Final report

INTERCOMPARISON MEASUREMENTS IN THE FIELD OF GAS FLOW AND VOLUME

Providing comparisons of the test stations for verification of
the gas meters in the flow range (from 4 up to 160) m^3/h.
The transfer device was a rotary gas meter Delta S-Flow, size G100

COOMET PROJECT № 412/UA/07
CIPM-MRA Supplementary Comparison COOMET.M.FF-S3

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Contents

Abstract

The national metrology institutes of Ukraine, Slovakia, Lithuania, and Russia conducted a comparison in gas flow from 4 m^3/h to 160 m^3/h using a positive displacement flow meter as the transfer device. The participants' flow standards are described. The uncertainty contributed to the comparison by the transfer device (0.13 %) was assessed by calibrations performed in the pilot laboratory at the beginning and end of the comparison. The standardized degrees of equivalence between each participant's results and the comparison reference values were less than unity except for one flow measurement at one lab where it was 1.07, demonstrating agreement within uncertainty expectations between the participants.

1. Introduction

The aim of the project is a comparison in the field of gas flow in the participating laboratories participating in the working group TK 1.4 of the metrological organization COOMET for establishing the degree of equivalence of national standards and evaluation of calibration and measurement capabilities of laboratories of national metrology institutes in the field of consumption.

COOMET project 412/UA/07 was begun in 2007. The comparisons were realized in the flow range (from 4 up to 160) m^3/h. The transfer device was a rotary gas meter Delta S-Flow, size G100. The measurement results are presented in the document "COOMET project 412/UA/07".

Four laboratories were involved in the comparison (GP IFCSMC Ivano-Frankovsk, Ukraine (coordinator of comparisons); SMU Bratislava, Slovakia; LEI Kaunas, Lithuania; FGUP VNIIR Kazan, Russia).

Every laboratory-participant used its procedure of calibration during the measurements,. The comparison was realized according to the "Recommendations on comparisons of the standards of the national metrological institutes of COOMET" and the BIPM directive on realization of key comparisons. In Table 1, a time schedule of measurements in individual participating participating laboratoriesis indicated.

Table 1 Time schedule and participants

Country	**Laboratory**	**Address of the place of comparison**	**The declared level of comparison**	**The date of the measurement**	**The responsible**
Ukraine	National Research & Metrological Laboratory	GP IFCSMC Vovchynetska St., 127 Ivano-Frankovsk	from 4 to 160 m^3/h	15.05. – 26.05.2009 y.	Denys Seredyuk
Slovakia	SMU Slovak Institute of Metrology	SMU Karloveská 63 842 55 Bratislava	from 4 to 160 m3/h	02.06. – 16.06.2009 y.	Stefan Makovnik
Lithuania	Lithuanian Energy Institute Research and Testing Laboratory	LEI 3 Breslaujos str. LT – 44403 Kaunas - 35	from 4 to 160 m3/h	01.07. – 15.07.2009 y.	Yuriy Tonkonoguy
Russia	FGUP VNIIR	FGUP VNIIR Vtoraya Aziyskaya 7a, 420029 Kazan	from 4 to 160 m3/h	03.08. – 17.08.2009 y.	Sergey Rainchik
Ukraine	National Research & Metrological Laboratory	GP IFSM Vovchynetska St., 127	from 4 to 160 m3/h	01.09. – 15.09.2009 y.	Denys Seredyuk

		Ivano-Frankovsk			

2. The transfer standard

A Delta S-Flow gas meter, size G100 and DN 50, the serial number of the gas meter was 8785901001, produced by the company “Actaris Gaszahlerbau Gmbh”, Karlsruhe, Germany was chosen as the transfer device.

The Delta S-Flow gas meter is a rotary meter with two three-blade rotors, each blade of which is placed at an angle of 120 degrees relative to each other and shifted by 60 degrees in length. This design completely avoids the resonance phenomena which are characteristic for the rotary meters with conventional two 8-shaped rotors.

The flow meter works in the flow range of 4 to 160 m^3/h. The appearance and design are indicated in Fig. 1. Its characteristic dimensions are given in Table 2. A 500 mm long DN 50 entering pipeline with the length 500 mm was transported along with the transfer device. On the output side should have been pipeline with the length 400 mm with ball valve DN50.

Mandatory condition for a normal functioning of the meter is strictly horizontal meters operating position on the test equipment. Tests are carried out without lubrication of meter bearings by oil.

Thermometer for the measurement of the gas temperature was mounted in the inlet pipe sleeve. Working pressure on the transfer device was measured from the output "P" of the meter. Output of the pulses is provided from the high-yield "Hf1" of the meter. Nominal conversion coefficient of the meter was 12390.19 pulses/m^3.

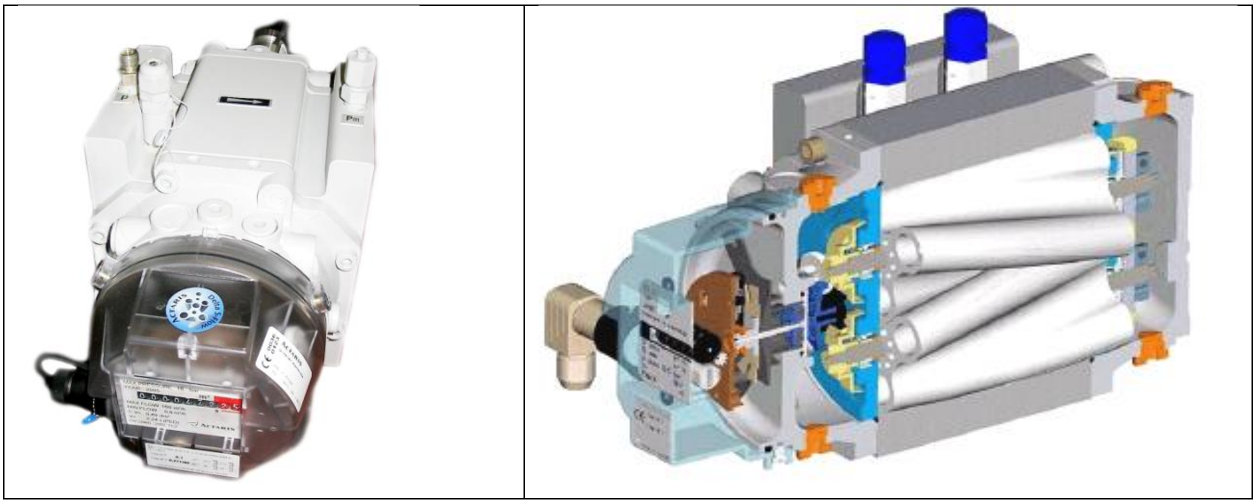

Fig. 1. The appearance and design of the Delta S-Flow G100 transfer device.

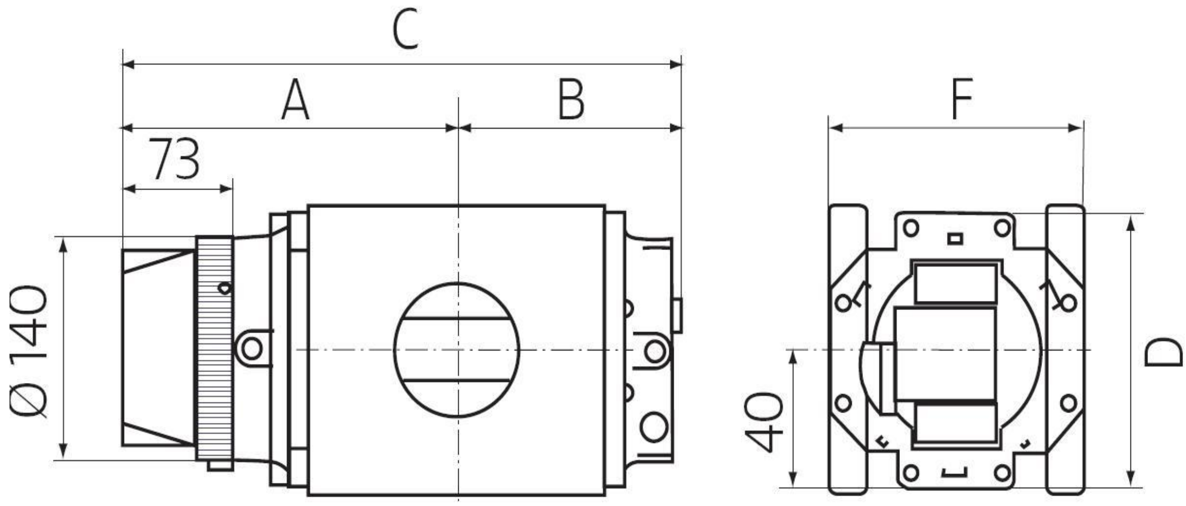

Fig. 2. The characteristic dimensions of the Delta S-Flow G100 meter.

Table 2 Dimensions of transfer device.

Dimensions of transfer device	Dimensions [mm]					
	DN	D	F	A	B	C
	140	182	171	224	158	382

3. Comparison conditions

The pulse emitter A1S with the pulse number 12390,19 pulses/m^3 was used for the tests.

The calibration should had been performed in the laboratory where the temperature was from 19,56°C up to 22,55°C. No oil lubrication was used.

3.1 The test points and the procedure of measurements

Comparison measurements were made at the following ten points of flow: 4 m^3/h, 5 m^3/h, 8 m^3/h, 12 m^3/h, 25 m^3/h, 40 m^3/h, 50 m^3/h, 60 m^3/h, 70 m^3/h, 90 m^3/h, 100 m^3/h, 120 m^3/h, 140 m^3/h and 160 m^3/h.

The test was repeated at least 3 times in direction from Qmax to Qmin at each flow and then the mean of the values in table 3 were calculated. The flow had to be in the interval ± 3% of the required value.

Table 3 The presentation of measurement results.

Flow in the meter	Absolute pressure in the meter	Temperature in the meter	Pressure loss of the meter	Error of the meter e_r	Uncertainty of the error U (k=2)
[m^3.h^{-1}]	[Pa]	[°C]	[Pa]	[%]	[%]
160					
140					
120					
100					
90					
70					
60					
50					
40					
25					
12					
8					
5					
4					

3.2 Calculation of the results

The result of measurements is the measurement error “e_r”, which is expressed by the difference of the data of the volume of the transfer device “V_M” and the reference value of the flow volume of the measurement means “V_E”. The relative error of the measurement, which is expressed in percent, is the part of the measurement error “e_r” and the real value of the flow volume of the reference measurement means “V_E” multiplied by 100. Such, we have the equation:

$$e_r = \frac{V_M - V_E}{V_E} \cdot 100 \qquad (1)$$

4. Test stations of the participating laboratories and the received results

4.1 Ukraine

GP «Ivano-Frankivskstandartmetrologia» performs calibration work using the national standard of the unit of gas volume and volume flow (of bell type) DETU 03-01-96, the range of volume flows of 4 to 200 m^3/h, uncertainty U = 0,10 % (k=2).

The principle of operation of the standard is based on the measurement of the time interval, during which the known with high precision volume of gas is displaced with the simultaneous measurements of gas temperature and pressure.

The gas volume, which has passed through the gas meter that is under test, is determined on the base of the equation of gas state:

$$V_П = V_K \cdot \frac{p}{p_0} \cdot \frac{T_0}{T},$$

where V_K – gas control volume, which is reproduced by the standard;

p, p_0 – the absolute pressure at the tested meter input and under the bell respectively;

T, T_0 – the temperature of the measuring environment in the tested meter and under the bell respectively.

The volume, which has been measured by the meter, is determined by the following:

$$V_{сч} = \frac{N}{K_{NOM}},$$

where N – the number of pulses, which are read from the meter;

K_{NOM} – nominal value of the meter conversion ratio, pulses/m^3.

The meter error is calculated by the following:

$$e_r = \frac{V_{сч} - V_П}{V_П} \cdot 100$$

Fig. 3. The National gas flow standard ДЕТУ 03-01-96

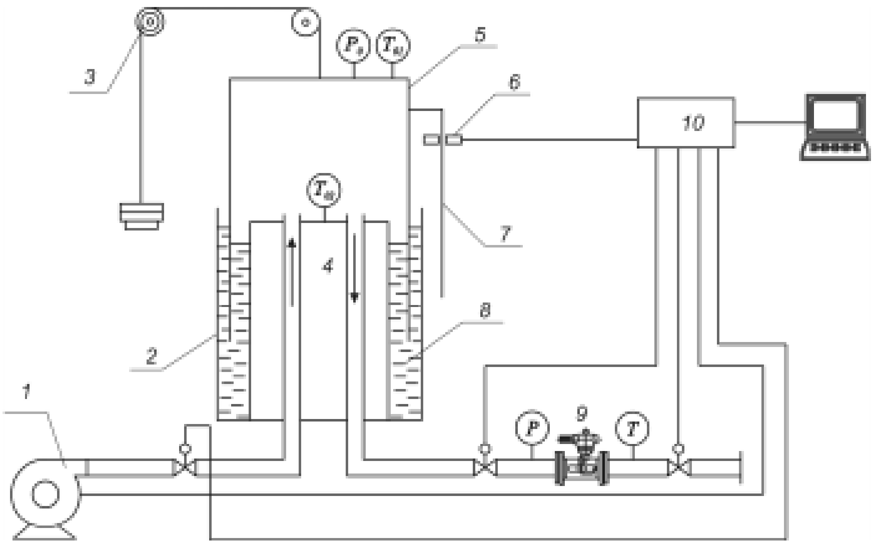

Fig. 4. Schematic of bell prover

STANDARD CONFIGURATION

1 – blower;
2 – tank;
3 – buoyancy effect (Archimedean force) compensator (cam);
4 – displacer;
5 – bell;
6 – linear bell displacement transducer;
7 – scale;
8 – sealing liquid (low vapor pressure mineral oil);
9 – meter under test;
10 – data gathering and handling system.

Table 4 Test results – Ukraine (before dispatch)

Flow in the meter	Absolute pressure in the meter	Temperature in the meter	Pressure loss of the meter	Error of the meter e_r	Uncertainty of the error U (k=2)
[$m^3.h^{-1}$]	[Pa]	[°C]	[Pa]	[%]	[%]
160,88	99913	19,79	550	0,23	0,12
140,50	100345	19,75	450	0,18	0,12
120,56	100674	19,74	350	0,13	0,12
100,41	100975	19,78	250	0,08	0,12
89,76	101106	19,73	210	0,05	0,12
69,77	101325	19,75	130	0,00	0,12
60,06	101408	19,80	110	-0,02	0,12
50,01	101488	19,81	80	-0,04	0,12
40,07	101557	19,81	50	-0,07	0,12
24,96	101637	19,79	25	-0,12	0,12
11,97	101674	19,71	8	-0,21	0,12
8,06	101675	19,72	5	-0,28	0,12
4,98	101680	19,73	3	-0,4	0,12
4,00	101682	19,72	2	-0,47	0,12

Table 5 Test results – Ukraine (after dispatch)

Flow in the meter	Absolute pressure in the meter	Temperature in the meter	Pressure loss of the meter	Error of the meter e_r	Uncertainty of the error U (k=2)
[$m^3.h^{-1}$]	[Pa]	[°C]	[Pa]	[%]	[%]
159,91	100239	20,62	548	0,39	0,12
139,90	100631	20,68	451	0,31	0,12
120,96	100971	20,64	349	0,21	0,12
99,91	101287	20,69	252	0,11	0,12
89,98	101418	20,64	210	0,07	0,12
70,22	101639	20,66	131	-0,05	0,12
60,10	101734	20,73	112	-0,16	0,12
49,95	101816	20,69	79	-0,16	0,12
40,19	101877	20,67	51	-0,18	0,12
24,90	101958	20,64	22	-0,19	0,12
12,07	101992	20,63	9	-0,26	0,12
8,01	101996	20,63	5	-0,29	0,12
5,05	101997	20,64	3	-0,4	0,12
4,05	101937	20,65	2	-0,42	0,12

4.2 Slovakia

The comparison measurement was realized in the Gas Flow Laboratory, in the Flow Centre of Slovak Institute of Metrology in Bratislava, in October, 21st and 23rd, 2009. The transfer device was a new type of rotary gas meter DELTA S-FLOW, size G65, DN 50, produced by ACTARIS Gaszahlerbau Gmbh, Karsruhe, Germany. Serial number of the gas meter is 8785901001.

Tests were performed using two flow standards. The first equipment was the Bell prover. The measurements were made in the flow range (4 to 70) m^3/h. Serial number of the Bell prover is 334/1999. The Bell prover is one part of the Slovak National standard of gas flow with the registration number 035/2007. The expanded uncertainty of the primary standard - Bell prover is U = 0,12% (k =2).

The second equipment was the secondary standard equipment TEZKD-2, serial number 322/1999. The measurements were made in the flow range (90 to 120) m^3/h. The expanded uncertainty of the standard equipment TEZKD-2 is U = 0,16% (k = 2).

The critical nozzles of the test equipment TEZKD-2 are gas flow standards. The critical nozzles are traceable to the Slovak national standard of gas flow.

The comparison measurement was realized according to the SMU working procedure No. 18/230/2004, Version 2 (the name of the working procedure is: “Working procedure for calibration of gas meters and flow with the primary standard - Bell prover”), and according to the SMU working procedure No. 13/230/2001, Version 2 (the name of the working procedure is: “Working procedure for calibration, validation and testing for type approval of gas meters by test equipment with critical nozzles”).

You can see both test equipments participated in this project in the picture.

Fig. 5. Gas flow standards.

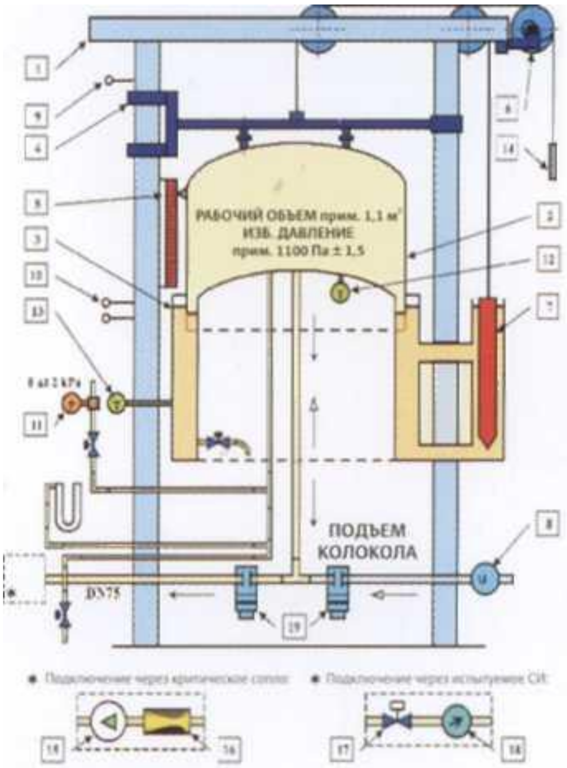

Fig. 6. Schematic of gas flow standard.

STANDARD CONFIGURATION

1 – algal frame
2 – bell
3 - high level of oil

4 - transverse holder
5 - optical ruler
6 - spiral of Archimedes
7 - cylinder-stabilizer
8 - ventilator
9 - sensor of top dead center
10 – sensor of bottom dead center
11 - pressure sensor
12 - temperature sensor
13 - temperature sensor
14 - counterweight
15 - vacuum pump
16 - critical nozzle
17 - valve controller
18 - tested SR
19 - clock

Table 6 Test results – Slovakia

Flow in the meter	Absolute pressure in the meter	Temperature in the meter	Pressure loss of the meter	Error of the meter e_r	Uncertainty of the error U (k=2)
[$m^3.h^{-1}$]	[Pa]	[°C]	[Pa]	[%]	[%]
119,71	97949	19,92	323	-0,05	0,24
100,99	98116	19,96	240	-0,08	0,20
88,91	98181	19,95	189	-0,01	0,24
71,08	98255	20,02	132	0,00	0,15
59,16	98275	20,03	98	-0,04	0,15
49,99	98278	20,05	73	-0,07	0,14
40,20	98290	20,04	50	-0,08	0,14
25,08	98305	20,12	23	-0,07	0,14
12,15	98322	20,13	8	-0,10	0,14
8,11	98354	20,16	5	-0,18	0,15
5,17	98373	20,17	3	-0,30	0,15
4,03	98386	20,18	2	-0,36	0,14

4.3 Lithuania

Place of the test:

Heat equipment research and testing laboratory of Lithuanian energy institute, 3 Breslaujos str. LT-44403 Kaunas-35, Lithuania.

The test method:

The rotor gas meter G160 was calibrated by the method of comparison of the meter's readings with readings of a reference gas meter. The calibration was carried out according to the document KM-2E/3-MP01:2004 «Air (gases) volume and flow rate meters, (1 – 9700) m^3/h. Methods of calibration».

The test at each flow was repeated 3 times and then the means were calculated. The deviation of real flow values did not exceed ± 3% of the required values.

The tests were carried out without lubrication of the turbine bearings.

The test facility:

The standard facility No. 2E/3 with reference gas meters was used for calibration. The main characteristics of the facility: measurement range is (1 – 9700) m^3/h, the best measurement capability in the range of flow rate (1 – 1600) m3/h is ± 0,25 %. The general view of the facility is presented at Fig.7.

Fig. 7. Appearance of the gas flow standard.

Round tubes of diameter DN50 were used as straight pipes. The length of upstream straight pipe was L1=1,8 m (12 DN), downstream – L2=1 m (6,6 DN). The schematic of the facility is presented at Fig.8.

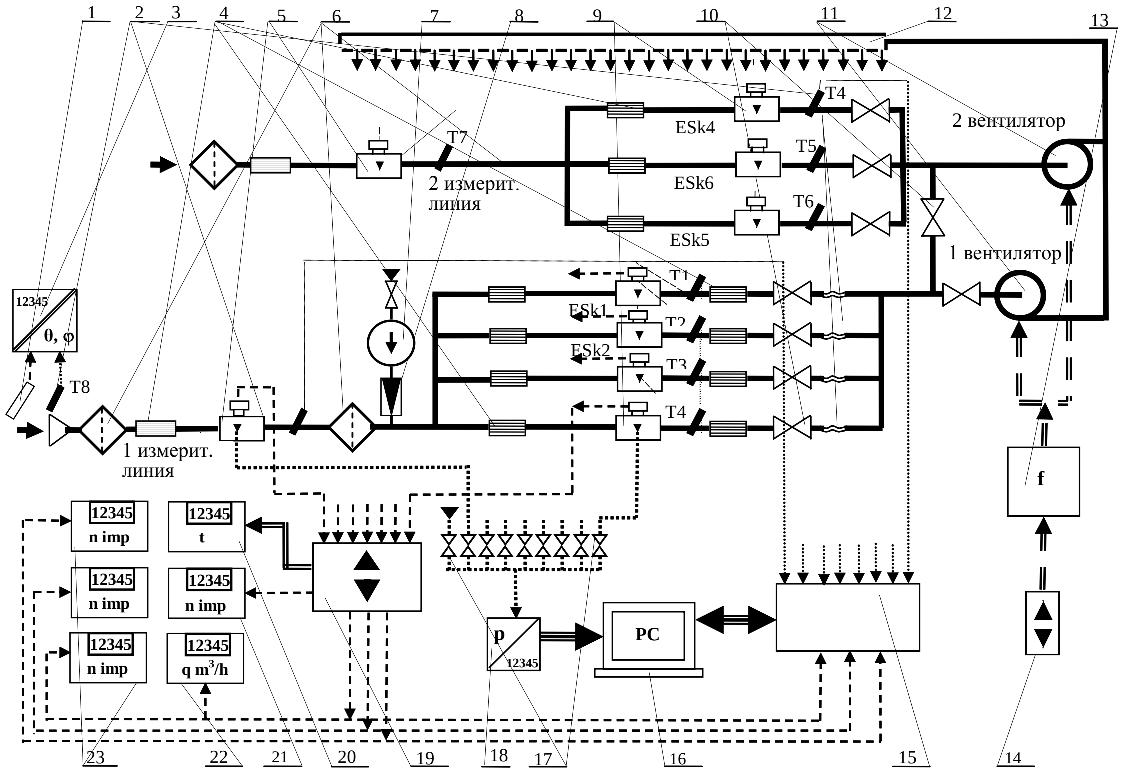

Fig. 8. The schematic of the standard facility. 1 – humidity sensor; 2 – thermometers; 3 – temperature and humidity transducer; 4 – flow straightener; 5 – meter under calibration; 6 – air filter; 7 – compressor; 8 – pressure reducer; 9 – reference gas meters; 10 – valves; 11 – fans; 12 – distributing air collector; 13 – frequency converter; 14 – controller of frequency converter; 15 – data acquisition and measurement device; 16 – personal computer ; 17 – pressure tapping connecting valves; 18 – absolute pressure meter; 19 – device of synchronization of time measurement and pulses counting; 20 – timer; 21 – calibrated meters pulses counter; 22 – electronic flow indicator; 23 – reference meters pulses counter.

Ambient conditions:

Atmospheric pressure (1002 ± 7) mbar; temperature (20,0 ± 0,5) ^{o}C; relative air humidity (35 ± 5) %.

Traceability:

The reference gas meter IRM ADUO, G100, DN80, production of the company “INSTROMET.

The temperature, pressure and time measurement devices are traceable to the Lithuanian national standards.

Table 7 Test results – Lithuania

Flow in the meter	Absolute pressure in the meter	Temperature in the meter	Pressure loss of the meter	Error of the meter e_r	Uncertainty of the error U (k=2)
[$m^3.h^{-1}$]	[Pa]	[°C]	[Pa]	[%]	[%]
90,1	99554	20,0	207	0,35	0,27
70,1	99830	20,0	134	0,25	0,27
60,1	99904	20,0	106	0,17	0,27
50,1	100044	20,0	78	0,15	0,27
40,2	100084	19,9	51	0,12	0,27
25,2	100104	20,1	23	0,05	0,27
12,1	100191	20,2	6,9	-0,01	0,29
8,0	100257	20,3	3,5	-0,09	0,29
5,0	100216	20,2	1,9	-0,19	0,29
4,1	100210	20,2	1,5	-0,28	0,29

4.4 Russia

Place of the test:

All-Russian Scientific Research Institute of Flowrate Measurement (VNIIR) 7a, str. 2 Azinskaya, 420029, Kazan, Russia.

Flow range of measurement: (from 4 up to 160) m^3/h

Condition of measurement:

Testing medium: air

Temperature: (20 ± 2) ^oC

Humidity: (68 up to 72) %

Pressure: (748 up to 752) mm Hg; (99,72 up to 100,26) kPa

The test facility:

The nozzle test rig standard for industrial gas meters was used for the calibration of the rotor meter G100.

Measurements were performed on a standard facility ЭУ-2, which is part of the state primary standard units of volume and mass flow of gas ГЭТ 118-06.

The main means of measuring flow in the facility are critical nozzles. Flow of the facility is from 2 m^3/h up to 10000 m^3/h. Places of the nozzles setting - 9, total exchangeable nozzles -30. Expanded uncertainty of the standard facility U = 0,2 % (k = 2).

Standard facility ЭУ-2 is linked to the initial reference facility ЭУ-1 gravimetric type state primary standard units of volume and mass flow of gas ГЭТ 118-06, on which the critical nozzles are calibrated.

During the measurements the following conditions were performed:
1. Consumption was installed smoothly, eliminating the possibility of air strike on the meter.
2. In the measurements of the reference flow value the air temperature, humidity, atmospheric pressure, and pressure loss on the counter were taken into account.
3. When introducing the amendments to the pressure difference in calibrated and reference tool as a difference was taken ½ of the pressure loss on the meter.
4. Pulses with a calibrated meter were taken at least 3 times for each measurement.
5. Time during which the pulses were recorded was no less than 100 seconds.

The scheme of the nozzle test rig standard is presented at followed Fig. 9.

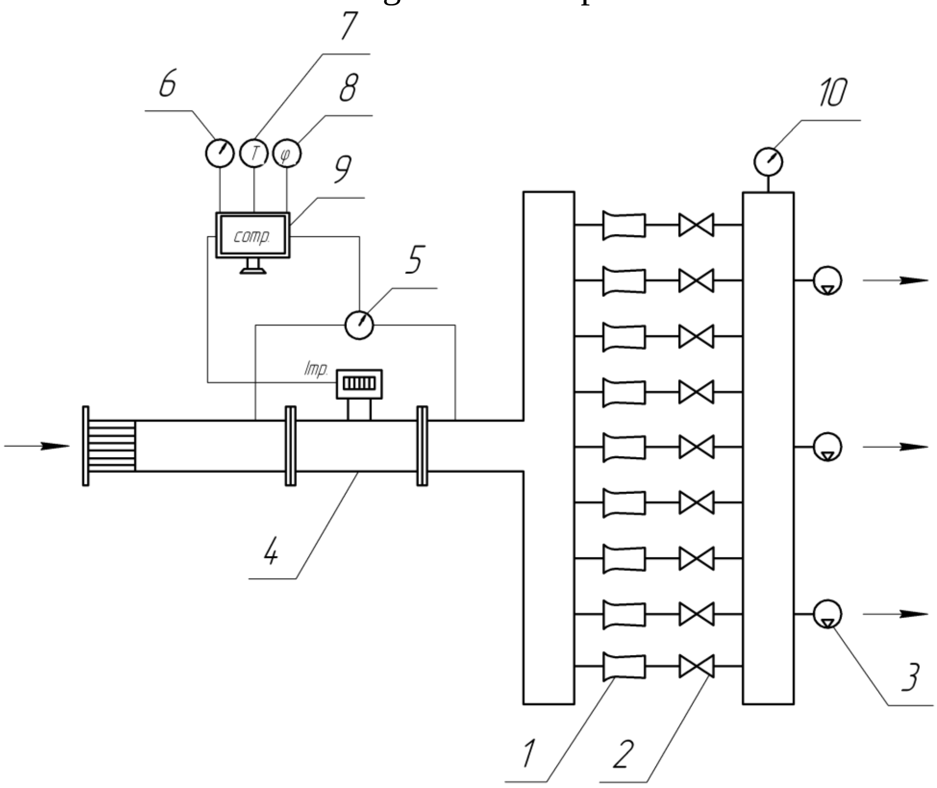

Fig. 9. The schematic of the nozzle test rig standard:
1 - critical nozzles; 2 – valves; 3 - vacuum pumps; 4 - calibrated meter; 5 – meter of the pressure loss on the gas meter; 6 - barometric pressure meter; 7 – thermometer; 8 - moisture meter; 9 – computer; 10 - vacuum gauge.

Fig. 10. Appearance of the gas flow standard.

Table 8 Test results – Russia

Flow in the meter	Absolute pressure in the meter	Temperature in the meter	Pressure loss of the meter	Error of the meter e_r	Uncertainty of the error U (k=2)
[m³.h⁻¹]	[Pa]	[°C]	[Pa]	[%]	[%]
160	100750	20,4	600	+0.27	0,20
140	100750	20,4	460	+0,25	0,20
120	100750	20,4	350	+0,22	0,20
100	100750	20,4	250	+0,20	0,20
90	100750	20,4	210	+0,17	0,20
70	100750	20,4	140	+0,14	0,20
60	100750	20,4	1 10	+0,12	0,20
50	100750	20,4	80	+0,09	0,20
40	100750	20,4	50	+0,07	0,20
25	100750	20,4	27	0	0,20
12	100750	20,4	11	-0.05	0,20
8	100750	20,4	7	-0,10	0,20
5	100750	20,4	5	-0,20	0,20
4	100750	20,4	3	-0,39	0,20

5. The stability of the compared measurement means and participating laboratories dependence

During the process of comparisons in the pilot laboratory, two measurements of the transfer device rotary gas meter were carried out. The first was at the beginning of comparisons in 2007, the second - after comparisons in 2011. The measurement results are shown in the Table 9 and Figure 12.

Expanded uncertainty arising from the stability of the transfer device has been quantified by the maximum value of absolute values of the differences between relative errors | Δe_r | first and second measurements. U = 0,13 %. This indication is based on the assumption of uniform distribution between the maximum and minimum value of the relative error.

Table 9 The results of measurements in the pilot laboratory

Flow in the meter	Error of the meter e_r in 2007	Error of the meter e_r in 2010	Uncertainty of the error U (k=2)
[$m^3.h^{-1}$]	[%]	[%]	[%]
160	0,23	0,39	0,09
140	0,18	0,31	0,08
120	0,13	0,21	0,05
100	0,08	0,11	0,02
90	0,05	0,07	0,01
70	0,00	-0,05	0,03
60	-0,02	-0,16	0,08
50	-0,04	-0,16	0,07
40	-0,07	-0,18	0,06
25	-0,12	-0,19	0,04
12	-0,21	-0,26	0,03
8	-0,28	-0,29	0,01
5	-0,4	-0,4	0,00
4	-0,47	-0,42	0,01

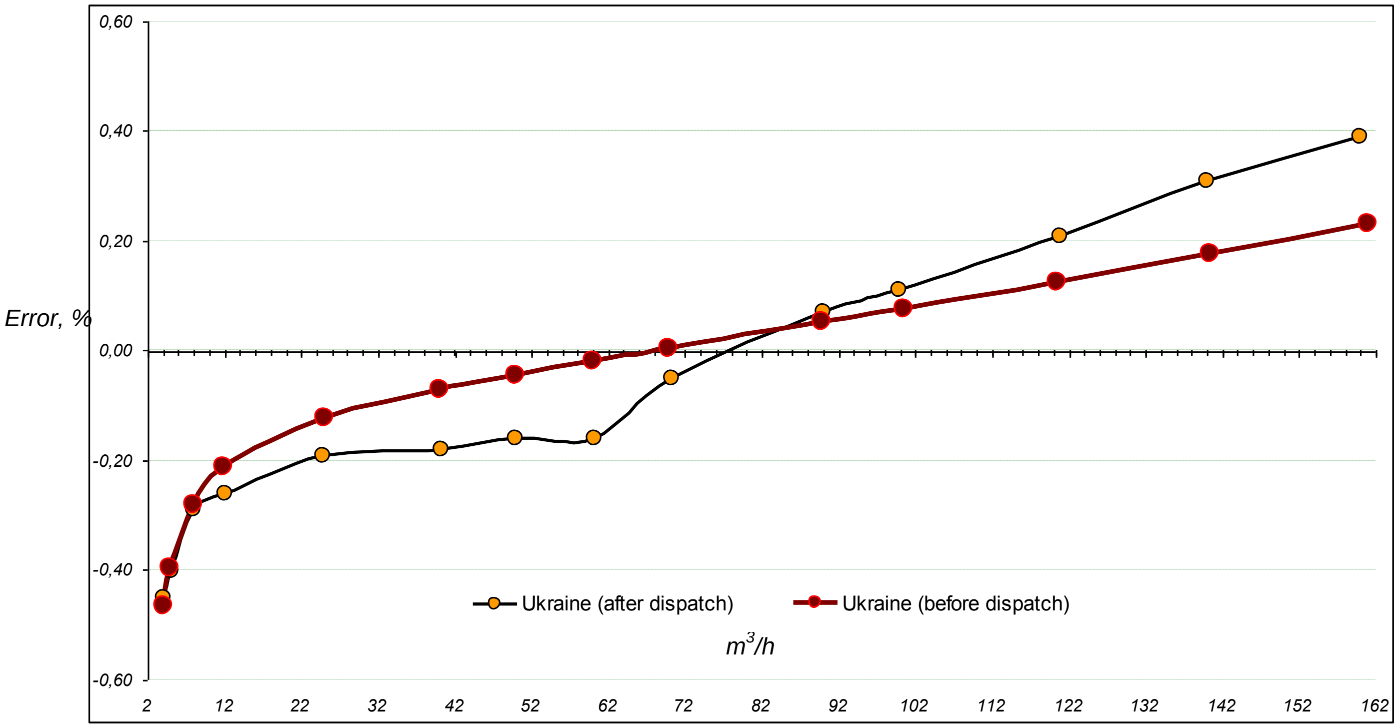

Fig. 11. Stability of the transfer device.

5.1 Participating laboratories dependence

Three independent laboratories participated in this comparison: Ukraine (IF CSMS), Slovakia (SMU) and Russia (VNIIR). These laboratories participated in establishing the initial flow KCRV (key comparison reference value) for each test point. Lithuania (LEI) is a dependent laboratory of the Federal Physical and Technical Institute (PTB), Germany.

6. Determination of the reference value for each flow set point and results of measurements in the participating laboratories

6.1 Description of the method

The reference value was determined at each flow separately. The method of determination of CRV in each flow rate corresponds to the procedure A presented by M. G. Cox.

6.1.1 Determination of the reference value and its uncertainty

The reference value y was calculated as the weighted mean error (WME) according to the following equation:

$$y = \frac{\frac{x_1}{u_{x1}^2} + \frac{x_2}{u_{x2}^2} + ... + \frac{x_n}{u_{xn}^2}}{\frac{1}{u_{x1}^2} + \frac{1}{u_{x2}^2} + ... + \frac{1}{u_{xn}^2}} \quad (2)$$

where: x_1, x_2, … x_n - error values, which were measured in the participating independent laboratories 1, 2, …n.

u_{x1}, u_{x2}, …u_{xn} - combined standard uncertainties connected with the values of errors, which were measured at the independent laboratories 1, 2, ...n, including also the uncertainty of the transfer device due to calibration stability.

The combined standard uncertainty of measurement at the individual participating laboratories u_{x1}, u_{x2},…u_{xn} was calculated according to the following equation taking into account the uncertainty of the transfer device due to calibration stability:

$$u_{xi} = \sqrt{\left(\frac{U_{xi\_lab}}{2}\right)^2 + \left(\frac{U_{tm}}{2}\right)^2} \quad (3)$$

where: U_{xi_lab} - expanded uncertainty (k=2), calculated at i-th laboratory and given in the results of measurements at i-th laboratory.

U_{tm} – evaluation of the measurement expanded uncertainty of the transfer device due to calibration stability.

The combined standard uncertainty of the CRV was calculated using the following equation:

$$\frac{1}{u_y^2} = \frac{1}{u_{x1}^2} + \frac{1}{u_{x2}^2} + ... + \frac{1}{u_{xn}^2} \qquad (4)$$

The expanded uncertainty of the CRV U_y is given by following equation:

$$U_y = 2 \cdot u_y \qquad (5)$$

"Chi-test" was used for determination of the admissible scatter of results of participating laboratories for determination of CRV. Some independent laboratories contribute their measured values of error and uncertainty of measurement into determination of χ^2_{obs} value. χ^2_{obs} square is calculated according to the following equation:

$$\chi^2_{obs} = \frac{(x_1 - y)^2}{u_{x1}^2} + \frac{(x_2 - y)^2}{u_{x2}^2} + ... + \frac{(x_n - y)^2}{u_{xn}^2} \qquad (6)$$

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

$$\nu = n - 1 \qquad (7)$$

where n - the number of the evaluated laboratories.

The independent participating laboratories must correspond to the following condition for realization of the reference value:

$$CHIINV(0{,}05;\nu) > \chi^2_{obs} \qquad (8)$$

If such condition is not followed, the reference value is calculated without the data of the laboratory, which has the highest value of parameter χ. This procedure is repeated until the condition is satisfied. Value of <u>y</u>, obtained in this way, is accepted as CRV - <u>x_{ref}</u>, and value <u>$U(y)$</u> is accepted as the expanded uncertainty of the measurement, which related to CRV as <u>$U(x_{ref})$</u>.

Function "*CHIINV(0,05;ν)*" is calculated by the standard method by means of tabulated editor MS Excel.

6.1.2 Calculation of the difference d_i between the laboratory value and CRV and its uncertainty *U(di)* and the normalized degree of equivalence *Ei*

Parameter *di* value is necessary for calculation of the comparison result, which is the degree of equivalence *Ei*. The difference calculation is made according to the following equation:

$$di = x_i - x_{ref} \qquad (9)$$

It is necessary to calculate the uncertainty of the difference *di*., for calculation of the degree of equivalence. At application of the law of the uncertainty expansion the expression of the required parameter follows from the equation:

$$u^2_{x_1 - x_2} = \begin{pmatrix} \frac{\partial(x_1 - x_2)}{\partial x_1} & \frac{\partial(x_1 - x_2)}{\partial x_2} \end{pmatrix} \begin{pmatrix} u_1^2 & \mathrm{cov} \\ \mathrm{cov} & u_2^2 \end{pmatrix} \begin{pmatrix} \frac{\partial(x_1 - x_2)}{\partial x_1} \\ \frac{\partial(x_1 - x_2)}{\partial x_2} \end{pmatrix} = u_1^2 + u_2^2 - 2 \cdot \mathrm{cov} \qquad (10)$$

It is clear that the standard uncertainty of measurement, which is obtained from the interferences at CRV determination between two dependent inputs, is created by the sum of squares of the standard uncertainties, which correspond to the individual introduced quantities minus twice their covariance.

Therefore we have to look at the different cases in this comparison:

A) Differences to the CRV

A1) Independent laboratories with contribution to the CRV.

The value of covariance is identical to the value of the measurement uncertainty related to CRV for the independent laboratories participants, which took part in CRV determination, and also for the independent laboratories participants. So, value *u(di)* is written according to the following equation:

$$u(di) = \sqrt{u_{xi}^2 + u_{xref}^2 - 2 \cdot u_{xref}^2} = \sqrt{u_{xi}^2 - u_{xref}^2} \qquad (11)$$

A2) Independent laboratories without contribution to the CRV.

The independent laboratories participants, which were excluded from CRV determination, do not have interference, so value *u(di)* is written according to the following equation:

$$u(di) = \sqrt{u_{xi}^2 + u_{xref}^2} \qquad (12)$$

A3) Laboratories with traceability to a laboratory contributing to the CRV.

In this case we have covariance between the laboratory and the CRV because the laboratory is linked to the CRV via the source of traceability. Although we have no detailed information about it, we can determine a conservative estimation of an upper limit of this covariance. The upper limit is determined for the theoretical case if we have no additional stochastic influence in the traceability of the lab from its source (which is the laboratory contributing to the CRV). Then the results of the laboratory considered here would be strongly correlated with the results of the laboratory contributing to the CRV (correlation coefficient = 1) and there would be the same covariance to the CRV as in case A1. In any case of additional uncertainty caused stochastically the correlation and consequently the covariance is smaller.

The expanded uncertainty is calculated according to the equation:

$$U(di) = k \cdot u(di) = 2 \cdot u(di) \qquad (13)$$

The basis for estimation of a laboratory’s successful participation in a comparison is the parameter of the normalized degree of equivalence (DoE) *Ei*. It is calculated according to the following equation:

$$Ei = \left| \frac{di}{U(di)} \right| \qquad (14)$$

At this the used value of uncertainty *U(di)* is liable to the above said conditions.

The expression $Ei \leq 1$ is the criterion for estimation of the participating laboratory’s success. The normalized degree of equivalence to the CRV is determined for the results of every laboratory according to the following evaluation:

- the results of the laboratory are **passed**, if ***Ei*** **≤ 1**
- the results of the laboratory are **failed**, if ***Ei*** **> 1,2**
- such estimation signals on the serious problems of the laboratory, which must be analyzed and removed for proper functioning of the laboratory
- the so-called **warning level** is established for values *Ei* in the interval **1 < *Ei* ≤ 1,2**, which signals to the participating laboratory to drawbacks of the less serious character, but it is the cause for taking corrective measures.

Such warning levels are the cause due to which we must take into account the significance of the uncertainties calculation (for the laboratory results, and also for CRV). They are usually established for the level of trustworthiness of 95%. The interval to *Ei* < 1,5 is used for such "warnings" in some comparisons. In this comparison, the lower value 1,2 was chosen, which reflects the predominance of non-stochastic "elements" of uncertainty in comparison with stochastic "elements". (The reproducibility is usually much better than the general uncertainty of the laboratory).

6.2 The results of the comparisons

Table 10 The measurements results at flow rate value of 160 m^3/h

Country	Error of the meter *x*, %	Uncertainty *U(k=2)*	*di*	*U(di)*	*Ei*	x_{ref}	$x_{ref} + U_{xref}$	$x_{ref} - U_{xref}$
Ukraine	0,23	0,17	-0,016	0,109	0,14	0,25	0,382	0,109
Russia	0,27	0,22	0,024	0,171	0,14	0,25	0,382	0,109

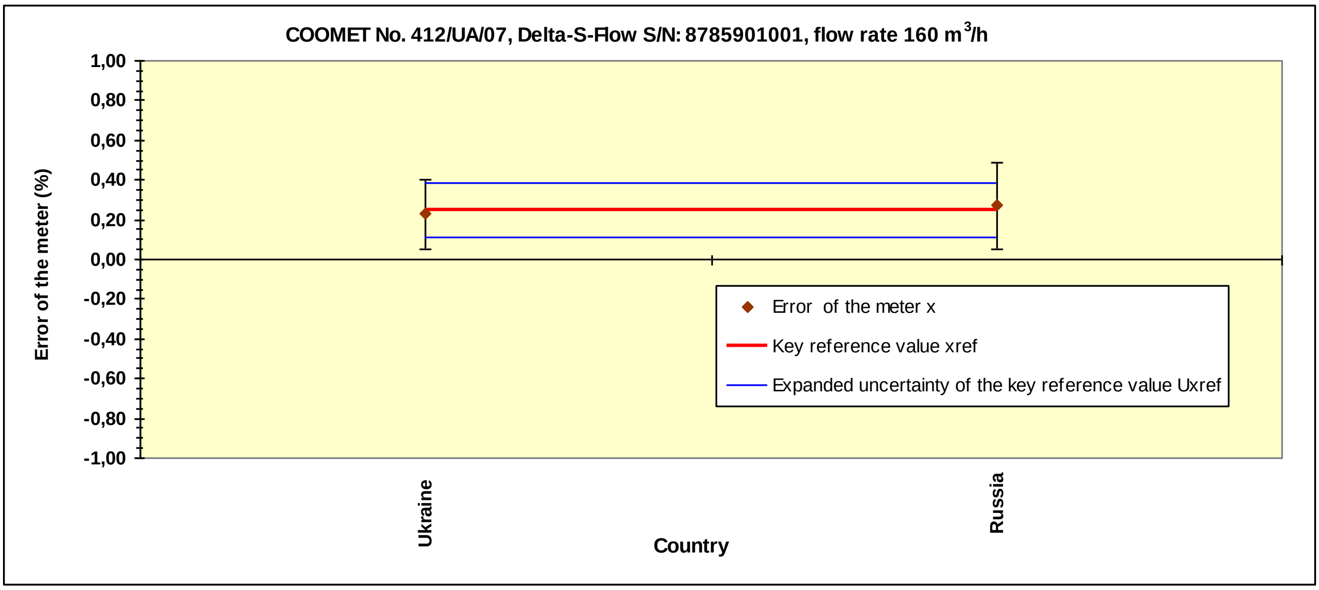

Fig. 12. The measurements results (flow of 160 m^3/h)

Table 11 The measurements results at flow rate value of 140 m^3/h

Country	Error of the meter *x*, %	Uncertainty *U(k=2)*	*di*	*U(di)*	*Ei*	x_{ref}	$x_{ref} + U_{xref}$	$x_{ref} - U_{xref}$
Ukraine	0,18	0,17	0,008	0,109	0,07	0,17	0,309	0,035
Russia	0,25	0,22	0,078	0,171	0,45	0,17	0,309	0,035

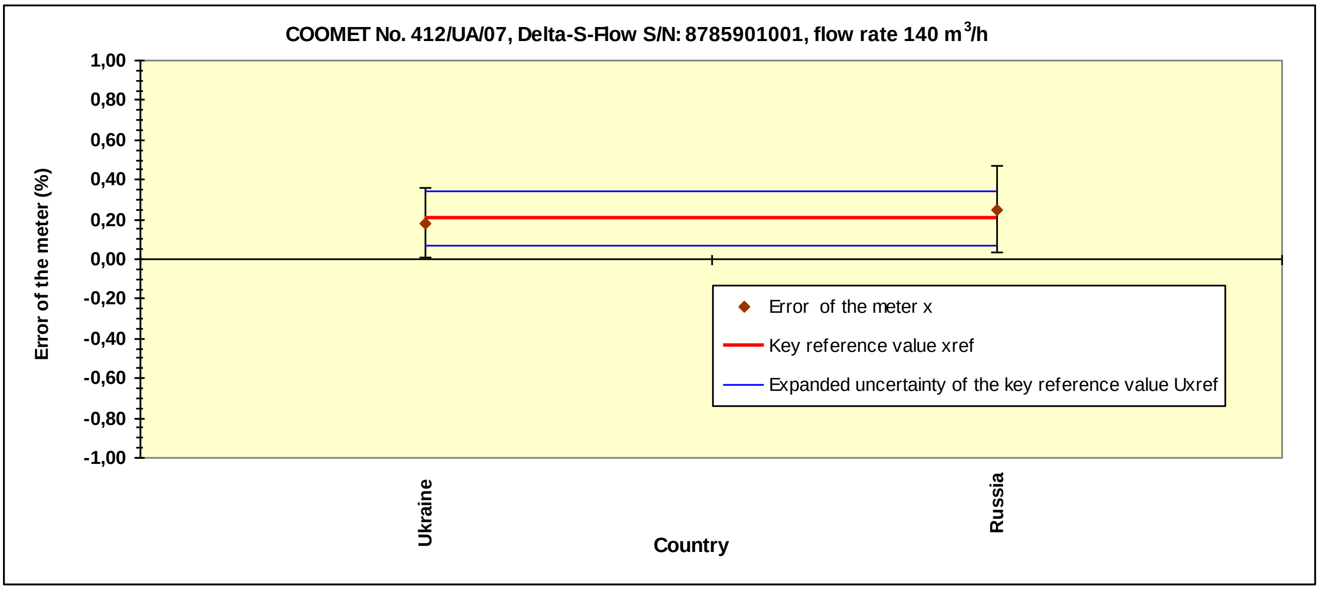

Fig. 13. The measurements results (flow of 140 m^3/h)

Table 12 The measurements results at flow rate value of 120 m^3/h

Country	Error of the meter *x*, %	Uncertainty *U(k=2)*	*di*	*U(di)*	*Ei*	x_{ref}	$x_{ref} + U_{xref}$	$x_{ref} - U_{xref}$
Ukraine	0,13	0,17	0,013	0,127	0,10	0,12	0,238	-0,003
Slovakia	-0,05	0,26	-0,167	0,226	0,74	0,12	0,238	-0,003
Russia	0,22	0,22	0,103	0,183	0,56	0,12	0,238	-0,003

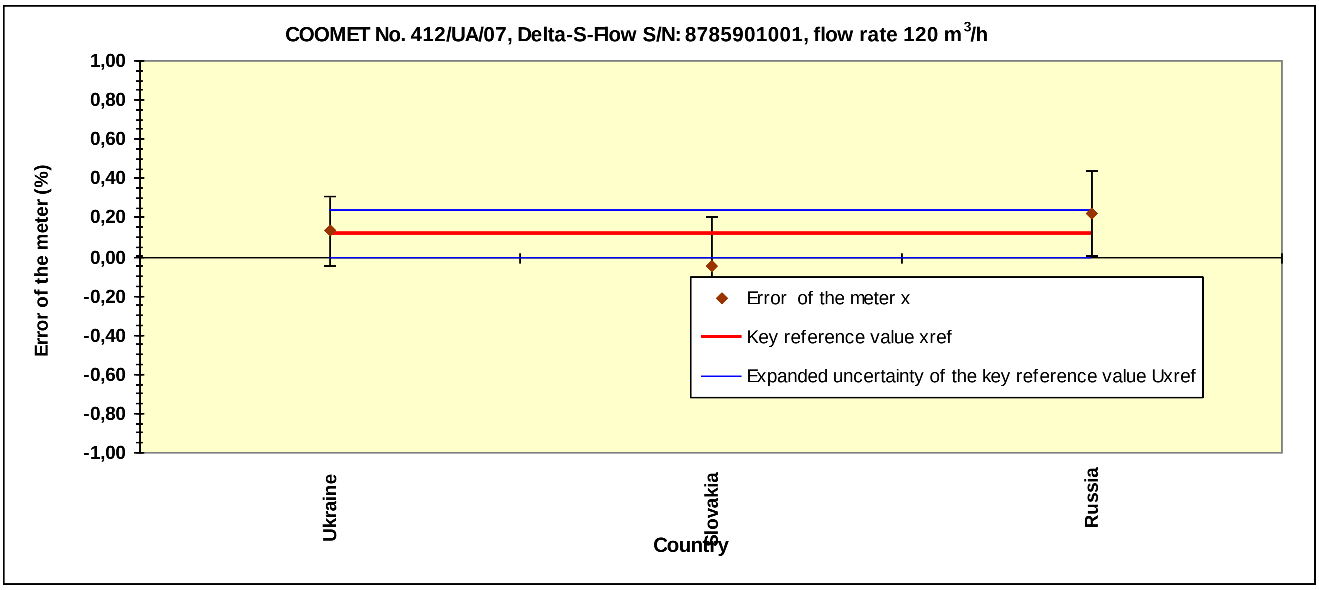

Fig. 14. The measurements results (flow of 120 m^3/h)

Table 13 The measurements results at flow rate value of 100 m^3/h

Country	Error of the meter *x*, %	Uncertainty *U(k=2)*	*di*	*U(di)*	*Ei*	x_{ref}	$x_{ref} + U_{xref}$	$x_{ref} - U_{xref}$
Ukraine	0,08	0,17	0,011	0,131	0,09	0,07	0,185	-0,047
Slovakia	-0,08	0,22	-0,149	0,186	0,80	0,07	0,185	-0,047
Russia	0,20	0,22	0,131	0,186	0,70	0,07	0,185	-0,047

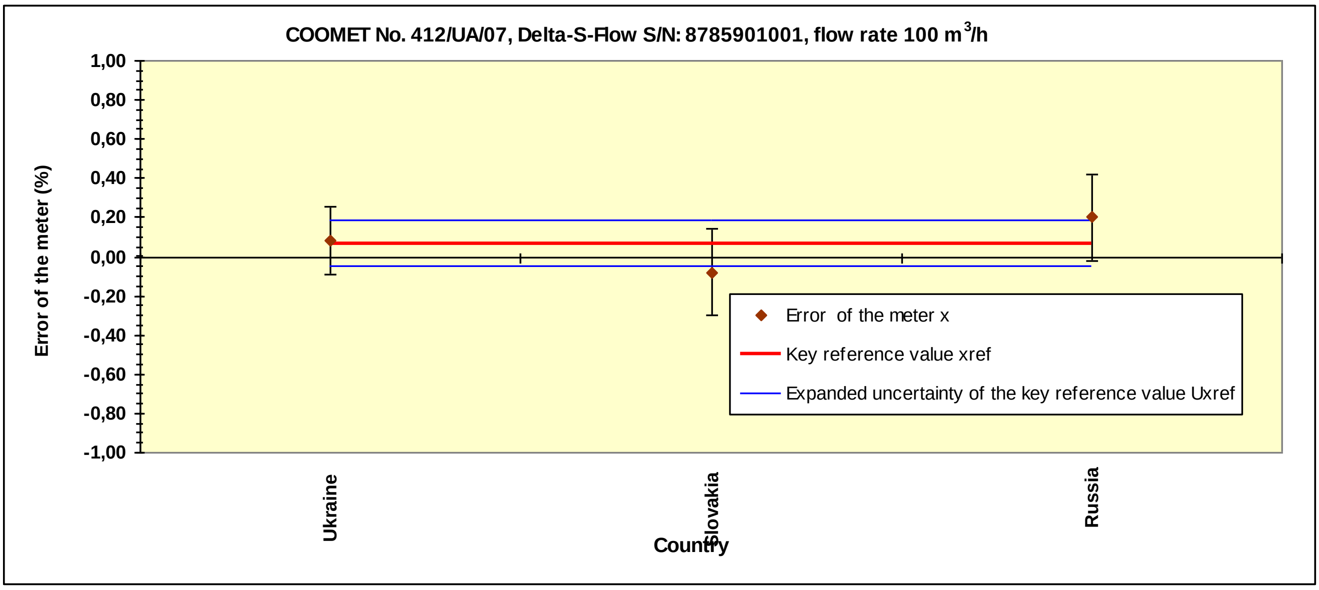

Fig.15. The measurements results (flow of 100 m^3/h)

Table 14 The measurements results at flow value of 90 m^3/h

Country	Error of the meter *x, %*	Uncertainty *U(k=2)*	*di*	*U(di)*	*Ei*	x_{ref}	$x_{ref} + U_{xref}$	$x_{ref} - U_{xref}$
Ukraine	0,05	0,17	-0,023	0,127	0,18	0,07	0,194	-0,048
Slovakia	-0,01	0,26	-0,083	0,226	0,37	0,07	0,194	-0,048
Lithuania	0,35	0,28	0,277	0,258	1,07	0,07	0,194	-0,048
Russia	0,17	0,22	0,097	0,183	0,53	0,07	0,194	-0,048

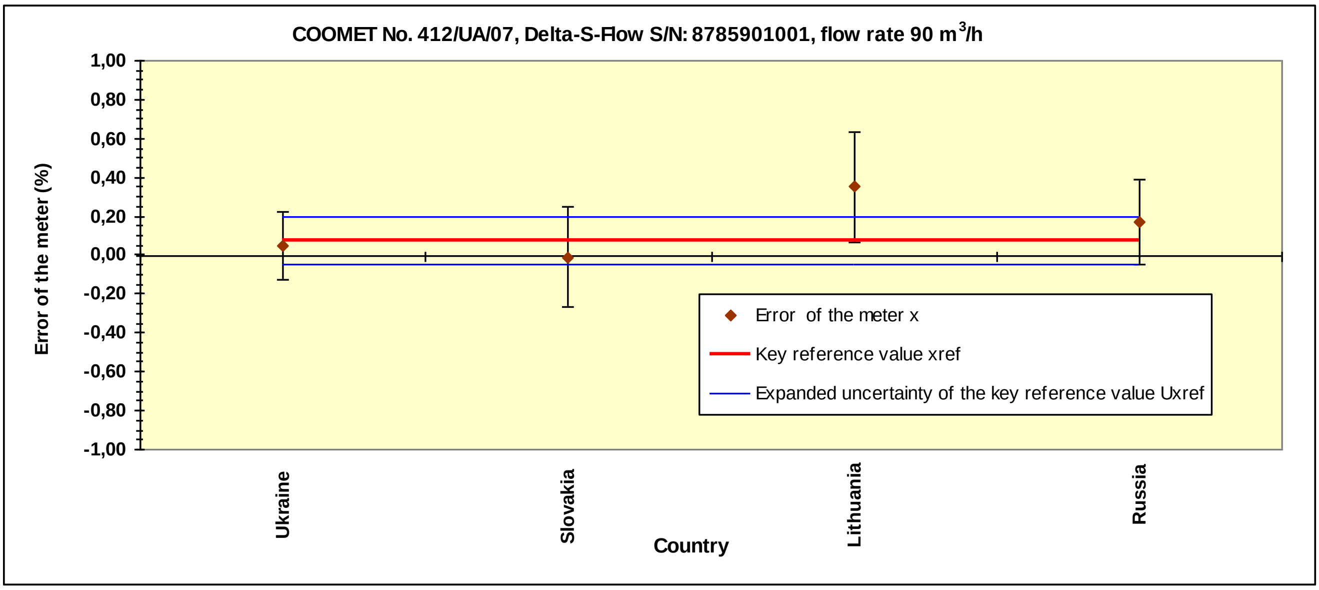

Fig. 16. The measurements results (flow of 90 m^3/h)

Table 15 The measurements results at flow rate value of 70 m^3/h

Country	Error of the meter *x, %*	Uncertainty *U(k=2)*	*di*	*U(di)*	*Ei*	x_{ref}	$x_{ref} + U_{xref}$	$x_{ref} - U_{xref}$
Ukraine	0,00	0,17	-0,034	0,138	0,25	0,03	0,142	-0,074
Slovakia	0,00	0,17	-0,034	0,138	0,25	0,03	0,142	-0,074
Lithuania	0,25	0,28	0,216	0,263	0,82	0,03	0,142	-0,074
Russia	0,14	0,22	0,106	0,191	0,56	0,03	0,142	-0,074

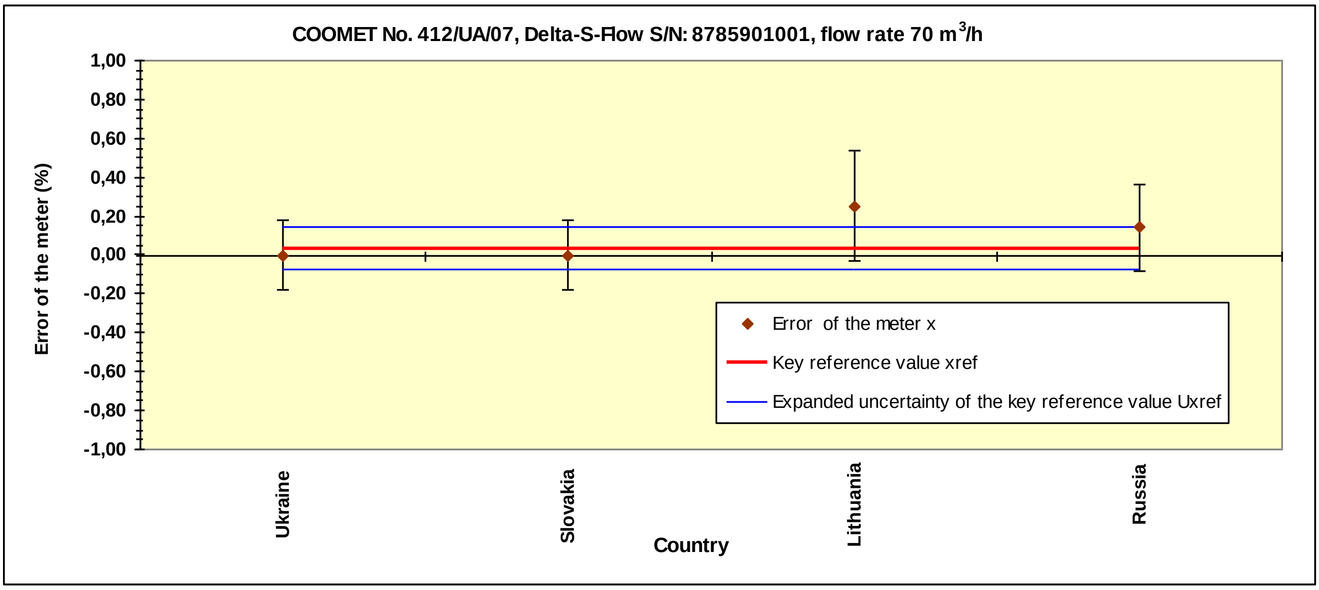

Fig.17. The measurements results (flow of 70 m^3/h)

Table 16 The measurements results at flow rate value of 60 m^3/h

Country	Error of the meter *x*, %	Uncertainty *U(k=2)*	*di*	*U(di)*	*Ei*	x_{ref}	$x_{ref} + U_{xref}$	$x_{ref} - U_{xref}$
Ukraine	-0,02	0,17	-0,026	0,138	0,19	0,01	0,114	-0,102
Slovakia	-0,04	0,17	-0,046	0,138	0,34	0,01	0,114	-0,102
Lithuania	0,17	0,28	0,164	0,263	0,62	0,01	0,114	-0,102
Russia	0,12	0,22	0,114	0,191	0,60	0,01	0,114	-0,102

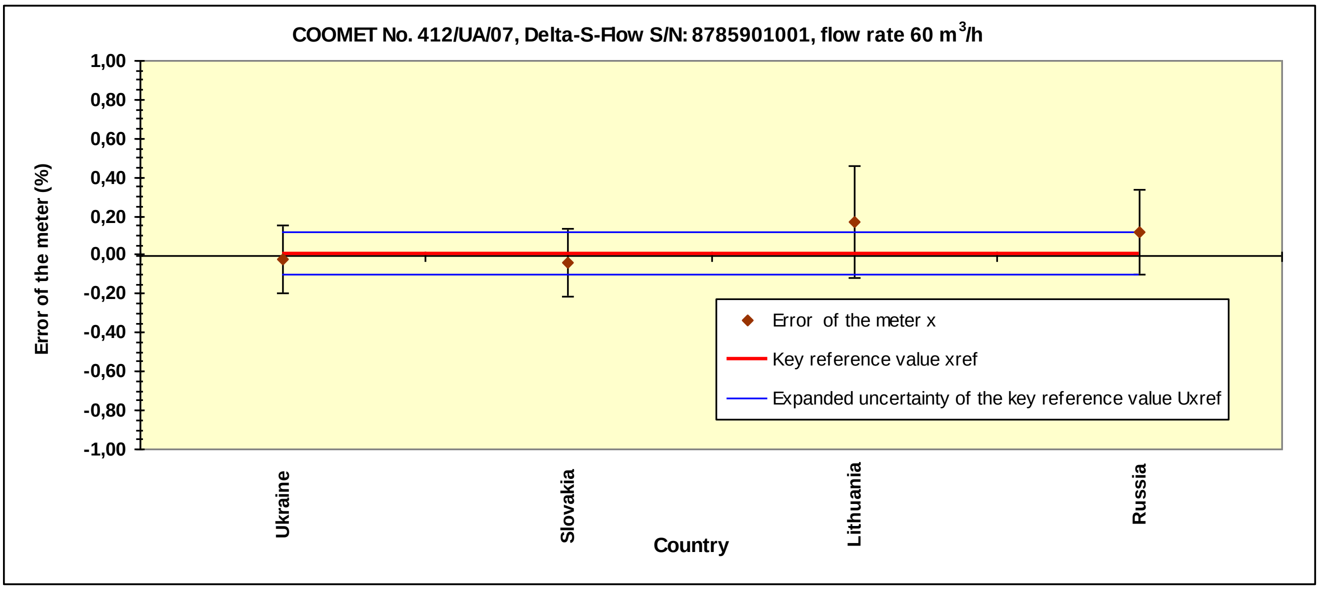

Fig. 18. The measurements results (flow of 60 m^3/h)

Table 17 The measurements results at flow rate value of 50 m^3/h

Country	Error of the meter *x*, %	Uncertainty *U(k=2)*	*di*	*U(di)*	*Ei*	x_{ref}	$x_{ref} + U_{xref}$	$x_{ref} - U_{xref}$
Ukraine	-0,04	0,17	-0,018	0,139	0,13	-0,02	0,084	-0,128
Slovakia	-0,07	0,17	-0,048	0,129	0,37	-0,02	0,084	-0,128
Lithuania	0,15	0,28	0,172	0,264	0,65	-0,02	0,084	-0,128
Russia	0,09	0,22	0,112	0,192	0,58	-0,02	0,084	-0,128

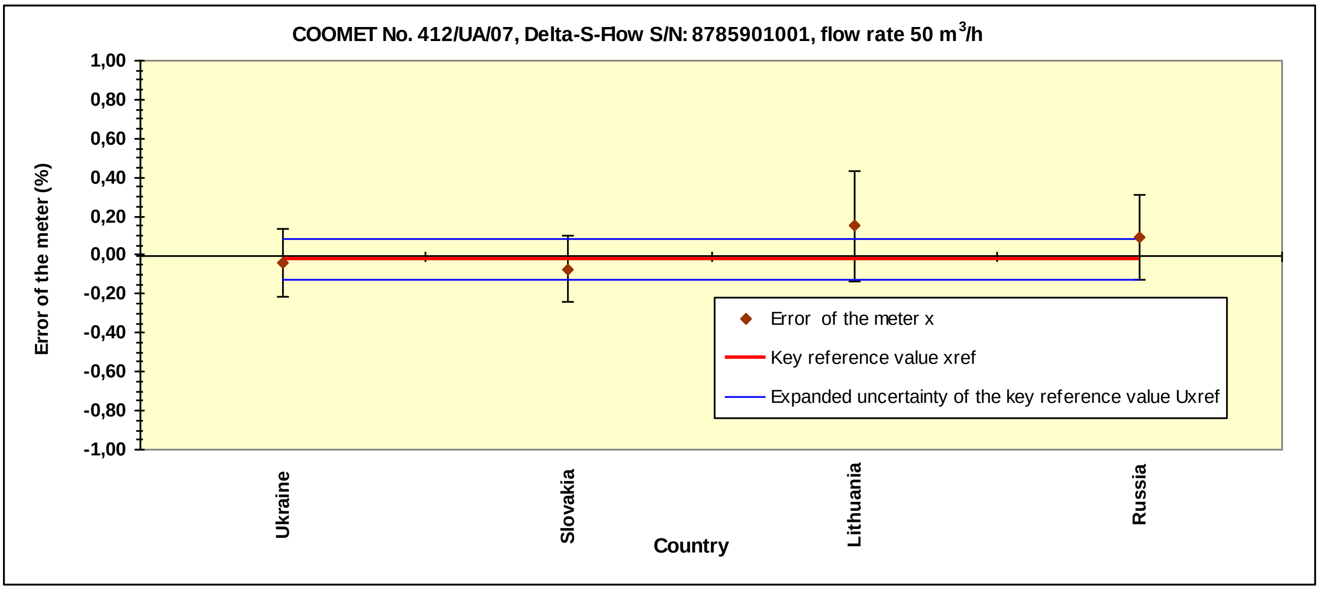

Fig. 19. The measurements results (flow of 50 m^3/h)

Table 18 The measurements results at flow rate value of 40 m^3/h

Country	Error of the meter *x*, %	Uncertainty *U(k=2)*	*di*	*U(di)*	*Ei*	x_{ref}	$x_{ref} + U_{xref}$	$x_{ref} - U_{xref}$
Ukraine	-0,07	0,17	-0,028	0,139	0,20	-0,04	0,064	-0,147
Slovakia	-0,08	0,17	-0,038	0,129	0,30	-0,04	0,064	-0,147
Lithuania	0,12	0,28	0,162	0,264	0,61	-0,04	0,064	-0,147
Russia	0,07	0,22	0,112	0,192	0,58	-0,04	0,064	-0,147

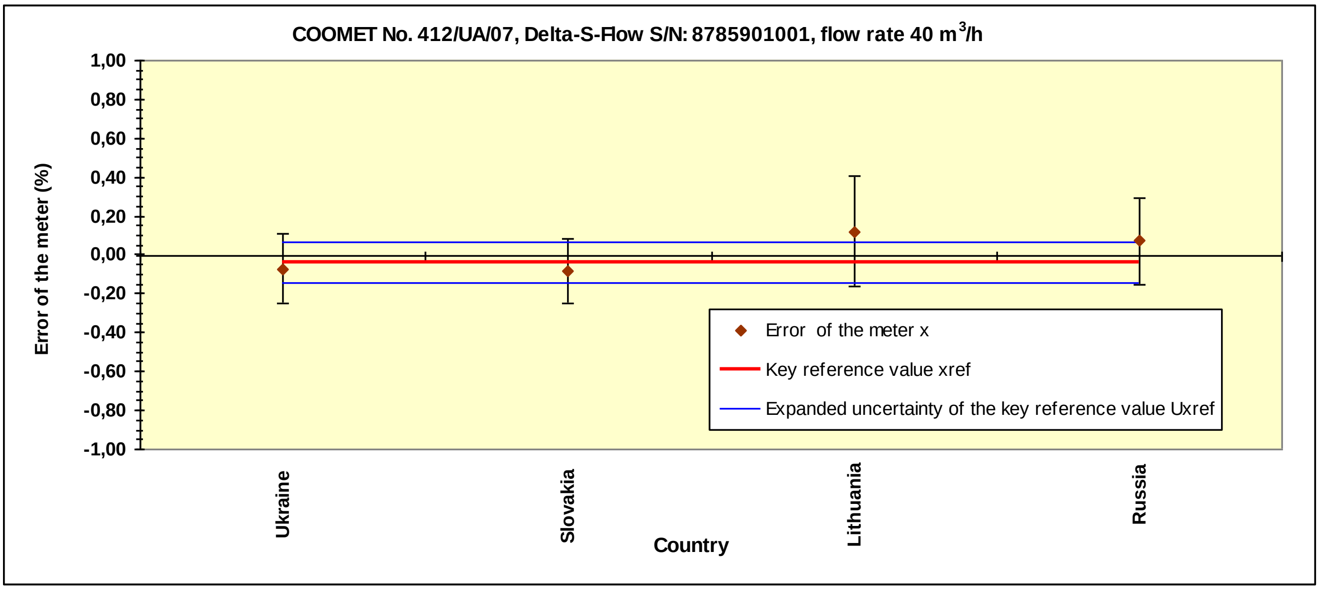

Fig. 20. The measurements results (flow of 40 m^3/h)

Table 19 The measurements results at flow rate value of 25 m^3/h

Country	Error of the meter *x*, %	Uncertainty *U(k=2)*	*di*	*U(di)*	*Ei*	x_{ref}	$x_{ref} + U_{xref}$	$x_{ref} - U_{xref}$
Ukraine	-0,12	0,17	-0,048	0,139	0,34	-0,07	0,034	-0,178
Slovakia	-0,07	0,17	0,002	0,129	0,02	-0,07	0,034	-0,178
Lithuania	0,05	0,28	0,122	0,264	0,46	-0,07	0,034	-0,178
Russia	0,00	0,22	0,072	0,192	0,37	-0,07	0,034	-0,178

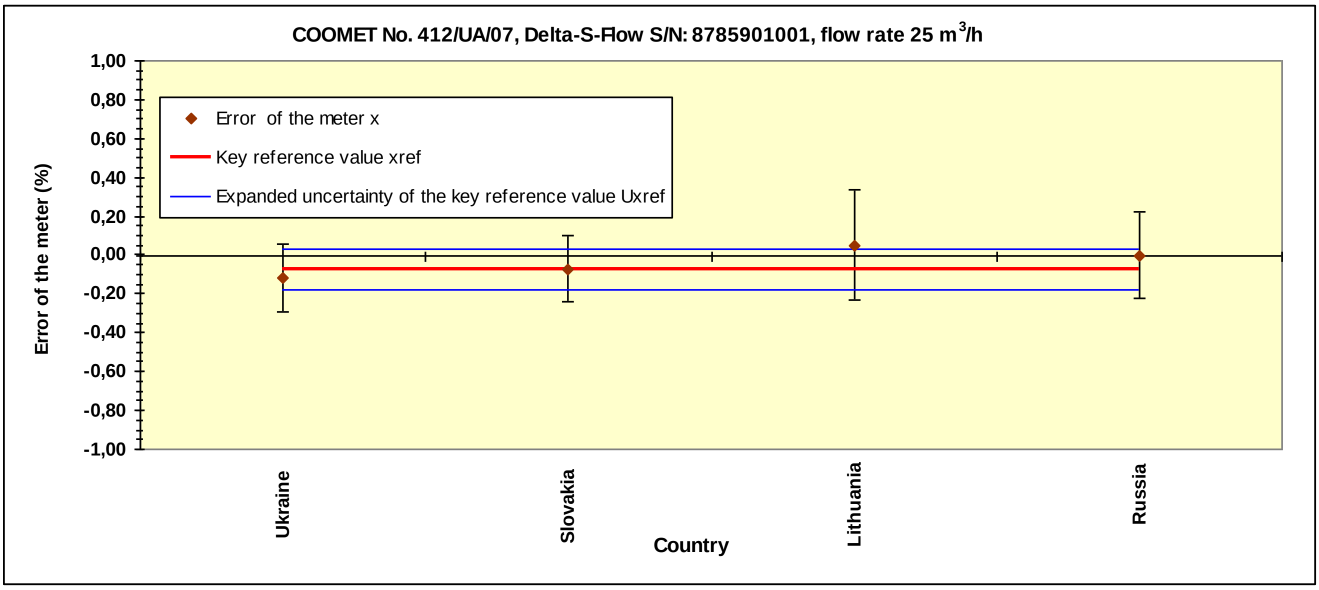

Fig. 21. The measurements results (flow of 25 m^3/h)

Table 20 The measurements results at flow rate value of 12 m^3/h

Country	Error of the meter *x*, %	Uncertainty *U(k=2)*	*di*	*U(di)*	*Ei*	x_{ref}	$x_{ref} + U_{xref}$	$x_{ref} - U_{xref}$
Ukraine	-0,21	0,17	-0,081	0,139	0,58	-0,13	-0,023	-0,234
Slovakia	-0,10	0,17	0,029	0,129	0,22	-0,13	-0,023	-0,234
Lithuania	-0,01	0,30	0,119	0,285	0,42	-0,13	-0,023	-0,234
Russia	-0,05	0,22	0,079	0,192	0,41	-0,13	-0,023	-0,234

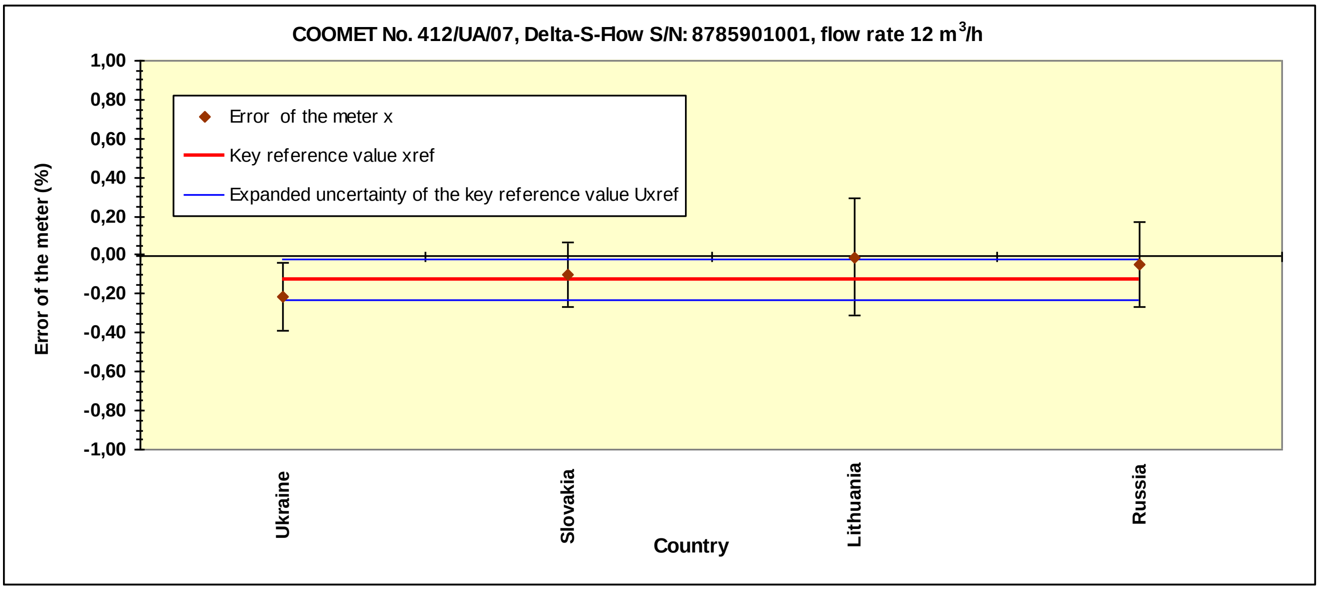

Fig. 22. The measurements results (flow of 12 m^3/h)

Table 21 The measurements results at flow rate value of 8 m^3/h

Country	Error of the meter *x*, %	Uncertainty *U(k=2)*	*di*	*U(di)*	*Ei*	x_{ref}	$x_{ref} + U_{xref}$	$x_{ref} - U_{xref}$
Ukraine	-0,28	0,17	-0,081	0,138	0,59	-0,20	-0,091	-0,306
Slovakia	-0,18	0,17	0,019	0,138	0,14	-0,20	-0,091	-0,306
Lithuania	-0,09	0,30	0,109	0,284	0,38	-0,20	-0,091	-0,306
Russia	-0,10	0,22	0,099	0,191	0,52	-0,20	-0,091	-0,306

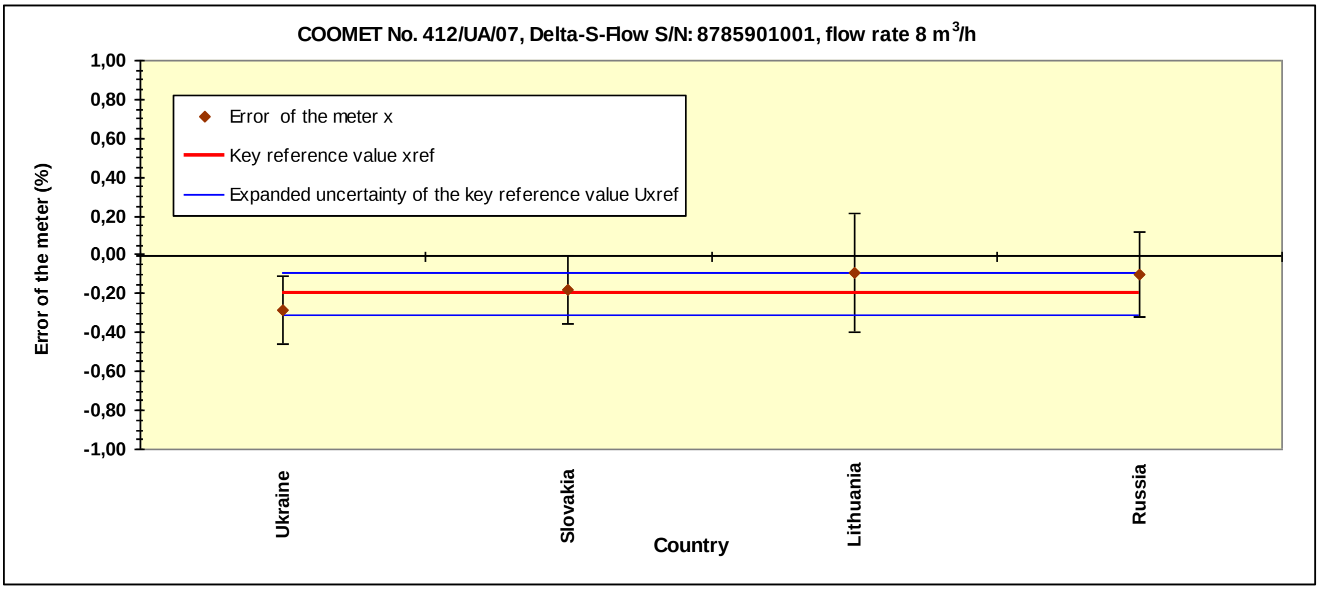

Fig. 23. The measurements results (flow of 8 m^3/h)

Table 22 The measurements results at flow rate value of 5 m^3/h

Country	Error of the meter *x*, %	Uncertainty *U(k=2)*	*di*	*U(di)*	*Ei*	x_{ref}	$x_{ref} + U_{xref}$	$x_{ref} - U_{xref}$
Ukraine	-0,40	0,17	-0,086	0,138	0,63	-0,31	-0,206	-0,422
Slovakia	-0,30	0,17	0,014	0,138	0,10	-0,31	-0,206	-0,422
Lithuania	-0,19	0,30	0,124	0,284	0,44	-0,31	-0,206	-0,422
Russia	-0,20	0,22	0,114	0,191	0,60	-0,31	-0,206	-0,422

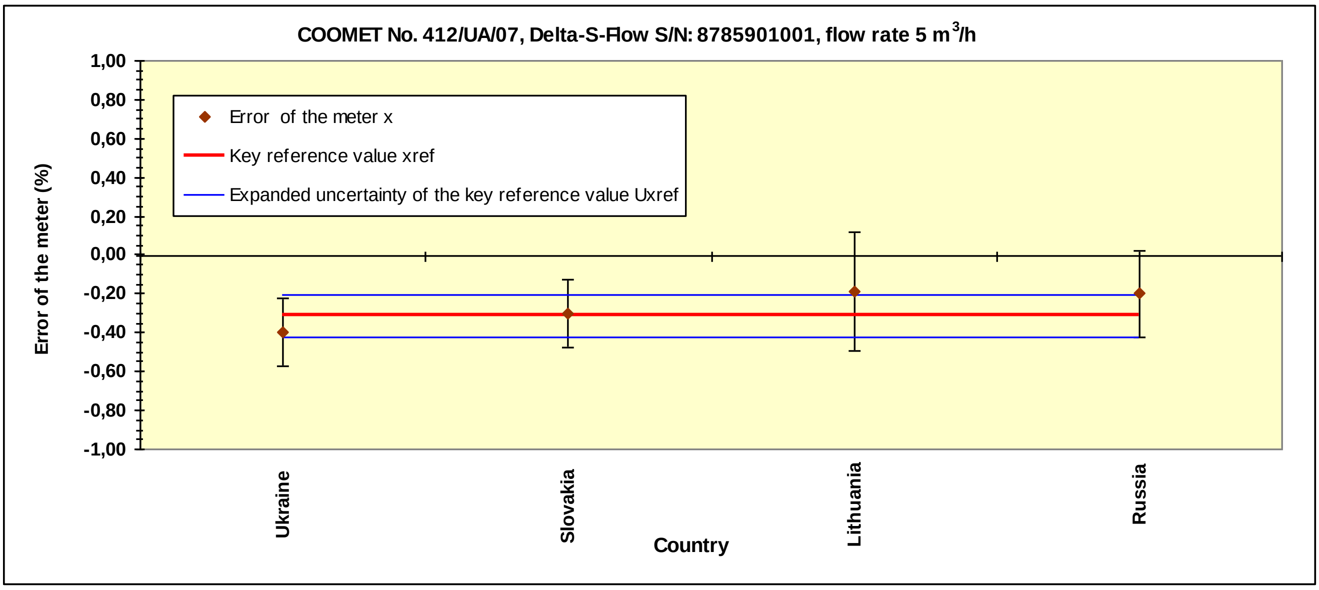

Fig. 24. The measurements results (flow of 5 m^3/h)

Table 23 The measurements results at flow rate value of 4 m^3/h

Country	Error of the meter *x, %*	Uncertainty *U(k=2)*	*di*	*U(di)*	*Ei*	x_{ref}	$x_{ref} + U_{xref}$	$x_{ref} - U_{xref}$
Ukraine	-0,47	0,17	-0,063	0,139	0,45	-0,41	-0,301	-0,513
Slovakia	-0,36	0,17	0,047	0,129	0,37	-0,41	-0,301	-0,513
Lithuania	-0,28	0,30	0,127	0,285	0,45	-0,41	-0,301	-0,513
Russia	-0,39	0,22	0,017	0,192	0,09	-0,41	-0,301	-0,513

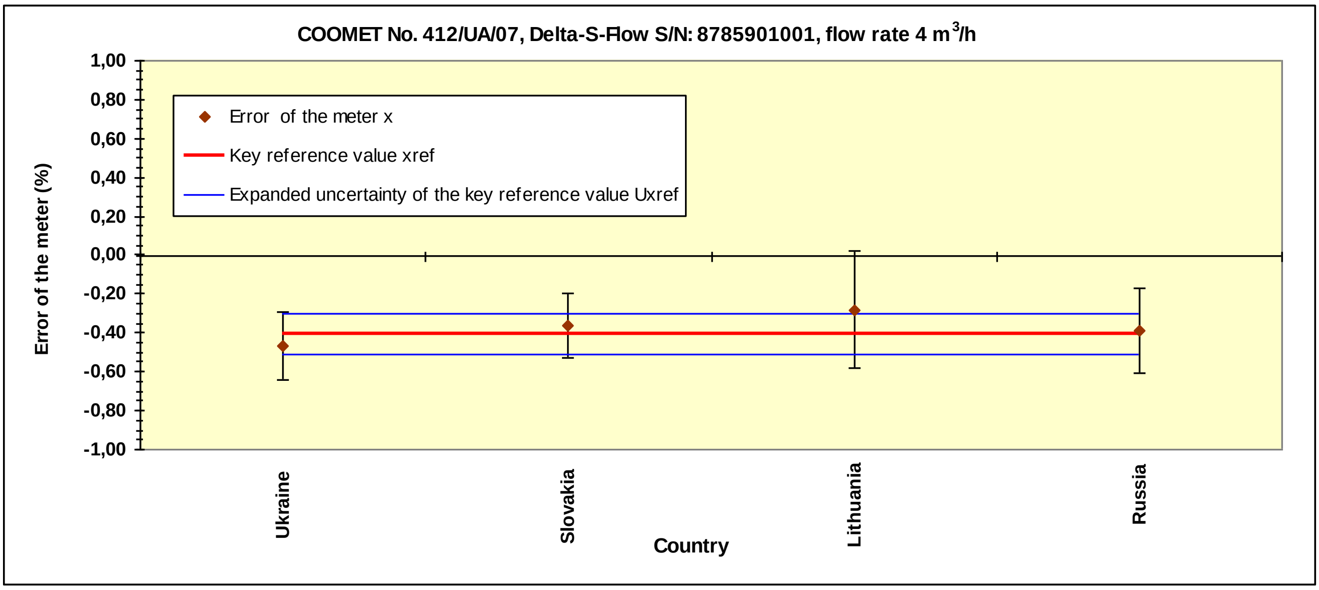

Fig. 25. The measurements results (flow of 4 m^3/h)

6.3 Comparisons analysis

6.3.1 Ukraine

flow in the meter	error of the meter	uncertainty of the error *U*(*k*=2)	reference value *y* (KCRV)	uncertainty of the reference value *U*(*k*=2)	*di*	*Ei*	result	consistency check
160,00	0,23	0,17	0,25	0,14	-0,02	0,14	passed	inside
140,00	0,18	0,17	0,21	0,14	-0,03	0,25	passed	inside
120,00	0,13	0,17	0,12	0,12	0,01	0,10	passed	inside
100,00	0,08	0,17	0,07	0,12	0,01	0,09	passed	inside
90,00	0,05	0,17	0,07	0,12	-0,02	0,18	passed	inside
70,00	0,00	0,17	0,03	0,11	-0,03	0,25	passed	inside
60,00	-0,02	0,17	0,01	0,11	-0,03	0,19	passed	inside
50,00	-0,04	0,17	-0,02	0,11	-0,02	0,13	passed	inside
40,00	-0,07	0,17	-0,04	0,11	-0,03	0,20	passed	inside
25,00	-0,12	0,17	-0,07	0,11	-0,05	0,34	passed	inside
12,00	-0,21	0,17	-0,13	0,11	-0,08	0,58	passed	inside
8,00	-0,28	0,17	-0,20	0,11	-0,08	0,59	passed	inside
5,00	-0,40	0,17	-0,31	0,11	-0,09	0,63	passed	inside
4,00	-0,47	0,17	-0,41	0,11	-0,06	0,45	passed	inside
				Mean	**-0,04**	**0,29**	**passed**	

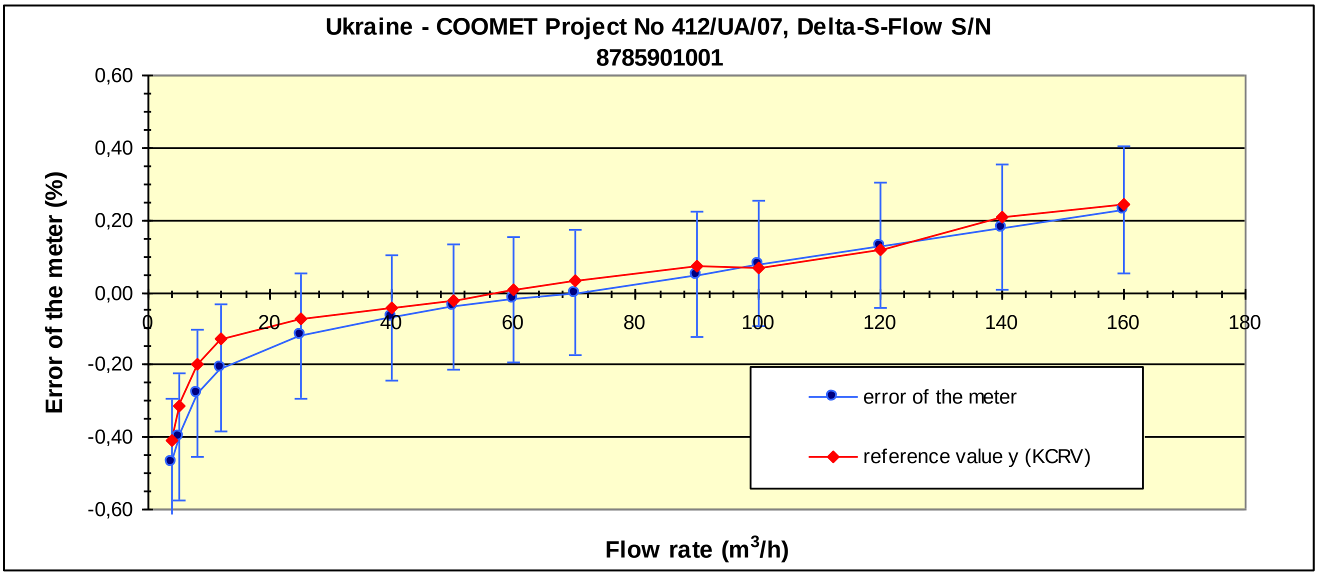

Fig. 26. The results of the comparisons in Ukraine.

6.3.2 Slovakia

flow in the meter	**error of the meter**	**uncertainty of the error *U*(*k*=2)**	**reference value *y* (KCRV)**	**uncertainty of the reference value *U*(*k*=2)**	***di***	***Ei***	**result**	**consistency check**
120,00	-0,05	0,26	0,12	0,12	-0,17	0,74	passed	inside
100,00	-0,08	0,22	0,07	0,12	-0,15	0,80	passed	inside
90,00	-0,01	0,26	0,07	0,12	-0,08	0,37	passed	inside
70,00	0,00	0,17	0,03	0,11	-0,03	0,25	passed	inside
60,00	-0,04	0,17	0,01	0,11	-0,05	0,34	passed	inside
50,00	-0,07	0,17	-0,02	0,11	-0,05	0,37	passed	inside
40,00	-0,08	0,17	-0,04	0,11	-0,04	0,30	passed	inside
25,00	-0,07	0,17	-0,07	0,11	0,00	0,02	passed	inside
12,00	-0,10	0,17	-0,13	0,11	0,03	0,22	passed	inside
8,00	-0,18	0,17	-0,20	0,11	0,02	0,14	passed	inside
5,00	-0,30	0,17	-0,31	0,11	0,01	0,10	passed	inside
4,00	-0,36	0,17	-0,41	0,11	0,05	0,37	passed	inside
				Mean	**-0,04**	**0,33**	**passed**	

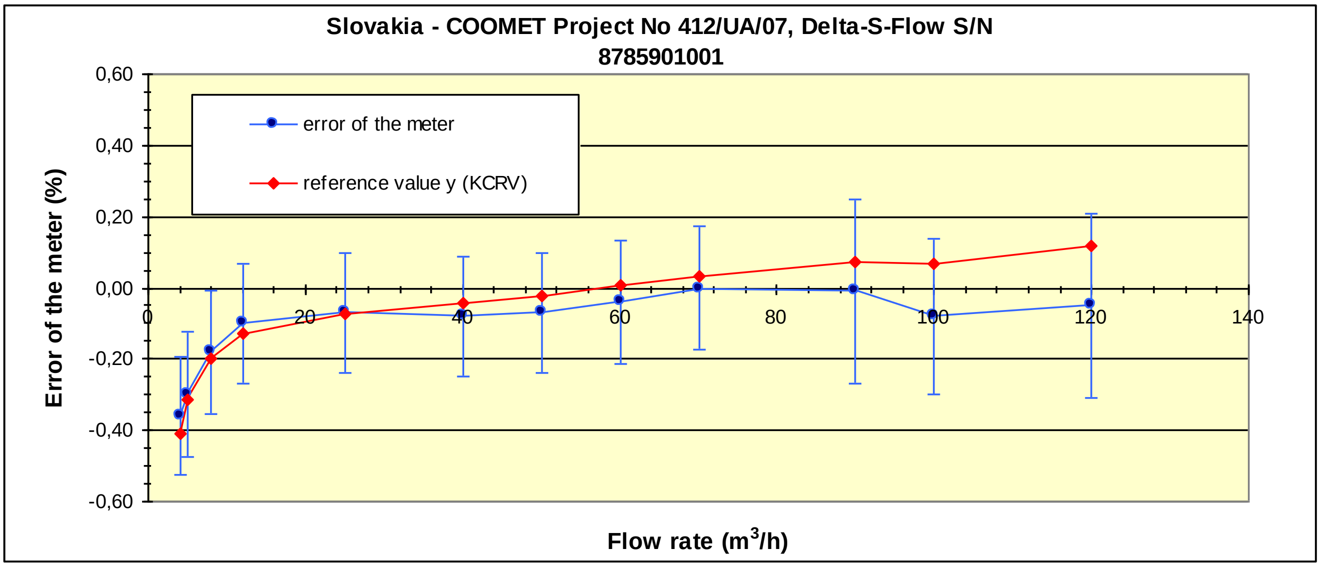

Fig. 27. The results of the comparisons in Slovakia.

6.3.3 Lithuania

flow in the meter	error of the meter	uncertainty of the error *U*(*k*=2)	reference value *y* (KCRV)	uncertainty of the reference value *U*(*k*=2)	*di*	*Ei*	result	consistency check
90,00	0,35	0,28	0,07	0,12	0,28	1,07	warning	inside
70,00	0,25	0,28	0,03	0,11	0,22	0,82	passed	inside
60,00	0,17	0,28	0,01	0,11	0,16	0,62	passed	inside
50,00	0,15	0,28	-0,02	0,11	0,17	0,65	passed	inside
40,00	0,12	0,28	-0,04	0,11	0,16	0,61	passed	inside
25,00	0,05	0,28	-0,07	0,11	0,12	0,46	passed	inside
12,00	-0,01	0,30	-0,13	0,11	0,12	0,42	passed	inside
8,00	-0,09	0,30	-0,20	0,11	0,11	0,38	passed	inside
5,00	-0,19	0,30	-0,31	0,11	0,12	0,44	passed	inside
4,00	-0,28	0,30	-0,41	0,11	0,13	0,45	passed	inside
				Mean	**0,16**	**0,59**	**passed**	

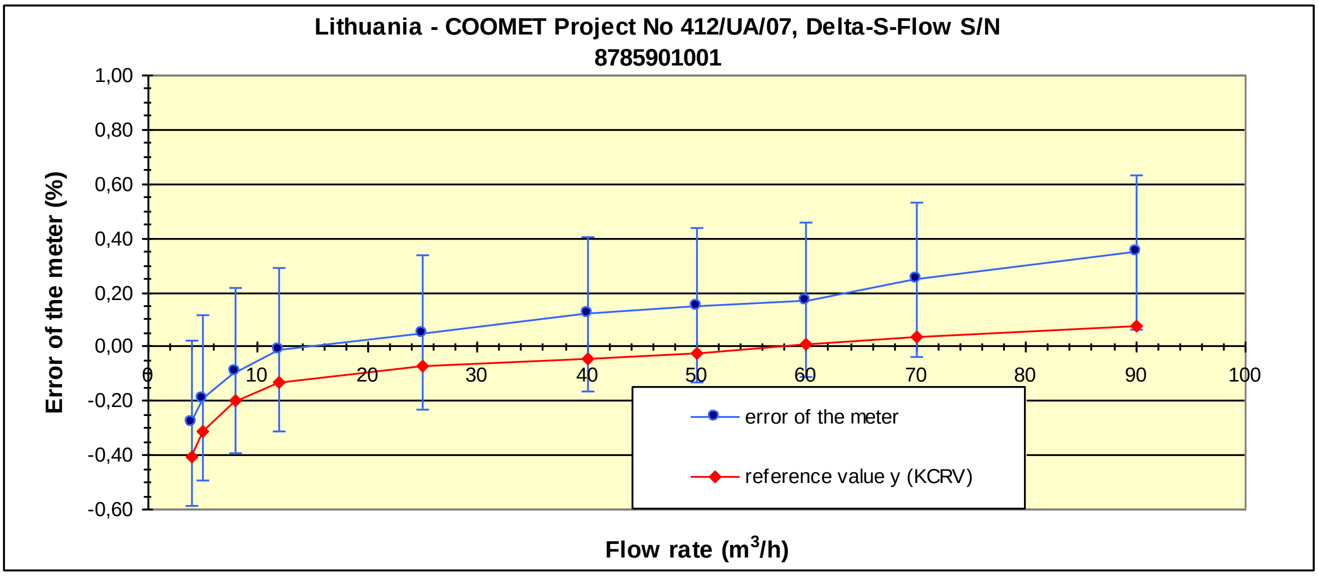

Fig. 28. The results of the comparisons in Lithuania.

6.3.4 Russia

flow in the meter	error of the meter	uncertainty of the error *U*(*k*=2)	reference value y (KCRV)	uncertainty of the refrence value *U*(*k*=2)	*di*	*Ei*	result	consistency check
160,00	0,27	0,22	0,25	0,14	0,02	0,14	passed	inside
140,00	0,25	0,22	0,21	0,14	0,04	0,25	passed	inside
120,00	0,22	0,22	0,12	0,12	0,10	0,56	passed	inside
100,00	0,20	0,22	0,07	0,12	0,13	0,70	passed	inside
90,00	0,17	0,22	0,07	0,12	0,10	0,53	passed	inside
70,00	0,14	0,22	0,03	0,11	0,11	0,56	passed	inside
60,00	0,12	0,22	0,01	0,11	0,11	0,60	passed	inside
50,00	0,09	0,22	-0,02	0,11	0,11	0,58	passed	inside
40,00	0,07	0,22	-0,04	0,11	0,11	0,58	passed	inside
25,00	0,00	0,22	-0,07	0,11	0,07	0,37	passed	inside
12,00	-0,05	0,22	-0,13	0,11	0,08	0,41	passed	inside
8,00	-0,10	0,22	-0,20	0,11	0,10	0,52	passed	inside

5,00	-0,20	0,22	-0,31	0,11	0,11	0,60	passed	inside
4,00	-0,39	0,22	-0,41	0,11	0,02	0,09	passed	inside
				Mean	**0,09**	**0,46**	**passed**	

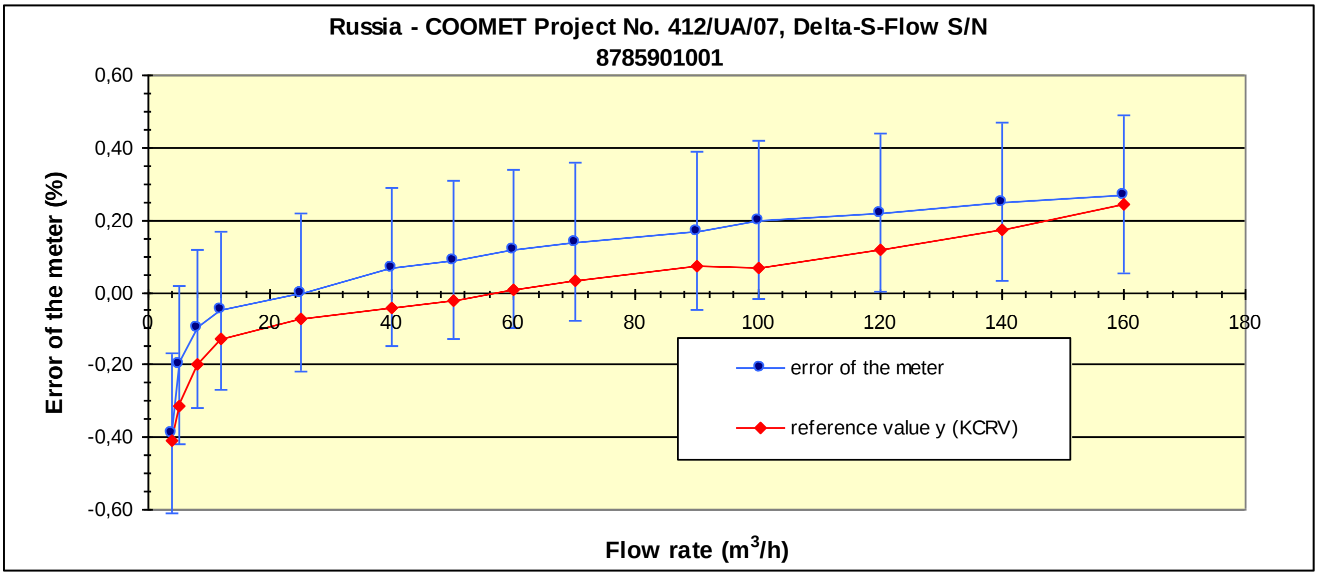

Fig. 29. The results of the comparisons in Russia.

7. Conclusions

For a more detailed depiction of relations among the participating laboratories, we prepared outcomes of comparison measurements, which bring an information on quality of metrology assurance and uniformity of measurements in the region of operation of participating laboratories.

Table 24 The initial data obtained during experimental studies

Flow rate in the meter (m^3/h)	Ukraine (%)	Slovakia (%)	Russia (%)	Comparison reference value (%)	Uncertainty of the reference value *U*(*k*=2)
160	0,23		0,27	0,25	0,14
140	0,18		0,25	0,21	0,14
120	0,13	-0,05	0,22	0,12	0,12
100	0,08	-0,08	0,2	0,07	0,12
90	0,05	-0,01	0,17	0,07	0,12

70	0,00	0,00	0,14	0,03	0,11
60	-0,02	-0,04	0,12	0,01	0,11
50	-0,04	-0,07	0,09	-0,02	0,11
40	-0,07	-0,08	0,07	-0,04	0,11
25	-0,12	-0,07	0	-0,07	0,11
12	-0,21	-0,10	-0,05	-0,13	0,11
8	-0,28	-0,18	-0,1	-0,20	0,11
5	-0,40	-0,30	-0,2	-0,31	0,11
4	-0,47	-0,36	-0,39	-0,41	0,11

Table 25 Analysis of the results of comparisons

Analysis of the results				
Evaluation	Independent laboratories			
	Ukraine	Slovakia	Russia	Lithuania
Satisfactory results	14	12	14	9
Results with a warning	0	0	0	1
Unsatisfactory results	0	0	0	0
Number of measured flow points	14	12	14	10

The following figure shows the error curve of compared measurement means, of rotary gas meter Delta S-Flow, the size G100, serial number 8785901001, which were obtained by individual participating laboratories.

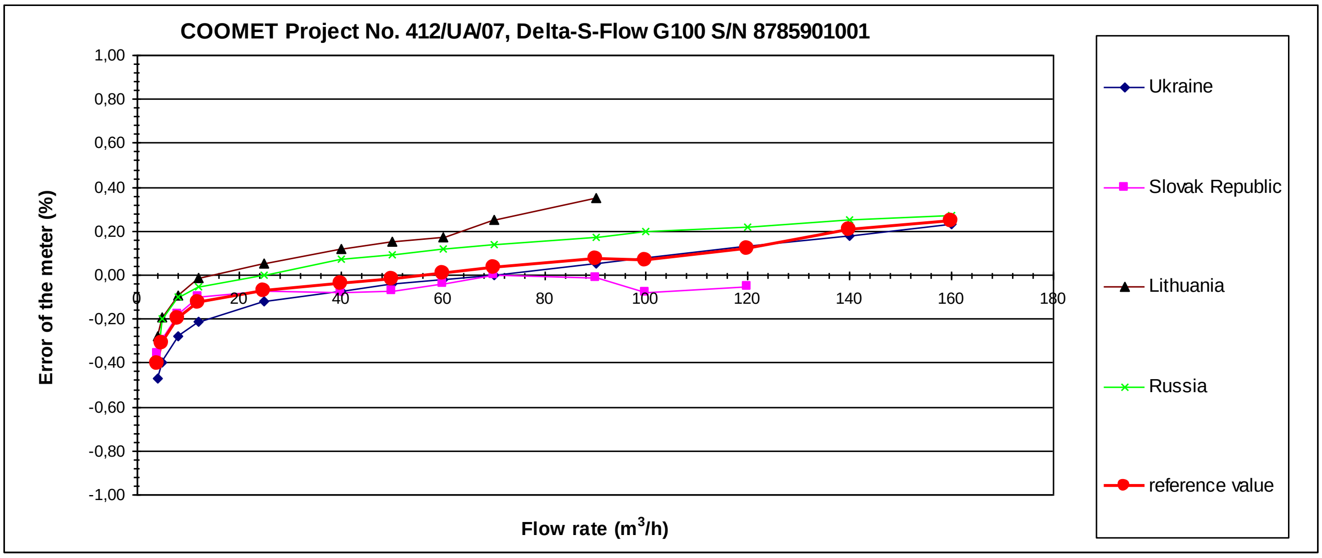

Fig. 30. Results of comparison.