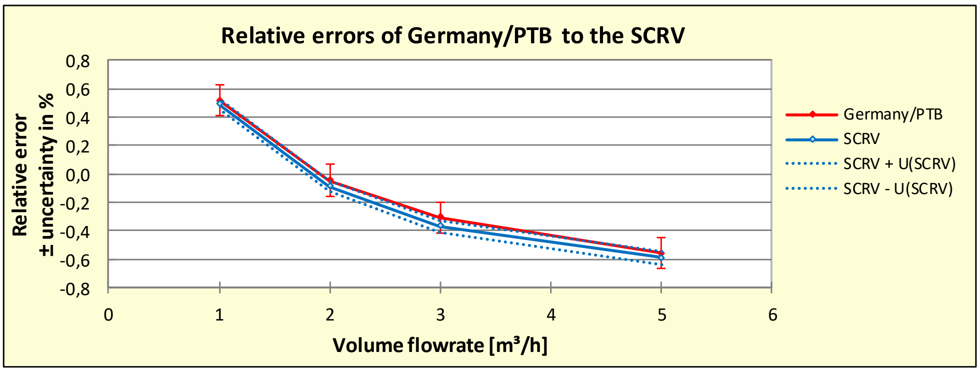
In accordance with the WGFF recommendation for comparison calculations (proposed by J. Wright, B. Mickan, M. Benkova, February 7, 2014), for a conclusive proof that the participant results are in agreement with the SCRV within its uncertainty claims, the comparison uncertainty ratio u_{Comp}/u_{Lab} should be < 2. The comparison ratios of Table 13 demonstartes the suitability of the used transfer meter (turbine meter M1 DN25) for all laboratories at all researched flowrates.

Table 13: Comparison ratios of u_{Comp}/u_{Lab} for each participated laboratory

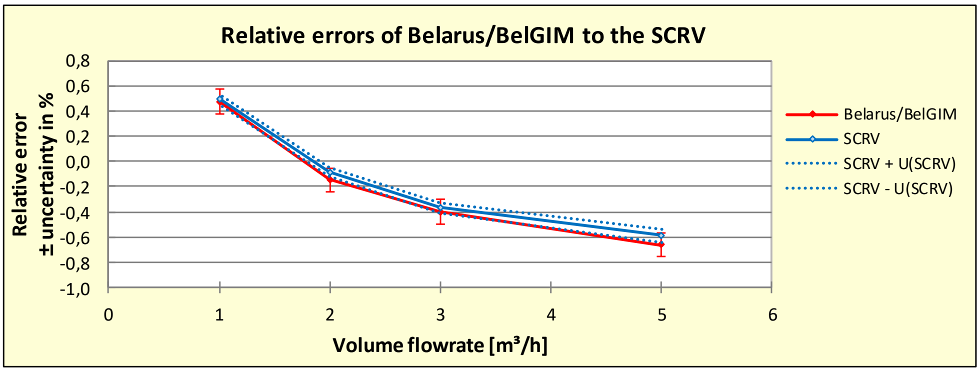
Flow in m³/h	**Germany** **PTB** **2012**	**Belarus** **BelGIM** **2011**	**Lithuania** **LEI** **2010**	**Russia** **VNIIR** **2011**	**Slovakia** **SMU** **2010**	**Uzbekistan** **UzStandard** **2010**
5	0,457	0,685	0,546	1,095	0,571	0,174
3	0,449	0,686	0,546	1,092	0,584	0,156
2	0,445	0,687	0,549	1,099	0,661	0,149
1	0,441	0,712	0,550	1,103	0,560	0,629

5.1.5 Final CMC-descicion table

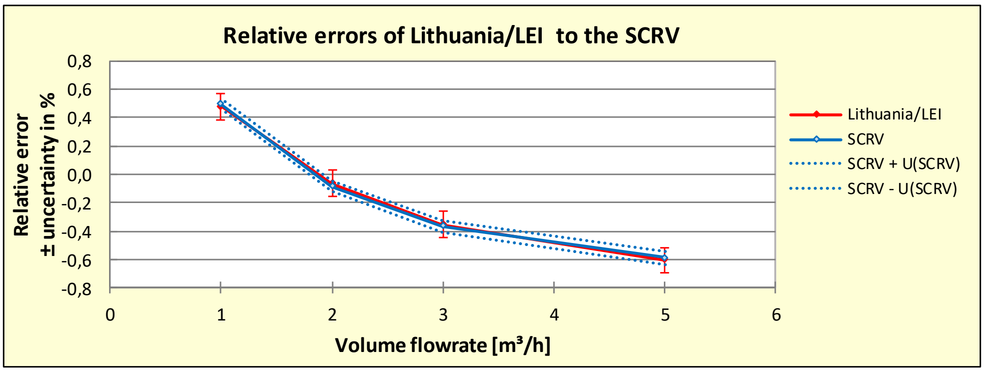
Germany / PTB EWZP							
Flow of the transfer standard Q in m³/h	Relative error of the transfer standard e_r in %	Expanded uncertainty of measurement declared by laboratory $U_{lab}(e_r)$ in %	Expanded uncertainty of measurement extended by stability U_{TS} and linking $U(d_i)$ in %	d_i in %	En_i	u_{comp}/u_{lab}	CMC decision status
4,939	-0,557	0,1	0,099	0,033	0,334	0,457	acceptable
2,983	-0,306	0,1	0,102	0,062	0,611	0,449	acceptable
2,006	-0,044	0,1	0,103	0,041	0,401	0,445	acceptable
1,034	0,520	0,1	0,103	0,026	0,250	0,441	acceptable



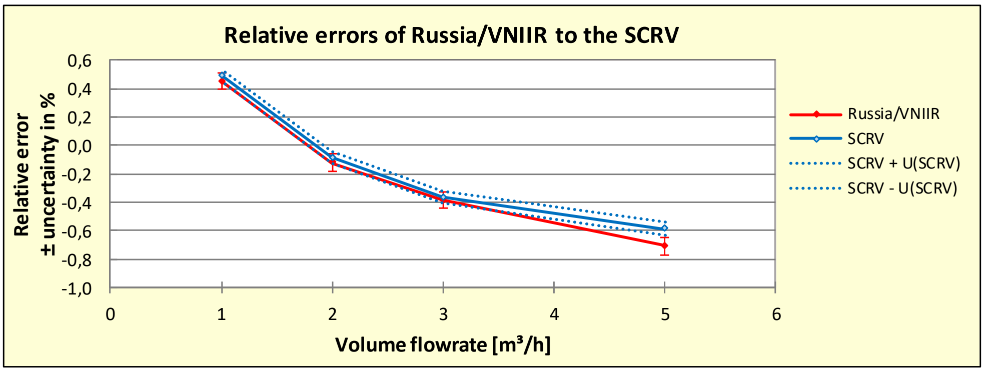
Belarus / BelGIM							
Flow of the transfer standard Q in m³/h	Relative error of the transfer standard e_r in %	Expanded uncertainty of measurement declared by laboratory $U_{lab}(e_r)$ in %	Expanded uncertainty of measurement extended by stability U_{TS} and linking $U(d_i)$ in %	d_i in %	En_i	u_{comp}/u_{lab}	CMC decision status
5,001	-0,662	0,08	0,084	-0,072	-0,849	0,685	acceptable
3,004	-0,401	0,08	0,088	-0,033	-0,372	0,686	acceptable
2,003	-0,147	0,08	0,089	-0,062	-0,688	0,687	acceptable
1,003	0,473	0,08	0,089	-0,021	-0,233	0,712	acceptable



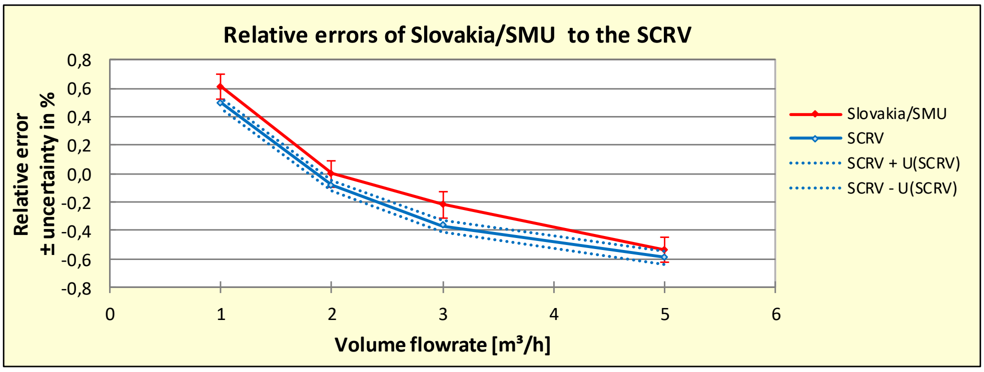
Lithuania / LEI							
Flow of the transfer standard Q in m³/h	Relative error of the transfer standard e_r in %	Expanded uncertainty of measurement declared by laboratory $U_{lab}(e_r)$ in %	Expanded uncertainty of measurement extended by stability U_{TS} and linking $U(d_i)$ in %	d_i in %	En_i	u_{comp}/u_{lab}	CMC decision status
5,049	-0,607	0,08	0,078	-0,017	-0,215	0,546	acceptable
3,034	-0,354	0,08	0,082	0,014	0,177	0,546	acceptable
2,009	-0,066	0,08	0,083	0,019	0,228	0,549	acceptable
1,008	0,477	0,08	0,083	-0,017	-0,206	0,550	acceptable



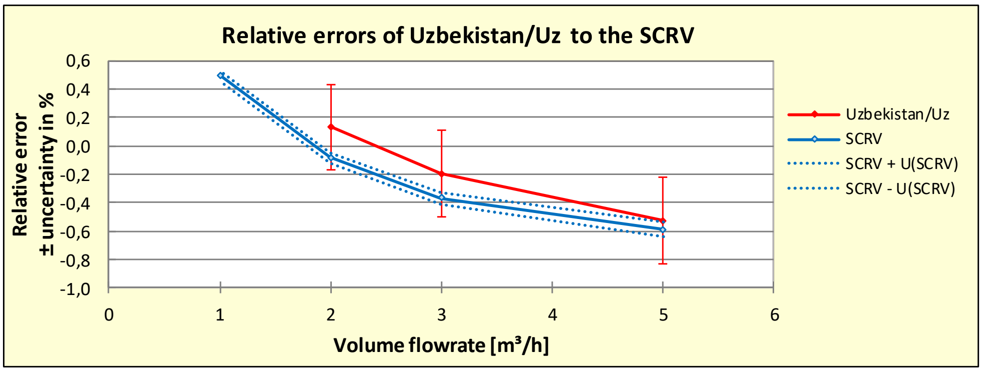
Russia / VNIIR							
Flow of the transfer standard Q in m³/h	Relative error of the transfer standard e_r in %	Expanded uncertainty of measurement declared by laboratory $U_{lab}(e_r)$ in %	Expanded uncertainty of measurement extended by stability U_{TS} and linking $U(d_i)$ in %	d_i in %	En_i	u_{comp}/u_{lab}	CMC decision status
5,003	-0,607	0,04	0,076	-0,119	-1,557	1,095	non-acceptable
3,001	-0,354	0,04	0,043	-0,018	-0,429	1,092	acceptable
2,000	-0,066	0,04	0,046	-0,037	-0,810	1,099	acceptable
1,000	0,477	0,04	0,046	-0,042	-0,899	1,103	acceptable



Slovakia / SMU							
Flow of the transfer standard Q in m³/h	Relative error of the transfer standard e_r in %	Expanded uncertainty of measurement declared by laboratory $U_{lab}(e_r)$ in %	Expanded uncertainty of measurement extended by stability U_{TS} and linking $U(d_i)$ in %	d_i in %	En_i	u_{comp}/u_{lab}	CMC decision status
5,073	-0,537	0,08	0,079	0,053	0,671	0,571	acceptable
3,055	-0,220	0,08	0,101	0,148	1,467	0,584	non-acceptable
2,063	-0,002	0,08	0,088	0,083	0,944	0,661	acceptable
1,032	0,610	0,08	0,084	0,116	1,392	0,560	non-acceptable



Uzbekistan / UzStandard							
Flow of the transfer standard Q in m³/h	Relative error of the transfer standard e_r in %	Expanded uncertainty of measurement declared by laboratory $U_{lab}(e_r)$ in %	Expanded uncertainty of measurement extended by stability U_{TS} and linking $U(d_i)$ in %	d_i in %	En_i	u_{comp}/u_{lab}	CMC decision status
4,991	-0,529	0,3	0,301	0,061	0,203	0,174	acceptable
3,001	-0,200	0,3	0,301	0,169	0,561	0,156	acceptable
2,001	0,130	0,3	0,301	0,215	0,715	0,149	acceptable



5.2 DN80 Transfer Package

5.2.1 Laboratory results

All data collected from the participating laboratories are summarized in the following tables and pictures.

Table 14: Relative errors $e_{r,i}$ (%) of the transfer standard obtained by the participating laboratories (Meter M1 DN80)

Flowrate in m³/h	**Germany PTB 2012** in %	**Belarus BelGIM 2011** in %	**Lithuania LEI 2010** in %	**Russia VNIIR 2011** in %	**Slovakia SMU 2010** in %	**Uzbekistan UzStandard 2010** in %
100	0,299	-	0,276	0,397	0,370	0,729
80	0,244	-	0,272	0,339	0,320	0,138
60	0,149	0,109	0,178	0,225	0,221	-0,225
40	0,026	-0,105	0,200	0,101	0,105	-0,128
30	-0,003	-0,130	0,107	-0,030	0,057	-0,407
20	0,026	-0,062	0,376	0,129	0,175	

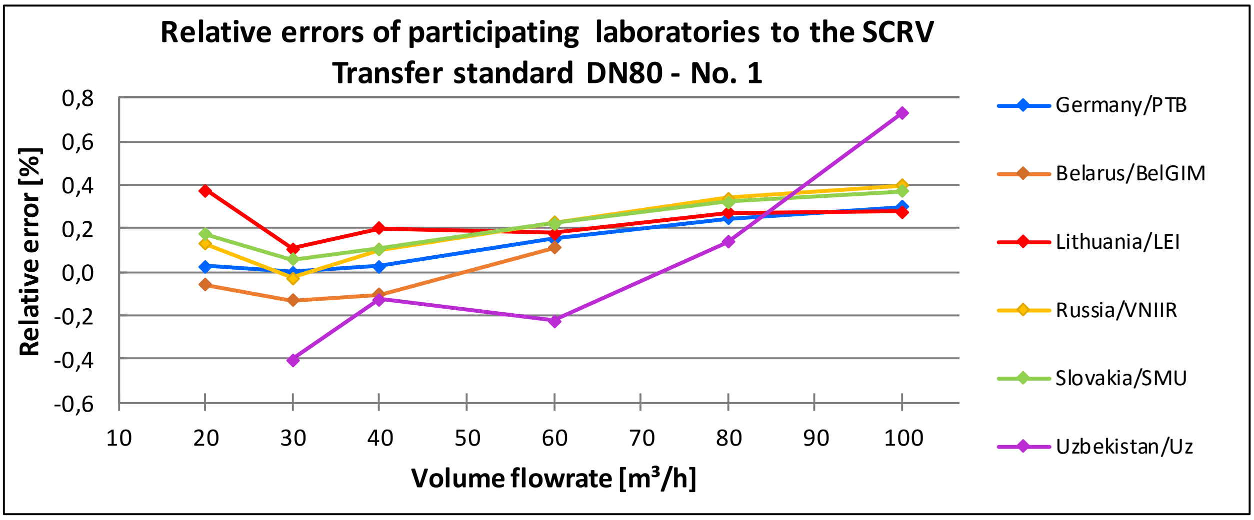


Fig. 23: Relative error $e_{r,i}$ of participating laboratories (Meter M1 DN80)

5.2.2 The SCRV and its uncertainty

The weighted mean e_{rSCRV} and its uncertainty $u(e_{rSCRV})$ was calculated based on the data from all of the laboratories. The results of $\frac{(e_{ri}-e_{rSCRV})^2}{u^2(e_{ri})}$ and consistency check are summarized in Table 15.

Table 15: Results of $\frac{(e_{ri}-e_{rSCRV})^2}{u^2(e_{ri})}$ for each participating laboratories (Meter M1 DN80)

Flow rate in m³/h	**Germany PTB 2012**	**Belarus BelGIM 2011**	**Lithuania LEI 2010**	**Russia VNIIR 2011**	**Slovakia SMU 2010**	**Uzbekistan UzStandard 2010**
100	0,566	-	0,905	0,436	0,059	4,049
80	0,438	-	0,045	0,503	0,159	0,415
60	0,034	0,448	0,045	0,827	0,581	5,472
40	0,215	4,267	3,318	0,386	0,366	1,238
30	0,044	2,057	2,458	0,0340	0,882	5,445
20	1,996	5,413	10,218	0,007	0,443	-

Table 16: Results of the chi-squared test at each flow

Flow rate in m³/h	**1. round**		
	χ^2_{obs}	$\chi^2(\nu)$	**Results of the chisquared test**
100	6,01	9,49	passed
80	1,56	9,49	passed
60	7,41	11,07	passed
40	9,79	11,07	passed
30	10,92	11,07	passed
20	18,08	9,49	failed

Based on the results of the highest value of $\frac{(e_{ri}-e_{rSCRV})^2}{u^2(e_{ri})}$, Lithuania (20 m³/h) in Table 15, were excluded for the next round of evaluation and the new reference value of e_{rSCRV}. The new standard uncertainty of the reference value $u(e_{rSCRV})$ and the chi-squared value χ^2_{obs} were recalculated, but without the values of the excluded laboratory. The revised results are given in *Table 17*, *Table 18* and *Fig. 24*.

Table 17: Results of 2nd calculation round for the chi-squared test at each flow without the values of the excluded laboratory

Flow in in m³/h	**2. round**		
	χ^2_{obs}	$\chi^2(\nu)$	**Results of the chisquared test**
100	6,01	9,49	passed
80	1,56	9,49	passed
60	7,41	11,07	passed
40	9,79	11,07	passed
30	10,92	11,07	passed
20	5,65	7,81	passed

Table 18: Key comparison reference values (SCRVs)

Flow in m³/h	e_{rSCRV} in %	$u(e_{rSCRV})$ in %
100	0,350	0,0361
80	0,289	0,0362
60	0,161	0,0326
40	0,057	0,0326
30	-0,017	0,0327
20	0,068	0,0368

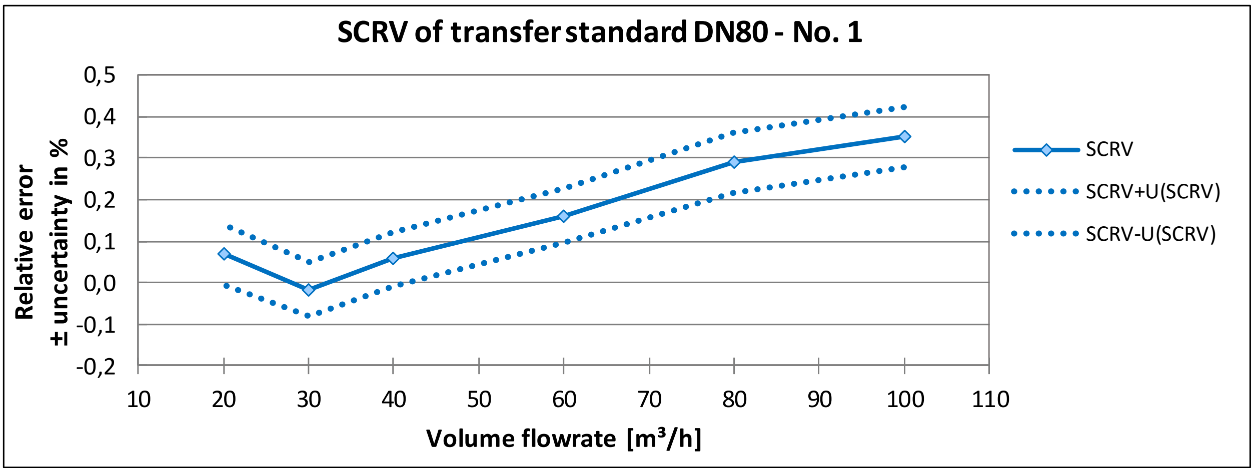


Fig. 24: *Suplementary comparison reference value and it`s expanded uncertainty U(SCRV)*

5.2.3 Summary

The degree of equivalence with the SCRV (En_i) is a measure of result agreement of each participating laboratory to the SCRV. The "lab to SCRV" values are summarized in *Fig. 25* the equivalence degrees of En_i in *Table 19*. All marked values of *Table 19* did not confirm to the discussions of the Chi²-test (section 0). This values were excluded from the calculation of all other not marked En-values.

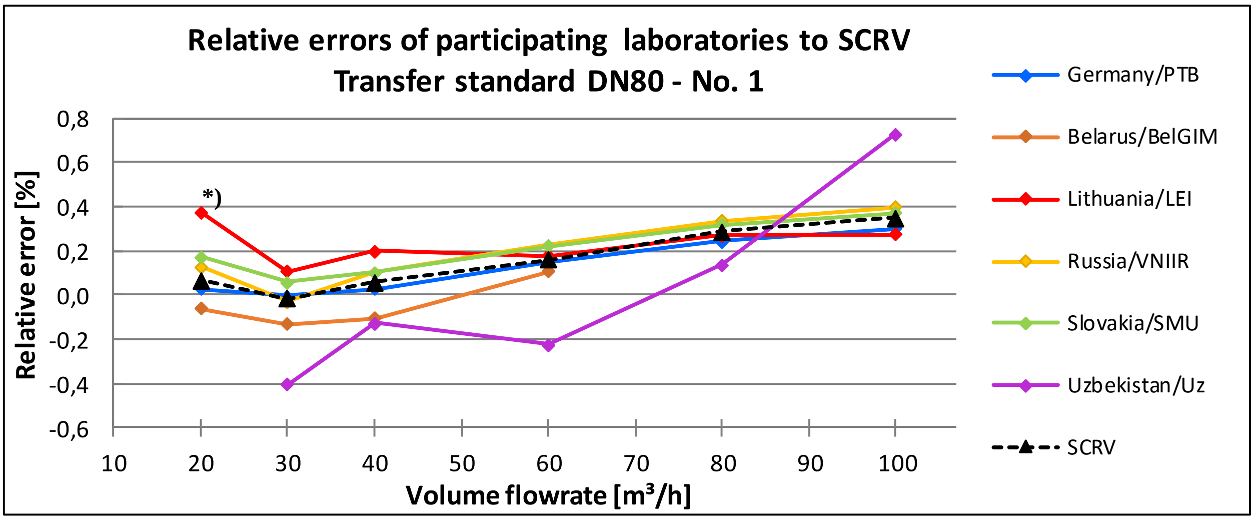


*Fig. 25: Relationship of lab results to the SCRV. The *) market value was excluded from SCRV-calculation*

*Table 19: Degree of Equivalence (E_n) to SCRV of all participated laboratories. The *-marked values do not contribute to the discussions of Chi²-test. This values were excluded from the caluculations of the other not marked E_N-values.*

Flow in m³/h	Germany PTB 2012	Belarus BelGIM 2011	Lithuania LEI 2010	Russia VNIIR 2011	Slovakia SMU 2010	Uzbekistan UzStandard 2010
100	-0,443		-0,535	0,384	0,137	1,025
80	-0,391		-0,120	0,414	0,225	-0,326
60	-0,105	-0,368	0,117	0,513	0,419	-1,193
40	-0,264	-1,135	1,001	0,351	0,333	-0,567
30	0,119	-0,788	0,861	-0,104	0,516	-1,190
20	-0,363	-0,924	1,763*	0,505	0,772	-

5.2.4 Test on conclusivity of the comparioson results

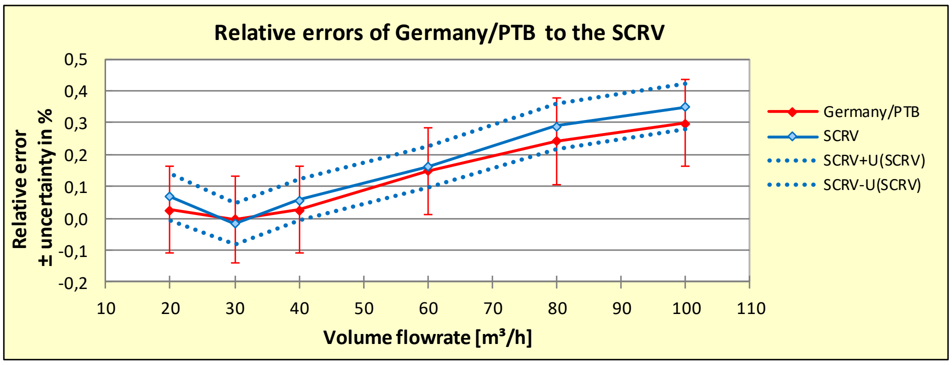
In accordance with the WGFF recommendation for comparison calculations (proposed by J. Wright, B. Mickan, M. Benkova, February 7, 2014), for a conclusive proof that the participant results are in agreement with the SCRV within its uncertainty claims, the comparison uncertainty ratio u_{Comp}/u_{Lab} should be < 2. The comparison ratios of Table 20 demonstartes the suitability of the used transfer meter (turbine meter M1 DN25) for the laboratories of Belarus, Lthuania, Slivakia and Uzbekistan only.

Table 20: Comparison ratios of u_{Comp}/u_{Lab} for each participated laboratory

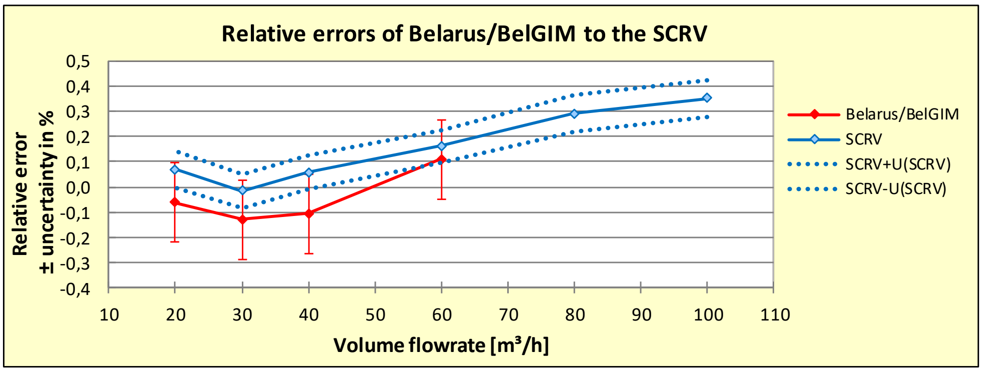
Flow in m³/h	**Germany** **PTB**	**Belarus** **BelGIM**	**Lithuania** **LEI**	**Russia** **VNIIR**	**Slovakia** **SMU**	**Uzbekistan** **UzStandard**
100	6,741		1,690	3,378	1,690	0,759
80	6,739		1,687	3,373	1,685	1,199
60	6,739	1,694	1,686	3,369	1,688	0,464
40	6,738	1,691	1,687	3,372	1,686	0,486
30	6,738	1,690	1,705	3,369	1,689	0,490
20	6,739	1,710	1,707	3,375	1,685	

5.2.5 Final CMC-descicion table

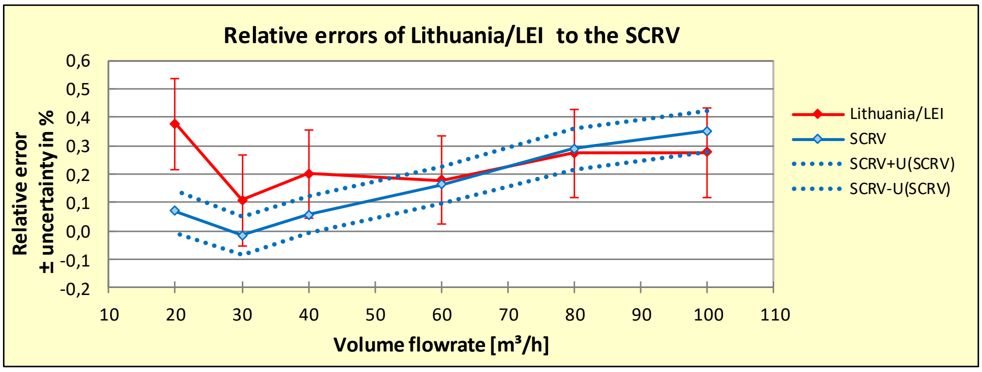
Germany / PTB_HDP							
Flow of the transfer standard Q in m³/h	Relative error of the transfer standard e_r in %	Expanded uncertainty of measurement declared by laboratory $U_{lab}(e_r)$ in %	Expanded uncertainty of measurement extended by stability U_{TS} and linking $U(d_i)$ in %	d_i in %	En_i	u_{comp}/u_{lab}	CMC decision status
99,462	0,299	0,02	0,116	-0,051	-0,443	6,741	inconclusiv
81,007	0,244	0,02	0,115	-0,045	-0,391	6,739	inconclusiv
60,452	0,149	0,02	0,120	-0,013	-0,105	6,739	inconclusiv
40,676	0,026	0,02	0,120	-0,032	-0,264	6,738	inconclusiv
30,118	-0,003	0,02	0,120	0,014	0,119	6,738	inconclusiv
20,073	0,026	0,02	0,115	-0,042	-0,363	6,739	inconclusiv



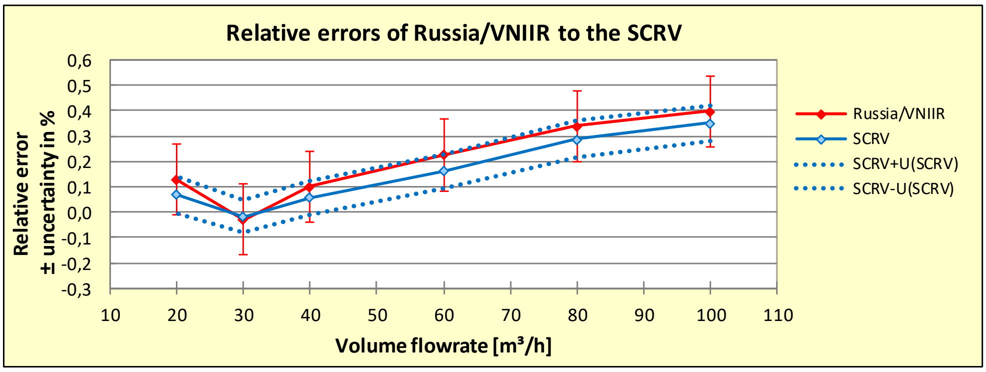
Belarus / BelGIM							
Flow of the transfer standard Q in m³/h	Relative error of the transfer standard e_r in %	Expanded uncertainty of measurement declared by laboratory $U_{lab}(e_r)$ in %	Expanded uncertainty of measurement extended by stability U_{TS} and linking $U(d_i)$ in %	d_i in %	En_i	u_{comp}/u_{lab}	CMC decision status
60,194	0,109	0,08	0,143	-0,053	-0,368	1,694	acceptable
39,990	-0,105	0,08	0,143	-0,162	-1,135	1,691	warning level
29,965	-0,130	0,08	0,143	-0,113	-0,788	1,690	acceptable
19,916	-0,062	0,08	0,140	-0,130	-0,924	1,710	acceptable



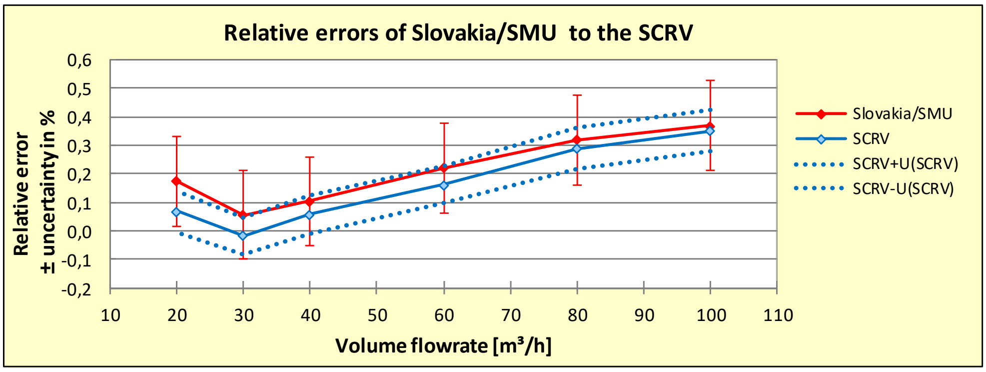
Lithuania / LEI							
Flow of the transfer standard Q in m³/h	Relative error of the transfer standard e_r in %	Expanded uncertainty of measurement declared by laboratory $U_{lab}(e_r)$ in %	Expanded uncertainty of measurement extended by stability U_{TS} and linking $U(d_i)$ in %	d_i in %	En_i	u_{comp}/u_{lab}	CMC decision status
100,401	0,276	0,08	0,140	-0,075	-0,535	1,690	acceptable
80,115	0,272	0,08	0,139	-0,017	-0,120	1,687	acceptable
60,689	0,178	0,08	0,143	0,017	0,117	1,686	acceptable
40,695	0,200	0,08	0,143	0,143	1,001	1,687	warning level
30,134	0,107	0,08	0,144	0,124	0,861	1,705	acceptable
20,113	0,376	0,08	0,175	0,308	1,763	1,707	non-acceptable



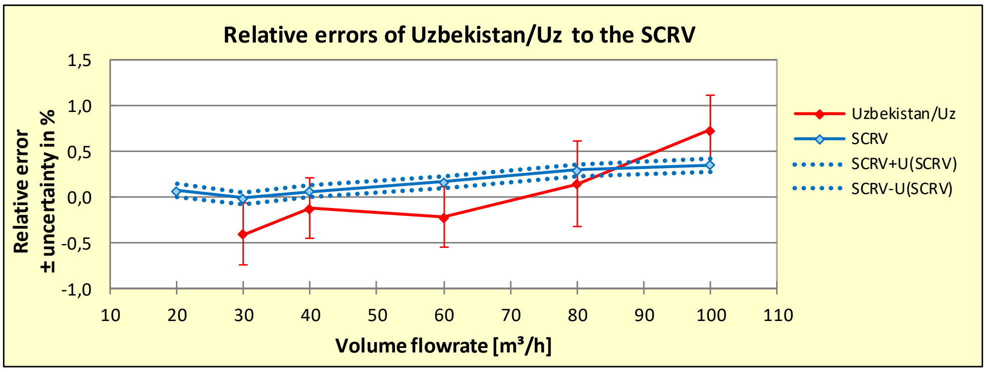
Russia / VNIIR							
Flow of the transfer standard Q in m³/h	Relative error of the transfer standard e_r in %	Expanded uncertainty of measurement declared by laboratory $U_{lab}(e_r)$ in %	Expanded uncertainty of measurement extended by stability U_{TS} and linking $U(d_i)$ in %	d_i in %	En_i	u_{comp}/u_{lab}	CMC decision status
99,931	0,397	0,04	0,121	0,047	0,384	3,378	inconclusiv
79,946	0,339	0,04	0,121	0,050	0,414	3,373	inconclusiv
59,934	0,225	0,04	0,125	0,064	0,513	3,369	inconclusiv
39,962	0,101	0,04	0,125	0,044	0,351	3,372	inconclusiv
29,983	-0,030	0,04	0,125	-0,013	-0,104	3,369	inconclusiv
19,971	0,129	0,04	0,120	0,061	0,505	3,375	inconclusiv



Slovakia / SMU							
Flow of the transfer standard Q in m³/h	Relative error of the transfer standard e_r in %	Expanded uncertainty of measurement declared by laboratory $U_{lab}(e_r)$ in %	Expanded uncertainty of measurement extended by stability U_{TS} and linking $U(d_i)$ in %	d_i in %	En_i	u_{comp}/u_{lab}	CMC decision status
106,044	0,370	0,08	0,140	0,019	0,137	1,690	acceptable
81,709	0,320	0,08	0,139	0,031	0,225	1,685	acceptable
62,550	0,221	0,08	0,143	0,060	0,419	1,688	acceptable
42,469	0,105	0,08	0,143	0,047	0,333	1,686	acceptable
31,383	0,057	0,08	0,143	0,074	0,516	1,689	acceptable
20,565	0,175	0,08	0,138	0,107	0,772	1,685	acceptable



Uzbekistan / UzStandard							
Flow of the transfer standard Q in m³/h	Relative error of the transfer standard e_r in %	Expanded uncertainty of measurement declared by laboratory $U_{lab}(e_r)$ in %	Expanded uncertainty of measurement extended by stability U_{TS} and linking $U(d_i)$ in %	d_i in %	En_i	u_{comp}/u_{lab}	CMC decision status
99,510	0,729	0,3	0,370	0,379	1,025	1,690	warning level
80,581	0,138	0,3	0,463	-0,151	-0,326	1,685	acceptable
60,026	-0,225	0,3	0,324	-0,387	-1,193	1,688	warning level
39,942	-0,128	0,3	0,327	-0,186	-0,567	1,686	acceptable
30,109	-0,407	0,3	0,328	-0,390	-1,190	1,689	warning level



APPENDIX A. General description and uncertainty budget of participating NMIs

In this appendix, the general description and the uncertainty budget of each participating NMI in order of testing schedule are present. Each part is taken from the document submitted by the participants and has not been edited by the pilot lab.

A.1. PTB, Germany

The comparison tests were made using two water flow facilities.

A.1.1. Hydrodynamic test field

The PTB hydrodynamic test field represents the national primary standard for the realization of the measurands volumetric and mass flow rate as well as the total volume and mass of flowing liquids with water being used as a test fluid. The facility has been designed for calibrating flowmeters with a nominal diameter range from DN 20 to DN 400, and a flow range from 0.3 to 2100 m³/h[3]. The realization of the measurands comprises an expanded measurement uncertainty of 0.02 % for totalized mass or volume and 0,04 % for mass flowrate or volume flowrate . Figure A.1 shows a simplified diagram of the liquid flow primary standard and Table A.1 describes the metrological characteristics of the facility. In principle it is a combined gravimetric-volumetric test rig, comprising diverter-weighing systems and a pipe prover, which can be used separately or together for comparison purposes.

Table A.1. Technical data and calibration capabilities:

Measurands:	Volume flowrate Mass flo rate Volume (totalized) Mass (totalized)	Flowrate meters *and* Volume and mass flow totalizing meters
Calibration modes:	a) flying START & FINISH b) standing START & FINISH	*Operation control via:* Diverter ON/OFF valve
Reference standards:	Gravimetric calibration Volumetric calibration	Balances: 30 t 3 t 0.3 t Pipe prover (reference volume: 250 l, 1.6 ... 1600 m³/h)
Operation modes:	Via constant-head tank Pump direct operation	Constant pressure in calibration line (approx. 0.35 MPa) Variable pressure in calibration line (max. approx. 0.6 MPa)
Meter / pipe sizes:	Calibration line A Calibration line B	DN 200 ... DN 400 DN 20 ... DN 150
Ranges of flow rate:	Calibration line A Calibration line B	3 m³/h ... 2100 m³/h 0.3 m³/h ... 320 m³/h
Pressure range:	0.2 MPa ... 0.6 MPa	(pump direct operation)
Adjustable temperature range:	20 °C ... 23 °C	(via constant-head tank)
Expanded measurement uncertainty:	± 0.02 % for mass or volume ± 0.042 % for mass flowrate or volume flowrate	(via constant-head tank)
Further plant items:	Storage tank Constant-head tank	380 m³ capacity 30 m³ capacity

[3] W. Poeschel, R. Engel, The concept of a new primary standard for liquid flow measurement at PTB Braunschweig. *Proceedings, the 9th International Conference on Flow Measurement* FLOMEKO'98, p. 7-12, Lund, Sweden, 1998.

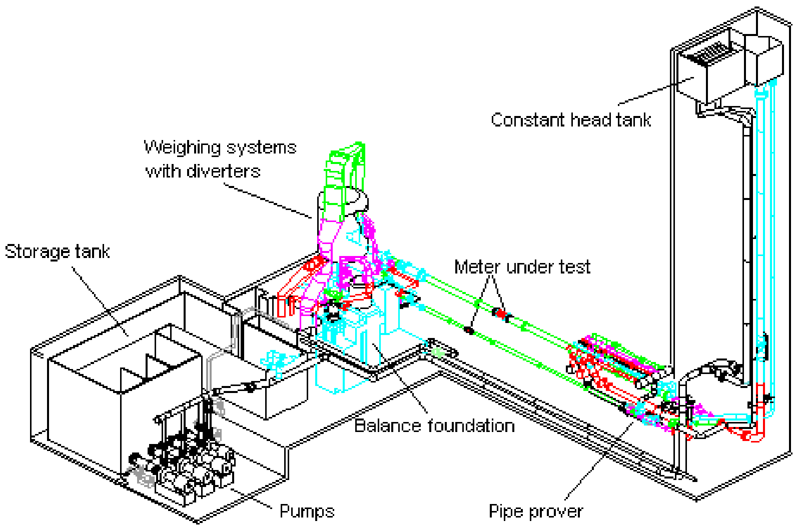


Figure A.1. Setup of the Hydrodynamic Test Field (without building)

For generating and stabilising flow rates, the supply system has a 200 m³ storage tank, a set of four pumps (all frequency controlled), a constant head tank (30 m³, at a height of 30 m) and two measuring sections A and B (see Table A.1). For each diameter an upstream straight pipeline with a length of 50D and downstream of 20D is available. All pipe work and valves are made of stainless steel. The pressure in the measuring section is between 1.5 and 3 bars when using the constant head tank, whereas the pressure is adjustable up to 5 bars when the direct pumping mode is used. The liquid temperature is adjusted and controlled by a heat exchanger.
The gravimetric measurement part consists of three pipelines with diverter and balance, thermometer and a density meter:

1. Diverter DN 400 for 24 ... 2100 m³/h, a weighing system with measuring range from 3,000 to 30,000 kg and a resolution of 10 g,
2. Diverter DN 150 for 3 ... 320 m³/h, a weighing system with measuring range from 300 to 3,000 kg and a resolution of 1 g,
3. Diverter DN 50 for 0.3 ... 30 m³/h, a weighing system with measuring range from 30 to 300 kg and a resolution 0.1 g.

For this comparison only the gravimetrical part of the standard is used (Figure A.2).

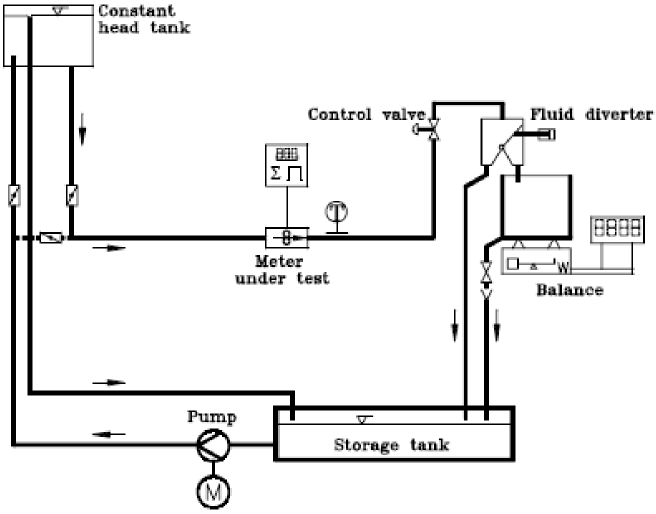


Figure A.2. Gravimetric part of the standard

Uncertainty contributions of the different parts of the facility are presented in Table A.2.[4]

Table A.2 Measurement uncertainty budget of the water flow calibration facility for the case of mass or volume measurement

Sources of uncertainty	***Relative standard uncertainty [%]***	
Mass		2,09E-03
Buoyancy		2,19E-05
Temperature of water		6,90E-04
Density of water		3,31E-03
Time (measurements/diversion)		2,31E-05
Diverter timing error		7,99E-03
Interconnecting piping volume		1,02E-04
Repeatability		3,50E-03
u_c	Combine uncertainty	0,010
U	Expanded Uncertainty (k=2)	0,019

A.1.2. Experimental water meter test facility

The experimental water meter test facility is a gravimetric liquid flow primary standard for the realization of the measurands volumetric and mass flowrates as well as total volume and mass of flowing liquids. The facility is capable of calibrating flowmeters within the diameter range from DN 25 to DN 50, and a flow rate range from 0.02 to 35.0 m³/h with water being used as a test fluid. Expanded measurement uncertainty of 0.05 %. The scheme of this facility is depicted in Figure A.2.
Figure A.3 shows a general view of the primary standard, and Table A.3 gives the metrological specifications of the facility.

[4] R. Engel, Modeling the uncertainty in liquid flowmeter calibration and application - Requirements and their technical realization for PTB's national water flow standard. 13th SENSOR Congress 2007, Nürnberg, Germany, May 22-24, 2007.

Table A.3. Technical data and calibration capabilities:

Measurands:	Volumetric flow rate Mass flow rate Volume (totalized) Mass (totalized)	Flow-rate meters *and* Volume and mass flow totalizing meters
Calibration modes:	a) flying START & FINISH b) standing START & FINISH	*Operation control via:* Diverter ON/OFF valve
Reference standards:	Gravimetric calibration	Balance: 150 kg (resolution 1 g)
Operation modes:	Via constant-head tank Pump direct operation	Constant pressure in calibration line (approx. 0.3 MPa) Variable pressure in calibration line (max. approx. 0.6 MPa)
Meter / pipe sizes:	Calibration line A Calibration line B	DN 25 DN 50
Ranges of flow rate:	Calibration line A Calibration line B	0.02 m^3/h ... 10.0 m^3/h 0.04 m^3/h ... 35.0 m^3/h
Pressure range:	0.2 MPa ... 0.6 MPa 0.3 MPa	(pump direct operation) (via constant-head tank)
Adjustable temperature range:	20 °C ... 23 °C	(via constant-head tank)
Expanded measurement uncertainty:	± 0.05 %	(via constant-head tank)
Further plant items:	Storage tank Constant-head tank	4.5 m^3 capacity 1.5 m^3 capacity

Figure A.3. General view of the facility and its calibration lines

A.3. National standards Centre of the Republic of Uzbekistan, Republic of Uzbekistan

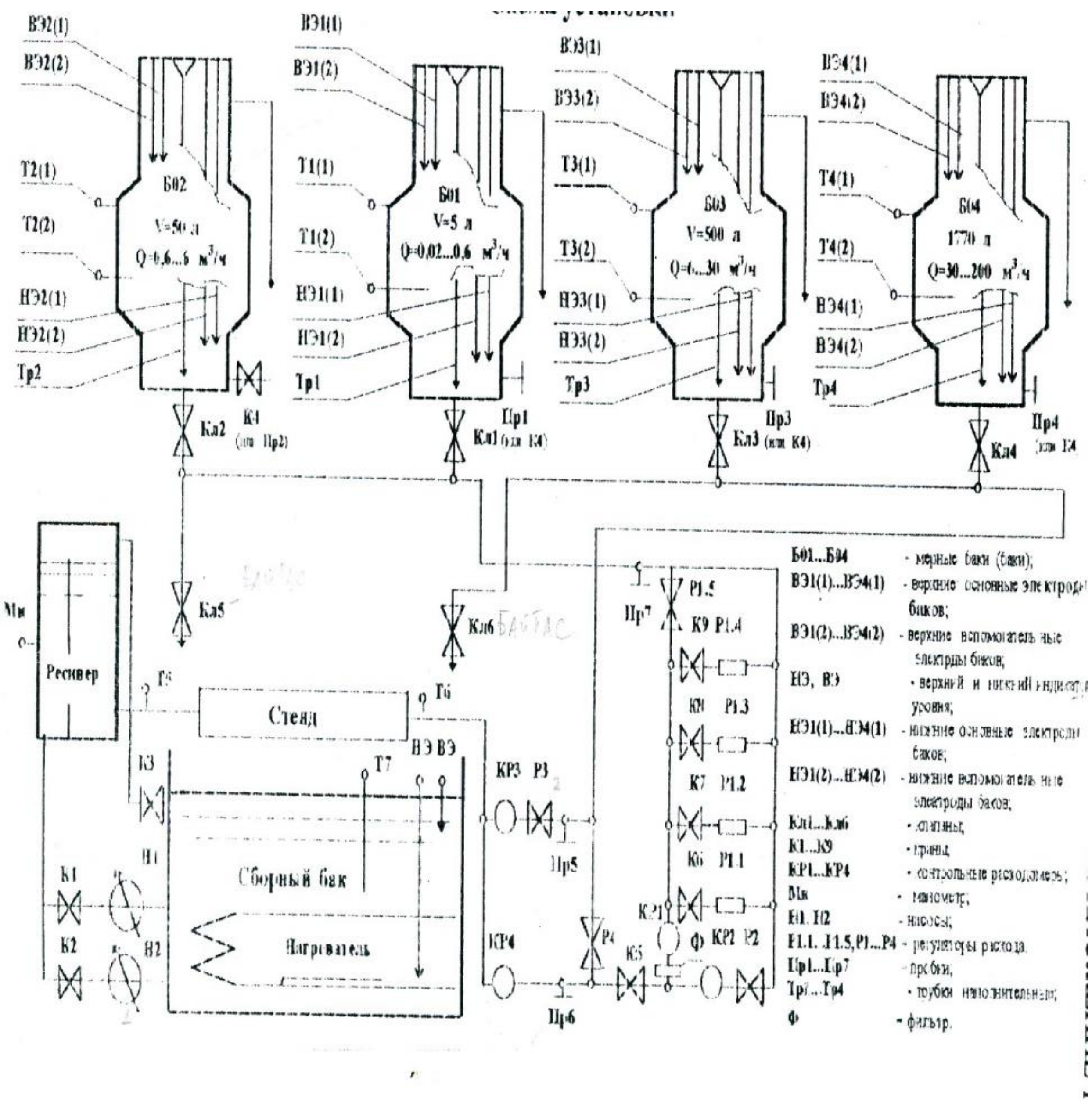


Figure A.9. Scheme of the test rig of National standards Centre of the Republic of Uzbekistan

Figure A.10. The facility of National standards Centre of the Republic of Uzbekistan

A.4. LEI, Lithuania

Table A.6 Technical parameters of flow facility of LEI

Parameter			Specifications
Mass flow (qm)			0.01 - 100 000 kg/h
Volume flow (qv)			0.01 - 100 000 l/h
Pipe dimension (DN)			Line №1 max. 100 mm
			Line №2 max. 50 mm
Water temperature - medium			18°C – 25 °C (50°C)- not accredited
Reservoir tank			10 m^3
Scales			1500 kg + 60 kg (Line №1)
			600 kg + 60 kg (Line №2)
Straight pipe length upstream			4.0 m (Line №1)
			1.0 m (Line №2)
Length of working zone			2.0 m (for bought lines)
Calibration principle	Calibration using mass and time (primary)	Flying start-stop with the use of a diverter	YES
		Standing start-stop	YES
	Calibration with a reference meter (secondary)	Flying start-stop with the use of a diverter	YES
		Standing start-stop	YES

Figure A.11. Water flow laboratory of LEI

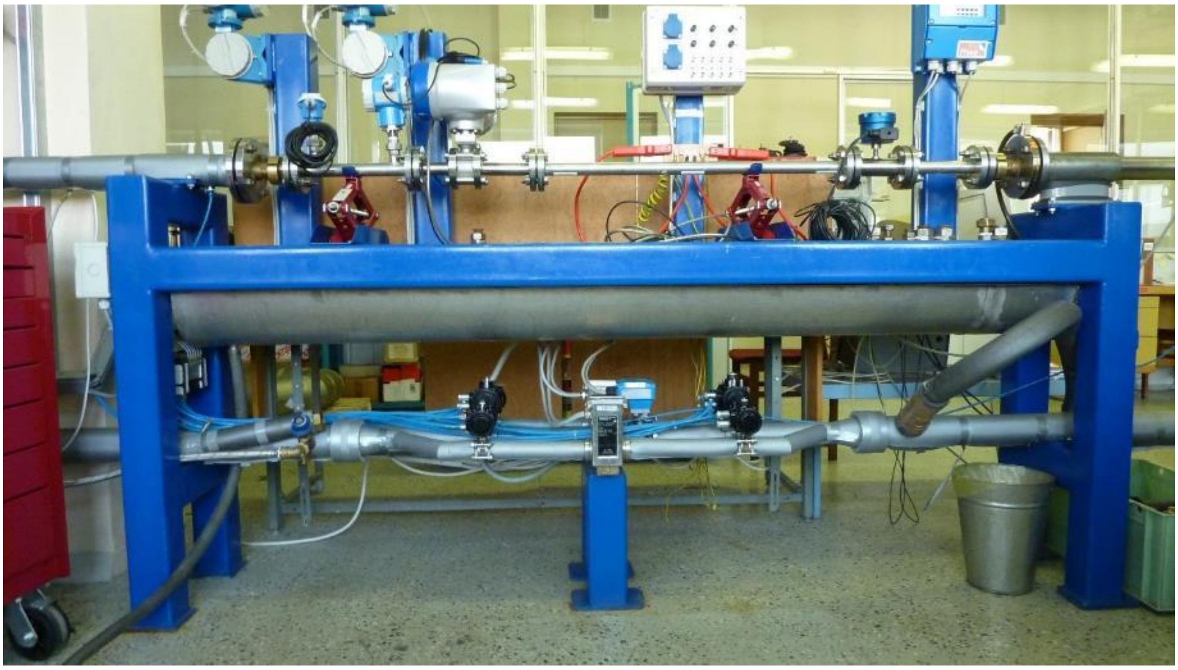


Figure A.12. Installation of the meter in LEI

A.5. SMU, Slovakia

Facility description

Establishment of the national standard of flow-rate and of delivered volume of water is constructed taking into consideration the requirements for quality system and requirements for possibility of measuring instruments tests. These tests are based on the different measuring principles with requirement to use different measuring methods (weighing or volumetric with flying or fixed starts with direct reading of impulses or a method of complete impulses). Also measuring instruments with mechanical counter, passive impulse output and active impulse output can be used. The device is composed of the following parts - source of flow-rate with a system of overflow tank, measuring lines – small and medium measuring lines, flow-meter branches, 3 different weighing systems and controlling system of measurement.

The main parameters of equipment are:
Measuring range of flow rate: (0,006 - 250) m3/h
Connecting diameter: DN 10 - DN 150
Minimum of testing delivered volume: 3 dm^3
Maximum of testing delivered volume: 5 000 dm^3
Water temperature: (10 - 85) °C
Expanded uncertainty of measurement (k=2): (0,05 - 0,20)%

Figure A.13. View at the national standard of flow-rate and delivered volume of water SMU, Slovakia

A.6. BelGIM, Belarus

General description

The reference standard for flow measurements is a hydrodynamic test installation (hereinafter referred to as installation) for realizing and measuring mass and volume flow rates and for determining totalized mass and totalized volume of liquid. The working liquid is piped water. This installation was designed for tests and calibrations on liquid flow-rate meters with primary transducer sizes from DN 10 to DN 50 across the mass flow range from 1 kg/h to 60000 kg/h and volumetric flow range from 0,001 m^3/h to 60 m^3/h, respectively. The tapers to fit DN 80 from DN 50 were fabricated specially for this comparison.
The expanded uncertainty, U (k=2, p=95 %) of installation is as follows: as for mass flow measurement of water: 0,024 % in the range from 60 000 kg/h to 10 kg/h inclusive and 0,058 % in the range from 10 kg/h to 1 kg/h. as for volumetric flow measurement of water: 0,025 % in the range from 60 m^3/h to 0,01 m^3/h inclusive and 0,060 % in the range from 0,01 m^3/h to 0,001 m^3/h.
The principle of measurement is based on weighing method. The system includes two test lines located on the bench, three weighing machines, four diverters and three branches for metering and adjusting the current flow-rate (using mass flow meters).
The most parts of installation are in the laboratory itself with the flow generator located in the special basement room beneath the laboratory floor level and the constant level head tank with weirs located some 6 m above the ground level as shown in figure A.14.
The flow laboratory is equipped with an automatic climate control system (automatic ventilation, air-conditioning and external air heating) which is managed via a microcontroller based on measurement data on temperature and humidity of external air in the laboratory.
The figure A.15 shows a simplified diagram of the installation and Table A.7 gives its basic specifications.

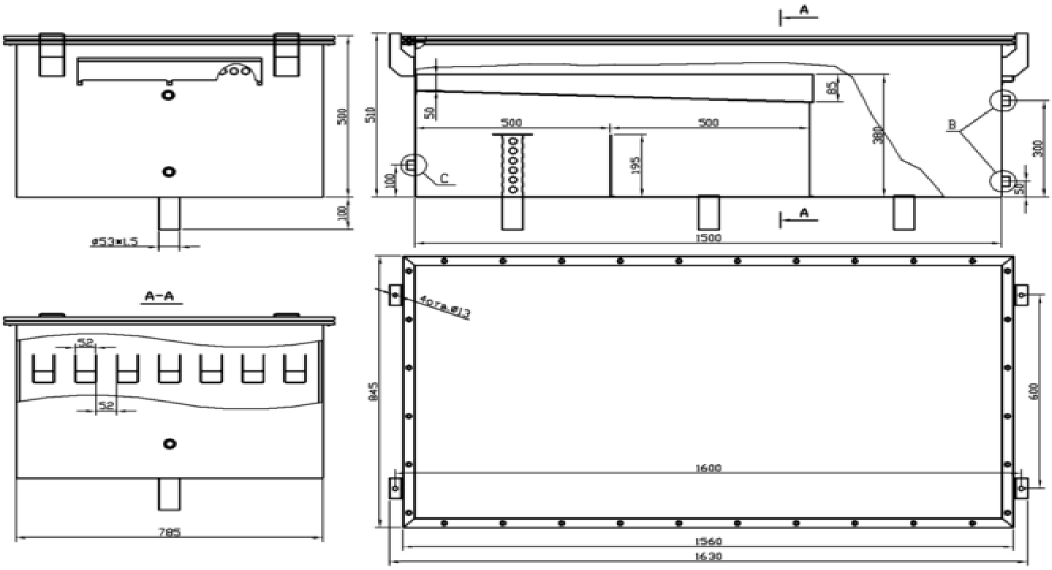


Figure A.14 - Constant level head tank of the installation

Table A.7. Specifications

	Volumetric flow rate Mass flow rate Volume (totalized) Mass (totalized)	Flow rate meters/ mass and volumetric flow meters
Tests and calibrations can be performed by the following methods:	Static weighing method (ISO 4185): a) start and finish method based on predetermined level of measurand synchronized by diverter; b) start and finish method based on predetermined time interval synchronized by diverter; c) start and finish method based on predetermined level of measurand synchronized by the device under test; d) start and finish method based on predetermined time interval synchronized by the device under test. Method by direct comparison with reference device: a) start and finish method based on predetermined level of measurand synchronized by the reference device; b) start and finish method based on predetermined level of measurand synchronized by the device under test;	Weighing machines: 600 kg 60 kg 15 kg Mass flow meters: from 60000 kg/h to 2000 kg/h from 2000 kg/h to 200 kg/h from 200 kg/h to 1 kg/h
Mode of operation:	a) using pump system b) using constant level head tank	a) Pressure level in the measuring section (up to 1,2 MPa) b) Constant pressure level in the measuring section (up to 0,06 MPa)
Size of the primary transducers of the devices under test	Test line 1 Test line 2	DN 50 to DN 32 DN 10 to DN 25
Flow rate range:	Test line 1 Test line 2	60 000 kg/h to 1 kg/h 60 m^3/h to 0,001 m^3/h 30 000 kg/h to 1 kg/h 30 m^3/h to 0,001 m^3/h
Working pressure range:	0,6 MPa to 1,2 MPa 0 MPa to 0,06 MPa	(if pump system is used) (if constant level head tank is used)
Water temperature range:	+ 20 ^{0}C to + 25 ^{0}C	

Expanded uncertainty of measurement (k=2, P=95%):	0,024% 0,058% 0,025% 0,060%	For mass flow-rate: a) in the range from 60000 kg/h to 10 kg/h inclusive b) in the range from 10 kg/h to 1 kg/h For volume flow-rate: a) in the range from 60 m^3/h to 0,01 m^3/h inclusive b) in the range from 0,01 m^3/h to 0,001 m^3/h
Other parameters:	Capacity of water storage vessel Constant level head tank Damping tank	5,22 m^3 a) total capacity: 0,59 m^3 b) constantly filled to: 0,31 m^3 0,64 m^3
Ambient air temperature range:	+ 20 ^{0}C to + 25 ^{0}C	Automatic climate control system (maximum variation of ambient air temperature during a one measurement run: ±0,2 °C)

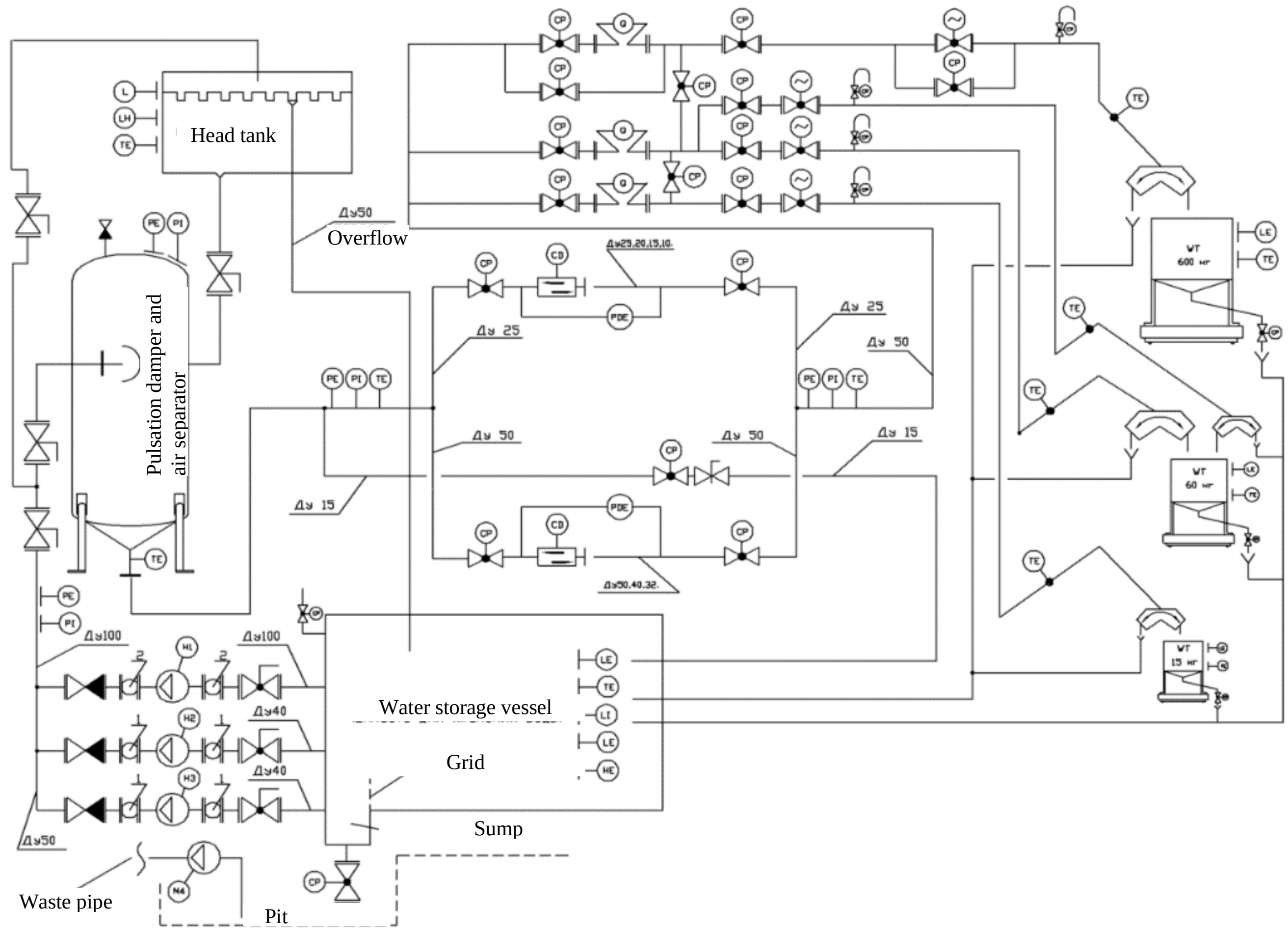


Figure A.15. Diagram of the installation

The stable metrological performance and good uncertainty in any particular flow range are achieved due to the availability of three different weighing machines connected in parallel (see Table A.8) and possibility to direct the water flow from each of two test lines to each of three weighing machines using any of four diverters. Four lines used to divert and adjust the flow, each having different length, ensure that the target flow-rate can be accurately adjusted and also allow for the amount of water in the pipe between the device under test and the weighing tank to be minimized. The system is designed in such a way that leaks can be detected. In order to be able to control and maintain a steady flow rate of water, the test lines are provided not only with the closed loop frequency-controlled drives in which switchable feedback device for flow rate/pressure is used but also with flow controllers based on closed loop variable electromagnetic valves with square-law characteristic and feedback for valve position. Also, there are automatically controlled variable electromagnetic valves installed upstream of the diverters which allow to maintain the steady pressure of water at the exit of test line (using software). The installation includes a damping tank which serves both as an equalization chamber to still the hydraulic pulsations of the flow and as a water deaerator (enables air to be separated and removed from the hydraulic channel).
All parts of the installation (pipes, weirs, tanks, water storage vessel etc.) except for the overflow pipe are made of stainless steel. The sections of piping which are located beneath the floor of the laboratory have double thermal isolation. The water storage vessel is filled and discharged using a remote control system (including pump, variable valves and pipes for filling and discharging

(draining) of the water) and also incorporates measuring instruments to measure temperature, level and water quality (electric conductivity).

Table A.8. The basic characteristics of the weighing machines.

Weighing machine	Maximum capacity, kg	Resolution, g	Nominal volume of the weighing tank, cm^3	Nominal size of the diverter, mm
1	600	1	600	DN50
2	60	0,1	60	DN10, DN25
3	15	0,01	10	DN6

The control system of the installation is designed to ensure that the measurement results are adequate and target uncertainty is achieved.
The complete data on flow measurements, status of controls and variable frequency drive control devices and environmental conditions is recorded and stored by the server of automatic system.
The measurement procedures can be chosen using a menu of the special software for PC.
Gravimetric part of the installation consists of four diverters (see fig. A.15). They are used to divert the flow either to the weighing tanks or to the by-pass which transports the water to the storage vessel.

Specifications of the diverter No1:

- Crossover valve DN 50;
- Range of the flow-rates diverted to the weighing machine No1 having capacity from 600 kg to 50 kg: 60 m^3/h to 5 m^3/h.

Specifications of the diverter No2:

- Crossover valve DN 25;
- Range of the flow-rates diverted to the weighing machine No2 having capacity from 60 kg to 5 kg: 7 m^3/h to 0,7 m^3/h.

Specifications of the diverter No3:

- Crossover valve DN 10;
- Range of the flow-rates diverted to the weighing machine No2 having capacity from 60 kg to 5 kg: 0,8 m^3/h to 0,05 m^3/h.

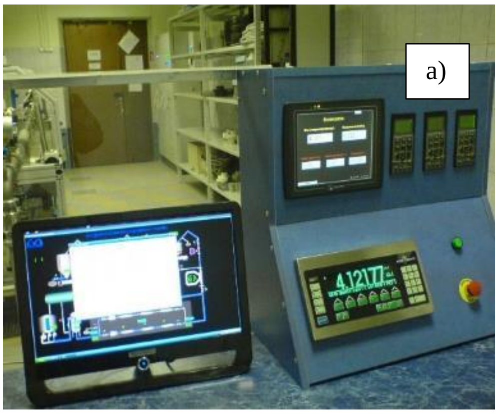
Specifications of the diverter No4:

- Crossover valve DN 6;
- Range of the flow-rates diverted to the weighing machine No3 having capacity from 10 kg to 0,1 kg: 0,08 m^3/h to 0,001 m^3/h.

This comparison used two test lines (No 1 and 2), three diverters (No 1 to 3) and two weighing machines No 1 and 2.
The standard uncertainties of various components of the total uncertainty of the installation for the volumetric flow rate are given in Table A.9.

Table A.9. Uncertainty budget

Sources of uncertainty	*Relative standard uncertainty [%]*	
	60 m^3/h to 0,01 m^3/h	0,01 m^3/h to 0,001 m^3/h
Mass	1,016E-02	2,657E-02
Buoyancy	2,725E-05	8,496E-05
Density of water	1,259E-03	1,259E-03
Time of measurement	5,034E-05	8,346E-05
Diverter	1,758E-03	1,758E-03
Volume of connecting pipe circuit	6,855E-06	5,215E-07
Volume of air dissolved in the water	4,340E-07	3,434E-08
Volume of water in the section between the test line and diverter	6,533E-04	2,090E-05
Water evaporation in the weighing tank during the measurement time	8,087E-13	9,705E-15
Output channels of the devices under test	1,592E-06	1,592E-06
Repeatability	6,948E-03	1,403E-02
Combined standard uncertainty, u_c	*0,0125*	*0,030*
Expanded uncertainty, U (k=2)	*0,025*	*0,060*



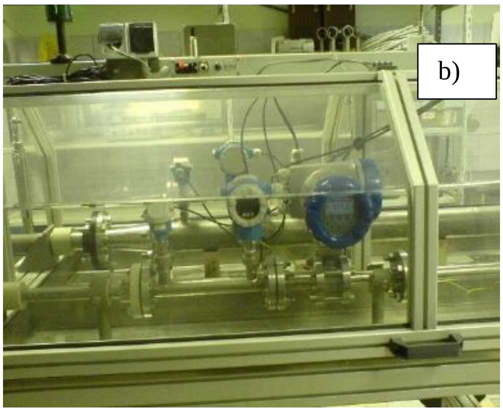
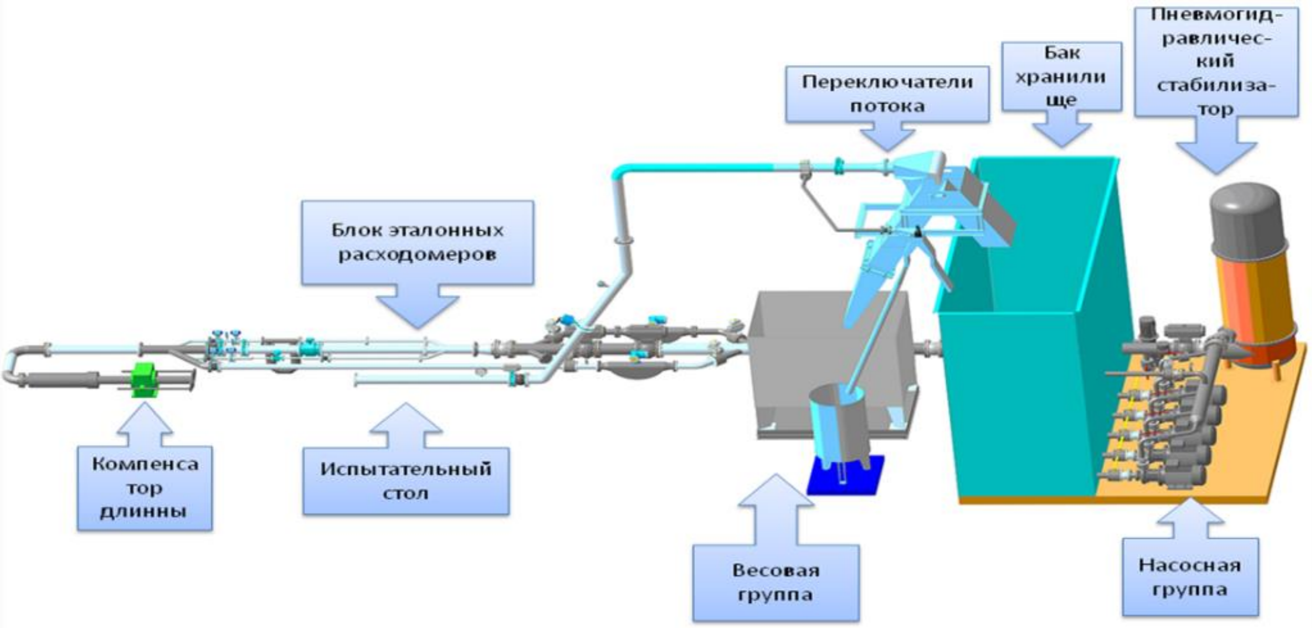


Figure A.16. a) Control panel and b) Bench with test lines

A.7. Federal state unitary enterprise "All-Russian scientific and research institute of flow measurement" (FGUP VNIIR), Russia

A.7.1. The national primary standard of the unit of mass liquid flow ГЭТ 63.

The national primary standard of the unit of mass liquid flow is intended for the reproduction and storage of the unit of mass liquid flow. Water is used as the operating medium.
This standard is intended for verification and calibration of measuring instruments with nominal diameter DN 25-150 in the flow range of 2.5 – 250 t/h. The diagram of the standard is presented in Picture A.17.



Picture 1A.17

The standard is located in closed room where the following ambient conditions are kept constant:
- air temperature 15-25 ^{0}C;
- relative humidity 30-80%;
- atmospheric pressure 98 - 106 kPa.

At the reproduction of the unit of the mass flow the following parameters of the measured medium (water) are kept constant:
- temperature, °C 15 ÷ 25;
- excessive pressure, MPa 0,1 ÷ 0,4

The reproduction of the unit of the average mass flow by the standard is based on static measurement of the liquid mass which passed through verified (calibrated) measuring instrument and which flew into weigh tank for a fixed period of time.
The circulation of water in hydraulic system is provided by a pump unit consisting of 5 pumps, the capacity of each is 120 m3/h and two pumps having capacity of 30 m3/h and 5 m3/h respectively.
The water from storage tank is discharged into pneumohydralic flow stabilizer and after the stabilizer the flow is directed into the measuring lines of working standards. The bench accommodating verified (calibrated) flowmeters with replaceable runs is mounted in series with

measuring lines of working standards. The replaceable runs are chosen by DN of verified flowmeters (25 – 150). For mounting of flowmeters of different length the bench is equipped with expansion joint and a sump for collection and drain of water into storage tank during removal of verified (calibrated) flowmeters. After the bench there is a flow control unit used for setting of flow in hydraulic loop. Two flow diverters are located behind the flow control unit. Flow diverters are equipped with Hall sensors for flow averaging interval indication.
The diverters direct the flow in one of weigh tanks mounted on the weight platform. After filling of weigh tanks the flow is directed into a transfer tank and from it by a pump into the storage tank.
Automated control system of the standard is intended for collection and processing of the measument information from weighing system, standard flow transducer, tested measuring instruments, flow diverters, water temperature and pressure trasnducers, for generation of control signals for flow diverters and flow-setting unit. The operation algorithm of automated control system provides for the calculation of mass flow measured by the standard and tested instrument, the forming of research protocols, verification and calibration and printing out of measurement results.
Parameters of ambient contions – air tempereture and humidity are controlled by humidity and temperature meter of ИВТМ-7 МК-С-2А type.

A.7.2. The national primary special standard of the unit of volumetric and mass water flow ГЭТ 119.

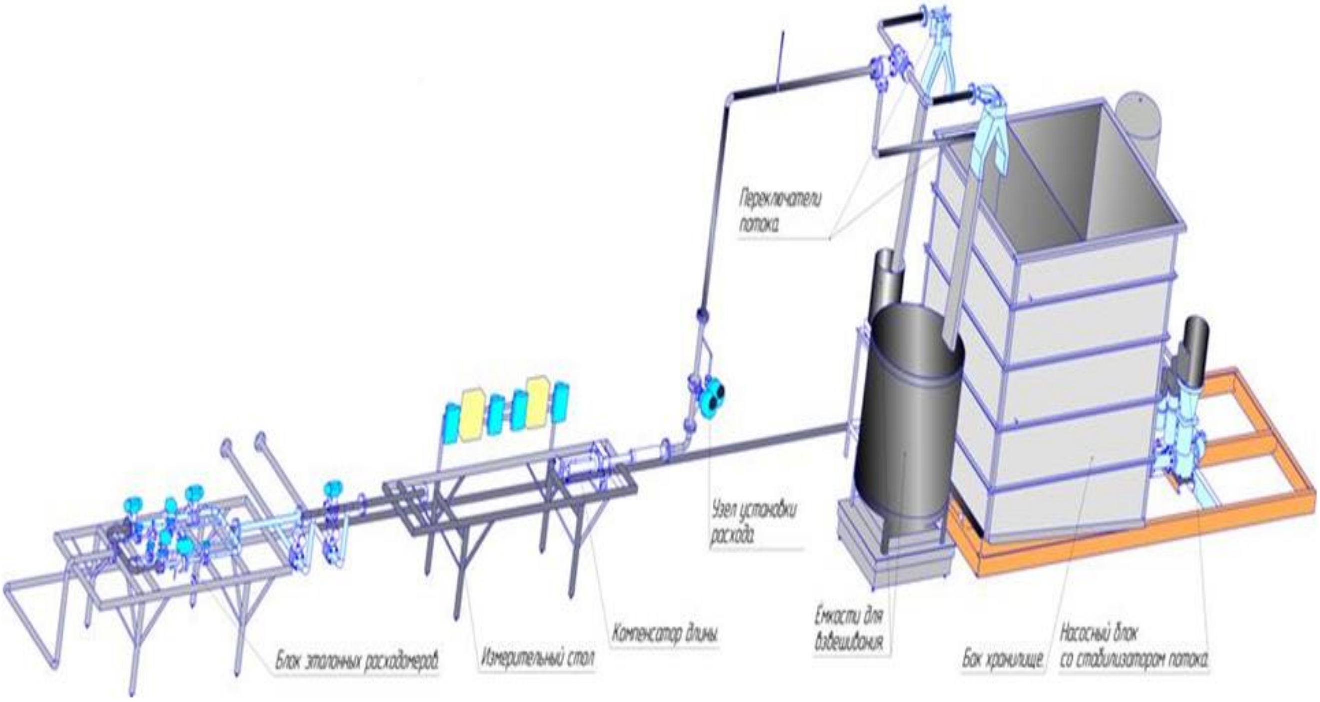
The national primary special standard of the unit of volumetric and mass water flow is intended for reproduction and storage of units of volumetric and mass water flow.
This standard is intended for verification and calibration of measuring instruments DN 10 – DN 50, and the range of flow 0.01 - 50 t/h (0.01 - 50 m3/h).
The standard is placed in closed room where the following climatic conditions are kept constant:

- air temperature 15 - 25 ^{0}C;
- relative humidity 30-80%;
- atmospheric pressure 98-106 kPa.

At reproduction of the unit of mass flow the following parameters of measured medium (water) are kept constant:

- temperature, °C 15 ÷ 25;
- excessive pressure, MPa 0,1 ÷ 0,4

The diagram of the standard is presented in Picture A.18.



Picture A.18

The design of water storage and water supply system ensure water circulation in hydraulic loop. Water from the storage tank by pump НЦ1 at the flowrate of 0.01-1.0 m3/h (by pump НЦ2 at the flowrate of 1.0-5.0 m3/h; by pump НЦ3 at the flowrate of 5.0-50.0 m3/h) is delivered into pressure and flow stabilizer. A bypass line is mounted after pumps and nonreturn valves – a part of water through an open valve returns back to the storage tank.

After the flow stabilizer water flows into measuring lines of standard flowmeters. The test bench accomodating verified (calibrated) flowmeters with changeable runs for mounting of tested measuring instruments is located in series with measuring lines of standard flowmeters.

Changeable runs are chosen by DN of verified (calibrated) measuring instruments (from 10 to 50 mm). The lengths of straight runs of changeable pipelines is at least 10 DN upstream and downstream of tested measuring instruments.

The test bench is equipped with a length compensator for mounting of tested measuring instruments, a sump and a drain system for collection and drain of water into the storage tank during mounting and removal of verified (calibrated) measuring instruments.

The parameters of measured medium are controlled by pressure transducers and a temperature transducer. The required value of water flowrate through the tested instrument is ensured by flow-setting unit. A butterfly valve and electrically driven ball valve ensuring regulation of flow in automatic and manual mode are used as flow regulators.

After the test bench the water flows to flow diverters, which are operated by the rod of pneumatic actuator mounted on their axis. The pneumatic actuator accomodates Hall sensors generating signals that determine the time interval for measuring the mass of water at filling the weigh tank with water).

Flow diverters direct the flow in one of weigh tanks located on the weight platform. After filling the

weigh tanks the flow is directed into a transfer tank, and from it by the pump to the storage tank. Automatic measuring system is intended for collection and processing of measuring information coming from the weighing system, standard flow transducer, tested instruments, diverters, water temperature and pressure transducer, for generation of control signals for the operation of diverter and flow-setting unit. The operation algorithm of automated control system provides for the calculation of volumetric and mass flow measured by the standard and tested instrument and printing out of measurement results.
Parameters of ambient conditions – the temperature and the humidity of air are controlled by a humidity and temperature meter of ИВТМ -7 МК-С-2А type.

Standard uncertainty values of different components of the standards are presented in table A.10.

Table A.10

Measured parameter	Relative standard uncertainty, %	
	U_A	U_B
Mass	0,007	0,0027
Buoyancy force	0,000035	0,0001
Water tempereture	-	0,0144
Water density	0,0048	0,0006
Measurement Time	0,00017	0,00007
Flow diverter	0,001	0,0008
Volume	0,007	-
Repeatability	0,008	-
Combined standard uncertainty	0,0136	0,0147
Total combined standard uncertainty, U_C,%	0,02	
Expanded uncertainty (k=2), U_P, %	0,04	
Level of confidence	P=0,95	

Picture A.19 represents the national standard ГЭТ 63, Picture A.20 – national standard ГЭТ 119, Picture A.21 – DN 80 transfer standard, mounted on ГЭТ 63.

Picture A.19. The national primary standard of the unit of mass liquid flow ГЭТ 63

Picture A.20. The national primary special standard ГЭТ 119

Picture A.21. DN80 transfer standard, mounted on standard ГЭТ 63