Final Report – Draft B

Inter-comparison in the gas flow range from 1 m^3/h to 250 m^3/h with sonic nozzles

EURAMET Project No. 1396

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Contents

1. Introduction

The project EURAMET no.1396 was an inter-comparison among three laboratories with sonic nozzles and the one officially started in July 2017 and was concluded in April 2018. The planned time schedule is mentioned down in *table 1*. Each country took almost 3 months to perform the calibration of sonic nozzles. The nominal range of flow rates was from 1 m^3/h to 250 m^3/h. The participating laboratories used their usual calibration procedure. The comparison was conducted with respect to guidelines1).

One participant of this project Germany (PTB) was also participants in the *CIPM key comparison CCM.FF-K6.2011* which covers flow rates only from 2 m^3/h to 100 m^3/h. Hence, in the moment when this report is issued, no CIPM key comparison was finished in the field of low pressure gas flow in all the relevant flow rates. One participant is not also a member of EURAMET. That is why this inter-comparison is EURAMET supplementary comparison.

Table 1 – Time schedule and participants

Country	**Laboratory**	**Address of the place of calibration**	**e-mail telephone**	**Date of calibration**	**Responsible person**
Germany	PTB Physikalisch-Technische Bundesanstalt	PTB Bundesallee 100 38116 Braunschweig Germany	Bodo.Mickan@ptb.de ++49 531 592 1331	July-September 2017	Bodo Mickan
Czech Republic (PILOT LAB)	CMI Czech Metrology Institute	CMI Regional Inspectorate Pardubice Prumyslova 455, 530 03 Pardubice, Czech Republic	tvalenta@cmi.cz +420 466 670 728	October 2017-January 2018	Tomas Valenta
Russia	All-Russian Research Institute of Flow Metering (VNIIR) Федеральное Государственное Унитарное Предприятие "Всероссийский научно-исследовательский институт расходометрии"	VNIIR Vtoraya Azinskaya St., 7A 420088 Kazan, Russia	nio13@vniir.org (ilya.isaev@mail.ru) +7(843) 272-11-24	February-April 2018	Ilya Isaev

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1) - for CIPM key comparisons http://www.bipm.org/utils/en/pdf/guidelines.pdf
- for EURAMET comparisons – EURAMET Guide no.4 https://www.euramet.org/get/?tx_stag_base%5Bfile%5D=31515&tx_stag_base%5Baction%5D=downloadRaw&tx_stag_base%5Bcontroller%5D=Base

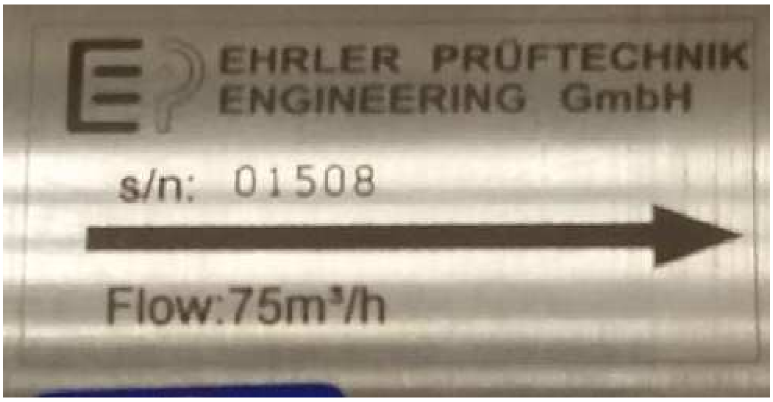
2. The instruments

Sonic nozzles were used for inter-comparison. The dimensional characteristics and marking stickers are specified in the pictures mentioned down.

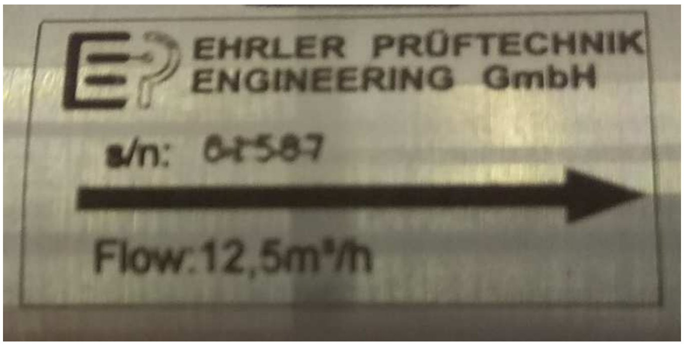
2.1. Sonic nozzle 250 m³/h

2.2. Sonic nozzle 150 m^3/h

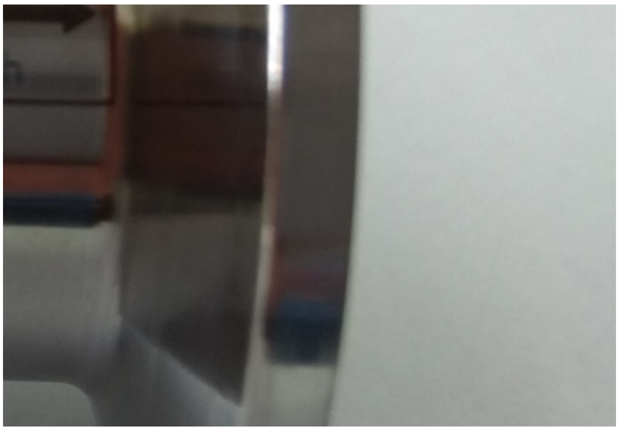
2.3. Sonic nozzle 75.0 m^3/h

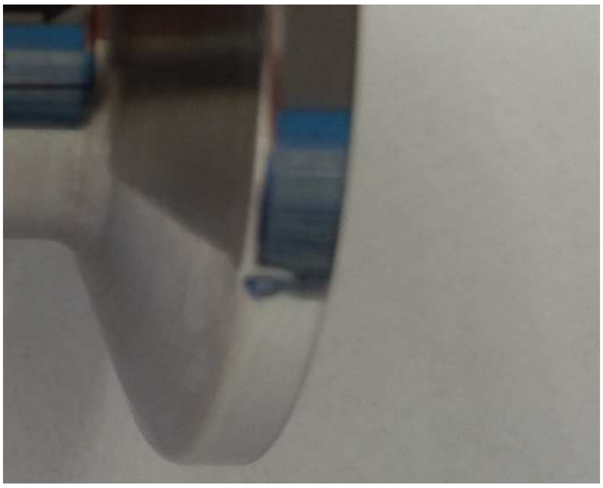


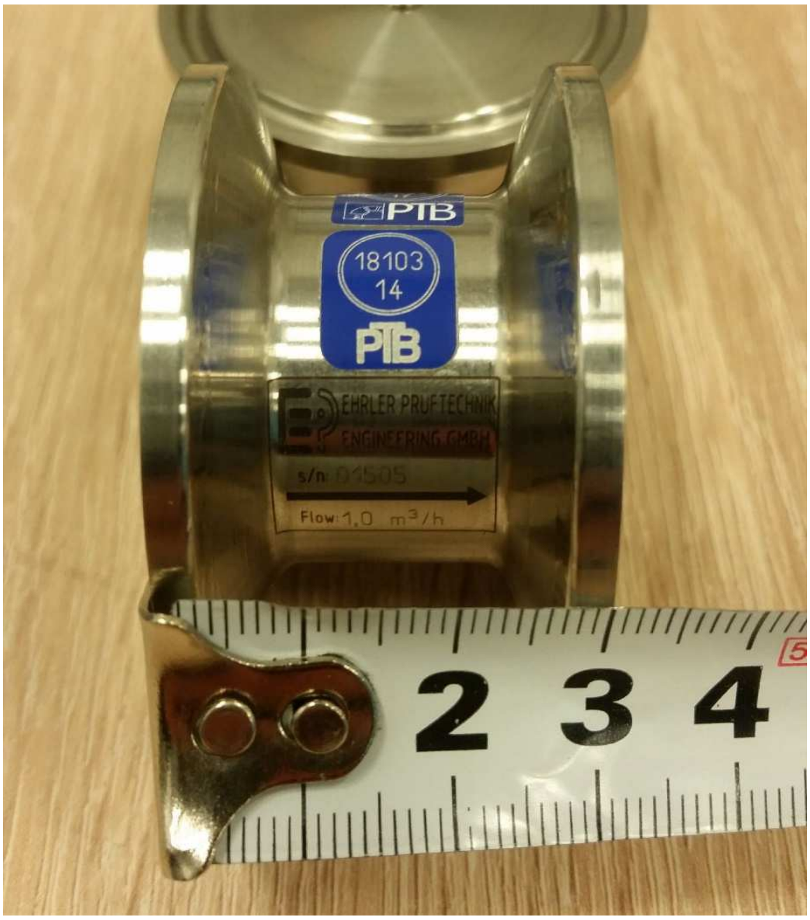
2.4. Sonic nozzle 12.5 m^3/h



2.5. Sonic nozzle 2.5 m3/h and 1.0 m3/h (identical dimensions)

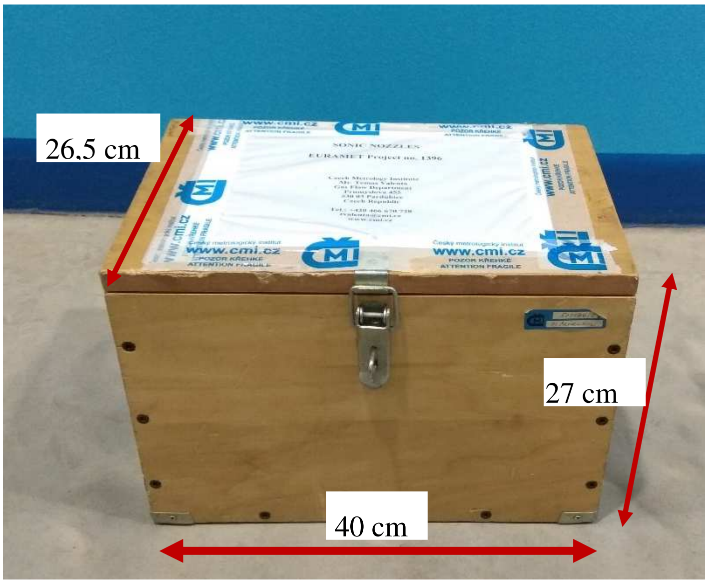





PTB
18103
14
PTB
EHRLER PRÜFTECHNIK
ENGINEERING GMBH
s/n: 01505
Flow: 1,0 m³/h
2 3 4


5m
2 3 4 5 6

The sonic nozzles were packed in wooden box for the transport among laboratories. The weight of the box was approximately 11 kg.



In the box there were the sonic nozzles and the copy of *Technical protocol.*

3. Calibration procedure

The calibration test procedure is mentioned in the document ***Wendt, G; Dietrich, H.; Jarosch, B.; Joest, R.; Natz, B.; Frössl, F.; Ruwe, M.: PTB testing instruction Volume 25: Gas meters – Test rigs with critical nozzles (English version 2000: 91 pages).***

The calibrations of a sonic nozzle with nominal flow rates **250 m^3/h, 150 m^3/h, 75 m^3/h** were performed according to the chapter *3.2.1 Determination of nozzle reference value* $Q_{v,20,dryAir}$ *(one point test).*

The calibrations of sonic nozzles with nominal flow rates **12.5 m^3/h, 2.5 m^3/h and 1.0 m^3/h** were performed according to the chapter *3.2.2 Determination of nozzle reference value* $Q_{v,20,tr,1000}$ *(two points test).*

The ambient temperature in laboratory had to be (21±1) °C and the relative humidity in laboratory had to be less than 80 % during the tests.

4. Test facility and obtained results

4.1. Germany

The Bell Prover of the Physikalisch-Technische Bundesanstalt serves as the fundamental realisation of the unit "Volume" within the field of gas measurement and is the primary standard for gas volume at lower pressure ranges. This one was used for calibration of three sonic nozzles with nominal flow rates 12.5 m^3/h, 2.5 m^3/h and 1.0 m^3/h. The unit of volume, respectively of its flow, can be passed on to various users by a direct or indirect connection for the calibration of secondary standards. The measurement uncertainty for the data acquisition during the measuring period amounts for the temperature to ± 0.02° C and for the pressure to ± 5 Pa. The verification of high- quality standards (critical nozzles) showed repeatability of ± 0.02 %.

Range of flow rate: (1 to 80) m^3/h
Temperature: (20 ± 2)°C
Working pressure: atmospheric conditions
Uncertainty CMC (k=2): 0.045 % (NMI Service Identifier: DE34)

Place of calibration: Physikalisch-Technische Bundesanstalt (PTB)
Bundesallee 100, D-38116 Braunschweig, Germany

The larger sonic nozzles with nominal flow rates 250 m^3/h, 150 m^3/h, 75 m^3/h were calibrated at large nozzle test rig with NMI Service Identifier DE35 with CMC U(k=2)=0.08% using a transfer meter.

Results:

Nozzle-ID s.n.	$Q_{V,20,\mathrm{dryAir}}$	U(k=2)	p_{Test}
	[m^3/h]	[%]	[kPa]
01510	248.85	0.08	101.04
01509	149.25	0.08	101.39
01508	74.522	0.08	101.50

Nozzle-ID s.n.	$Q_{v.20.tr.1000}$	U(k=2)	c_{pE}
	[m^3/h]	[%]	[1/mbar]
01507	12.20144	0.045	9.06E-05
01506	2.47513	0.045	1.54E-04
01505	0.98604	0.045	1.42E-04

4.2. Czech Republic

Place of the test

Czech Metrology Institute, Gas Flow Department, Prumyslova 455, 530 03 Pardubice, Czech Republic

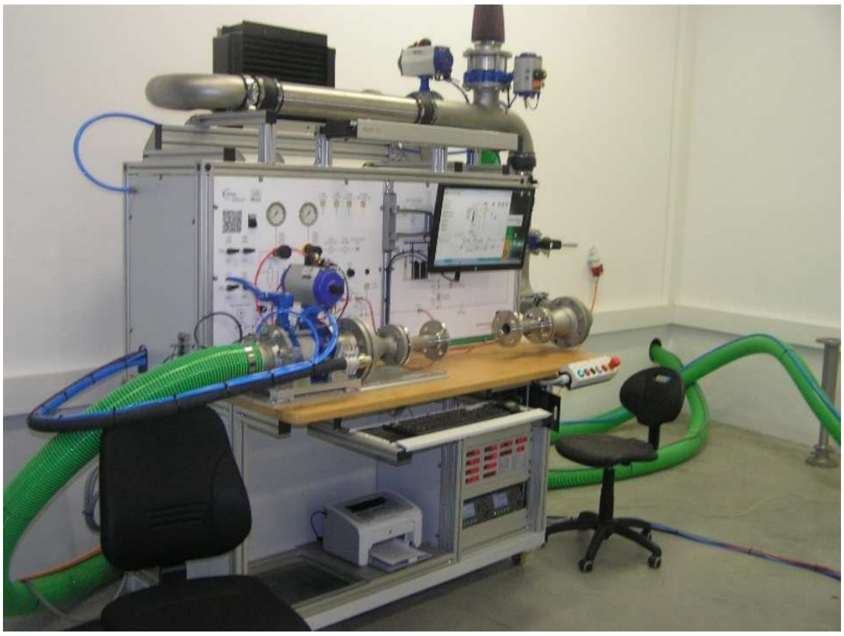
The test facility

A new national standard Bell Prover with the range from 0.5 m^3/h to 280 m^3/h was used for the calibrations of all the sonic nozzles. The bell was dimensionally very accurately evaluated by PTB. The manufacturer was company EP Ehrler Prüftechnik Engineering GmbH, Germany. The Bell Prover consists of:

- exactly dimensioned stainless steel bell
- connection system with switching device
- oil Shell Morlina 5
- fan, vacuum pump
- pressure vessel 2.7 m3
- control PC with software
- electronic digital thermometers with 0.01°C graduation scale, 4 pieces of manufacturer Temperaturmeßtechnik Geraberg GmbH,
- electronic digital pressure instruments with 1 Pa graduation scale , 5 pieces
  manufacturer PAROSCIENTIFIC, INC, 1 piece
  manufacturer YOKOGAWA, 3 pieces
  manufacturer ROSEMOUNT, 1 piece
- incremental rulers with 0.001 mm graduation scale, 2 pcs
  producer HEDENHEIN

- timing circuit in a collecting unit serving as a stopwatch with a message of 0.001 s, 1 piece
  manufacturer Brehm + Jung
- hygrometer, 1 pc
  manufacturer JUMO

The nozzles were tested in sinking mode. Waiting time between measurements is 300 seconds. This Bell Prover is mentioned in CMC with NMI Service Identifier CZ21 and U(k=2)=0.07 %.



Results:

Nozzle-ID s.n.	$Q_{V,20,dryAir}$	U(k=2)	p_{Test}
	[m^3/h]	[%]	[kPa]
01510	248.783	0.076	100.12
01509	149.212	0.073	100.36
01508	74.504	0.073	100.38

Nozzle-ID s.n.	$Q_{v.20.tr.1000}$	U(k=2)	c_{pE}
	[m^3/h]	[%]	[1/mbar]
01507	12.209	0.077	1.36E-05
01506	2.4759	0.077	1.09E-05
01505	0.98680	0.079	9.27E-06

4.3. Russia

Place of the test

All-Russian Research Institute of Flow Metering (VNIIR)
Федеральное Государственное Унитарное Предприятие "Всероссийский научно-исследовательский институт расходометрии"
Vtoraya Azinskaya St., 7A, 420088 Kazan, Russia

The test facility

A new Bell Prover with the range from 0.4 m^3/h to 100 m^3/h was used for the calibrations of 4 sonic nozzles with nominal flow rates 75 m^3/h, 12.5 m^3/h, 2.5 m^3/h and 1.0 m^3/h. The manufacturer was company EP Ehrler Prüftechnik Engineering GmbH, Germany, too. The specification of the Bell Prover is:

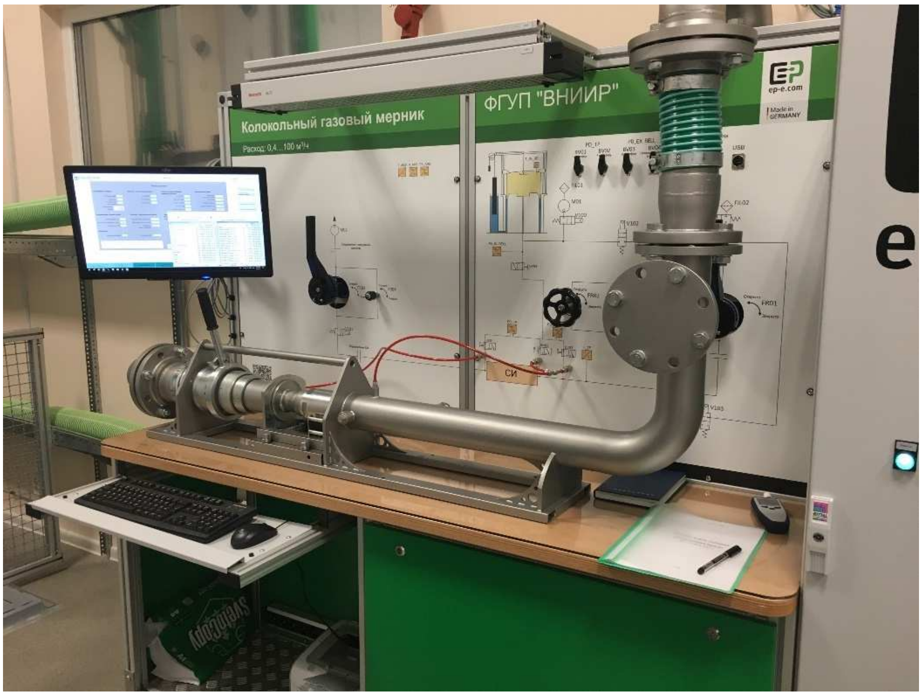
Operating range: 0.4 m^3/h to 100 m^3/h
- Measuring time: 20 seconds to 30 minutes
- Test volume: 0.2 m^3 to 1 m^3
- Bell diameter: approximately 1050 mm
- Max. stroke: approximately 1200 mm
- Operating pressure: approximately 1100 Pa
- Test medium: ambient air
- Bell material: stainless steel
- Sealing liquid: Morlina 5 Shell

On the https://kcdb.bipm.org/AppendixC/M/RU/M_RU.pdf there only CMC with NMI Service Identifier *VNIIR13.04* can be found with this specification:

Instrument Type or Method: Critical nozzles
Range: (1-100) m^3/h, air
U/(k=2)=0.15 %

Actual uncertainties of the Bell Prover used during this inter-comparison are these ones:

Q_{MuT} [m^3/h]	t_{meas} [s]	$U(Q_{MuT})$ (k = 2)	
		For Q_{MuT}	For $Q_{V,nozzle,20,tr}$
0,4	2830	0,097%	0,093%
1	2830	0,060%	<0,06%
16	160	0,060%	<0,06%
65	48	0,060%	<0,06%
100	20	0,066%	0,065%



Results:

Nozzle-ID s.n.	$Q_{V.20.dryAir}$	U(k=2)	p_{Test}
	[m^3/h]	[%]	[kPa]
01508	74.4848	0.06	100.21

Nozzle-ID s.n.	$Q_{v.20.tr.1000}$	U(k=2)	c_{pE}
	[m^3/h]	[%]	[1/mbar]
01507	12.2132	0.06	1.18E-05
01506	2.4757	0.06	1.61-05
01505	0.98669	0.06	2.46E-05

5. Stability of the meter and the dependency of laboratories

All the sonic nozzles were tested in PTB in 2014 and also during this project. The stability of the sonic nozzles was calculated from the differences of these results from PTB.

Nozzle-ID s.n.	*nominal flow rate*	Stability U_{tm}(k=2)
	[m^3/h]	[%]
01510	250	0.006
01509	150	0.016
01508	75	0.034
01507	12.5	0.037
01506	2.5	0.047
01505	1.0	0.042

In this project there were 3 independent laboratories from the point of view of metrological traceability:
Germany, Czech Republic Russia

6. Determination of the reference values in determined flow rates

6.1. Description of the method

The reference value was determined in each flow rate separately, it means separately for each sonic nozzle. The method of determination of the reference value in each flow rate corresponds to the procedure A presented by M.G.Cox[2)]. Results from independent laboratories were taken into account for the determination of the key comparison reference value (KCRV) and of the uncertainty of the key comparison reference value.

6.1.1. The determination of the Key Comparison Reference Value (KCRV) and its uncertainty

The reference value y was be calculated as weighted mean of parameters (determined flow rates) $Q_{v,20,tr}$ or $Q_{v,20,tr,1000}$.

[2)] Cox M.G., *Evaluation of key comparison data*, Metrologia, 2002, **39**, 589-595

$$y = \frac{\frac{x_1}{u_{x1}^2} + \frac{x_2}{u_{x2}^2} + \frac{x_3}{u_{x3}^2}}{\frac{1}{u_{x1}^2} + \frac{1}{u_{x2}^2} + \frac{1}{u_{x3}^2}} , \qquad [1]$$

where	x_1, x_2, x_{n3}	are parameters $\boldsymbol{Q_{v,20,tr}}$ or $\boldsymbol{Q_{v,20,tr,1000}}$ of a sonic nozzle in different independent laboratories *1,2,3* [m^3/h]
	u_{x1}, u_{x2},u_{x3}	are standard uncertainties (not expanded) in different independent laboratories *1,2,3* including the uncertainty caused by stability of a sonic nozzle [m^3/h]

The standard uncertainties (not expanded) of measurement in different laboratories u_{x1}, u_{x2},.....u_{x3} (equation [2]) will include the stability of a sonic nozzle. These uncertainties were calculated by

$$u_{xi} = \sqrt{\left(\frac{U_{xi\_lab}}{2}\right)^2 + \left(\frac{U_{tm}}{2}\right)^2} \qquad [2]$$

where	U_{xi_lab}	is the expanded uncertainty (k=2) determined by laboratory *i* and presented in results of laboratory *i* [m^3/h]
	U_{tm}	is estimated expanded uncertainty caused by the stability (reproducibility) of a sonic nozzle (Sonic nozzles were tested twice in PTB and from these results U_{tm} was determined.) [m^3/h]

The standard uncertainty of the reference value u_y is given by

$$\frac{1}{u_y^2} = \frac{1}{u_{x1}^2} + \frac{1}{u_{x2}^2} + \frac{1}{u_{x3}^2} \qquad [3]$$

The expanded uncertainty of the reference value *U(y)* is

$$U(y) = 2.u_y \qquad [4]$$

The chi-squared test for consistency check will be performed using parameters $\boldsymbol{Q_{v,20,tr}}$ or $\boldsymbol{Q_{v,20,tr,1000}}$ of a sonic nozzle. At first the chi-squared value χ^2_{obs} will be calculated by

$$\chi^2_{obs} = \frac{(x_1 - y)^2}{u^2_{x1}} + \frac{(x_2 - y)^2}{u^2_{x2}} + \frac{(x_3 - y)^2}{u^2_{x3}} \qquad [5]$$

The degrees of freedom ν will be assigned

$$\nu = n - 1 \qquad [6]$$

where n is number of evaluated laboratories.

The consistency check will be failing if

$$Pr\{\chi^2_\nu > \chi^2_{obs}\} < 0{,}05 \qquad [7]$$

(The function *CHIINV(0,05;ν)* in MS Excel will be used. The consistency check will be failing if *CHIINV(0,05; ν)<* χ^2_{obs})

If the consistency check does not fail then y will be accepted as the key comparison reference value x_{ref} and *U(y)* will be accepted as the expanded uncertainty of the key comparison reference value $U(x_{ref})$.

If the consistency check fails then the laboratory with the highest value of $\frac{(x_i - y)^2}{u^2_{xi}}$ will be excluded for the next round of evaluation and the new reference value y (WME), the new standard uncertainty of the reference value u_y and the chi-squared value χ^2_{obs} will be calculated again without the values of excluded laboratory. The consistency check will be calculated again, too. This procedure will be repeated till the consistency check will pass.

6.1.2. The determination of the differences "Lab to KCRV" and "Lab to Lab" as well as their uncertainties and Degrees of Equivalence

When the KCRV was determined, the differences between the participating laboratories and the KCRV were calculated according to

$$di = x_i - x_{ref} \qquad [8]$$

$$dij = x_i - x_j \qquad [9]$$

Based on these differences, the **D**egree **o**f **E**quivalence (*DoE*) was calculated according to:

$$Ei = \frac{di}{U(di)} \qquad [10]$$

and $$Eij = \frac{dij}{U(dij)} \quad , \quad \text{respectively.} \qquad [11]$$

The *DoE* is a measure for the equivalence of the results of any laboratory with the KCRV or with any other laboratory, respectively:

- The results of a laboratory is ***equivalent (passed) if*** **|*Ei*| *or* |*Eij*|≤*1.***
- The laboratory was determined as ***not equivalent (failed) if*** **|*Ei*| *or* |*Eij*| *>1.2*.**
- For values of *DoE* in the range ***1* < |*Ei*| *or* |*Eij*| ≤ *1.2*** we define "**warning level**" were actions to check is recommended to the laboratory.

  The reason for such "warning level" is that we have to consider the confidence in the determination of the uncertainties (for the results of labs as well the KCRV). Conventionally we work at a 95% confidence level. Therefore in some comparisons a range up to |*E*| < *1.5* is used for these "warnings"[3]. This is a reasonable value where stochastic influences dominate the uncertainty budgets. In the case of comparisons for gas flow, the smaller value 1.2 was chosen, which reflects the dominance of non-stochastic parts of uncertainty compared to the stochastic parts. (The reproducibility is usually much better than the total uncertainty of a laboratory). [4]

The calculation of the *DoE* needs the information about the uncertainty of the differences *di* and *dij* (equations [11] and [12]). To make statements about this, let us consider first the general problem of the difference of two values x_1 and x_2. If we look to the pure propagation of (standard) uncertainty we find:

$$u_{x_1-x_2}^2 = \begin{pmatrix} \frac{\partial(x_1-x_2)}{\partial x_1} & \frac{\partial(x_1-x_2)}{\partial x_2} \end{pmatrix} \begin{pmatrix} u_1^2 & \mathrm{cov} \\ \mathrm{cov} & u_2^2 \end{pmatrix} \begin{pmatrix} \frac{\partial(x_1-x_2)}{\partial x_1} \\ \frac{\partial(x_1-x_2)}{\partial x_2} \end{pmatrix} = u_1^2 + u_2^2 - 2.\mathrm{cov} \qquad [12]$$

Simply spoken, the (standard) uncertainty of the difference is the quadratic sum of the uncertainties of the inputs (u_1 and u_2) subtracting twice the covariance (*cov*) between the two input values.

Therefore, it is possible find the different cases in this comparison:

A) Differences to the KCRV

A1) *Independent laboratories with contribution to the KCRV*

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[3] C. Ullner et al., *Special features in proficiency tests of mechanical testing laboratories*, and P. Robouch et al., *The „Naji Plot", a simple graphical tool for the evaluation of inter-laboratory comparisons*,

[4] D.Dopheide, B.Mickan, R.Kramer, H.-J.Hotze, J.-P.Vallet, M.R.Harris, Jiunn-Haur Shaw, Kyung-Am Park, *CIPM Key Comparisons for Compressed Air and Nitrogen, CCM.FF-5.b – Final Report*, 07/09/2006 http://kcdb.bipm.org/appendixB/appbresults/ccm.ff-k5.b/ccm.ff-k5.b_final_report.pdf

The covariance between the result of a laboratory (with contribution to the KCRV) and the KCRV is the variance of the KCRV itself.5)

$$\Rightarrow u(di) = \sqrt{u_{xi}^2 + u_{xref}^2 - 2.u_{xref}^2} = \sqrt{u_{xi}^2 - u_{xref}^2} \qquad [13]$$

A2) *Independent laboratories without contribution to the KCRV*

There is no covariance between the result of a laboratory without contribution and the KCRV.

$$\Rightarrow u(di) = \sqrt{u_{xi}^2 + u_{xref}^2} \qquad [14]$$

B) Differences Lab to Lab

B1) *Independent laboratories*

There is no covariance between the results of two independent laboratory i and j

$$\Rightarrow u(dij) = \sqrt{u_{xi}^2 + u_{xj}^2} \qquad [15]$$

The equations from [13] to [15] use the standard uncertainties ($k = 1$). The expanded uncertainties *U(di)* and *U(dij)* (see equations [16],[17]) are determined by

$$U(di) = 2.u(di) \qquad [16]$$

$$U(dij) = 2.u(dij) \qquad [17]$$

6.2. Sonic nozzle with nominal flow rate 250 m³/h

The first and last round of evaluation:

Country	$Q_{V,20,\mathrm{dryAir}}$ x	Uncertainty $U(k=2)$	Uncertainty +stability $U(k=2)$	$\dfrac{(x_i - y)^2}{\left(\dfrac{U(x_i)}{2}\right)^2}$	*1/u^2*
	(m³/h)	(%)	(m³/h)		
Germany	248.849	0.080	0.19964	0.121	100.363
Czech Republic	248.783	0.076	0.18966	0.109	111.197

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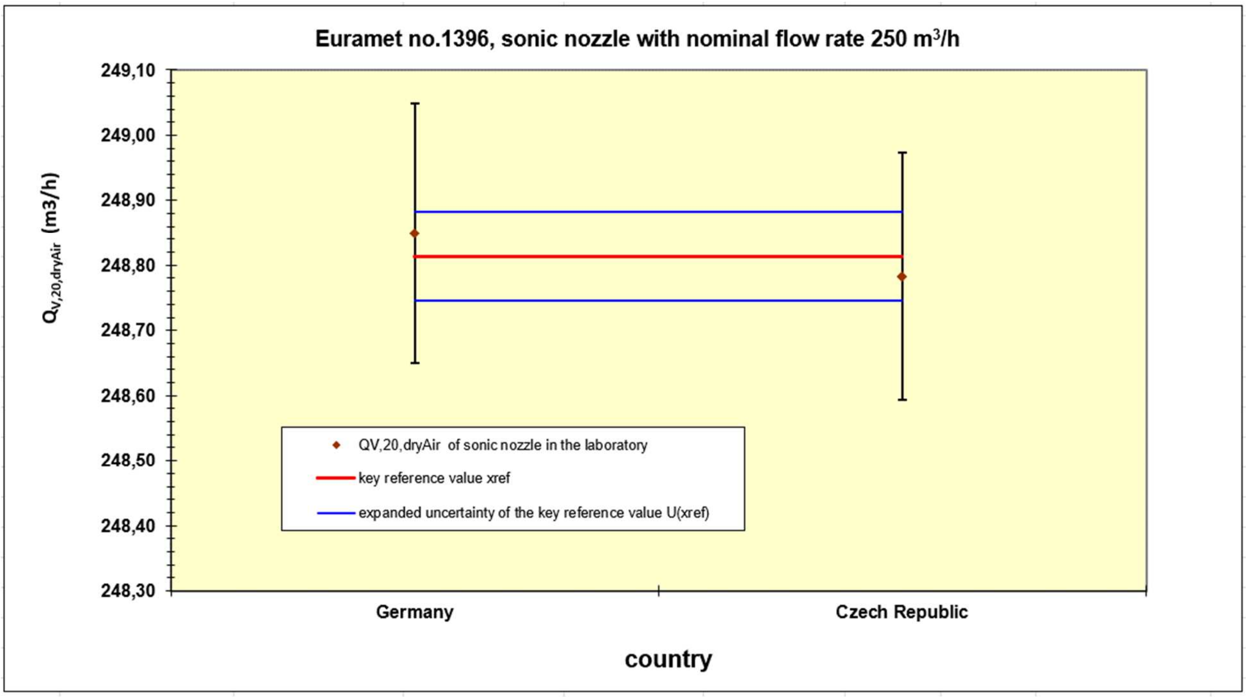
5) Cox M.G., *Evaluation of key comparison data*, Metrologia, 2002, **39**, 589-595

WME = y =	248.814	m^3/h
U(y)=	0.06875	m^3/h
CHIINV	3.84146	
χ^2_{obs} =	0.230	

The consistency check passed because CHIINV > χ^2_{obs}

Country	$Q_{V.20.dryAir}$ x	Uncertainty $U(k=2)$	Uncertainty +stability $U(k=2)$	*di*	*U(di)*	*Ei*
	(m^3/h)	(%)	(m^3/h)	(m^3/h)		
Germany	248.849	0.080	0.19964	0.0347	0.1447	0.24
Czech Republic	248.783	0.076	0.18966	-0.0313	0.1306	-0.24



6.3. Sonic nozzle with nominal flow rate 150 m^3/h

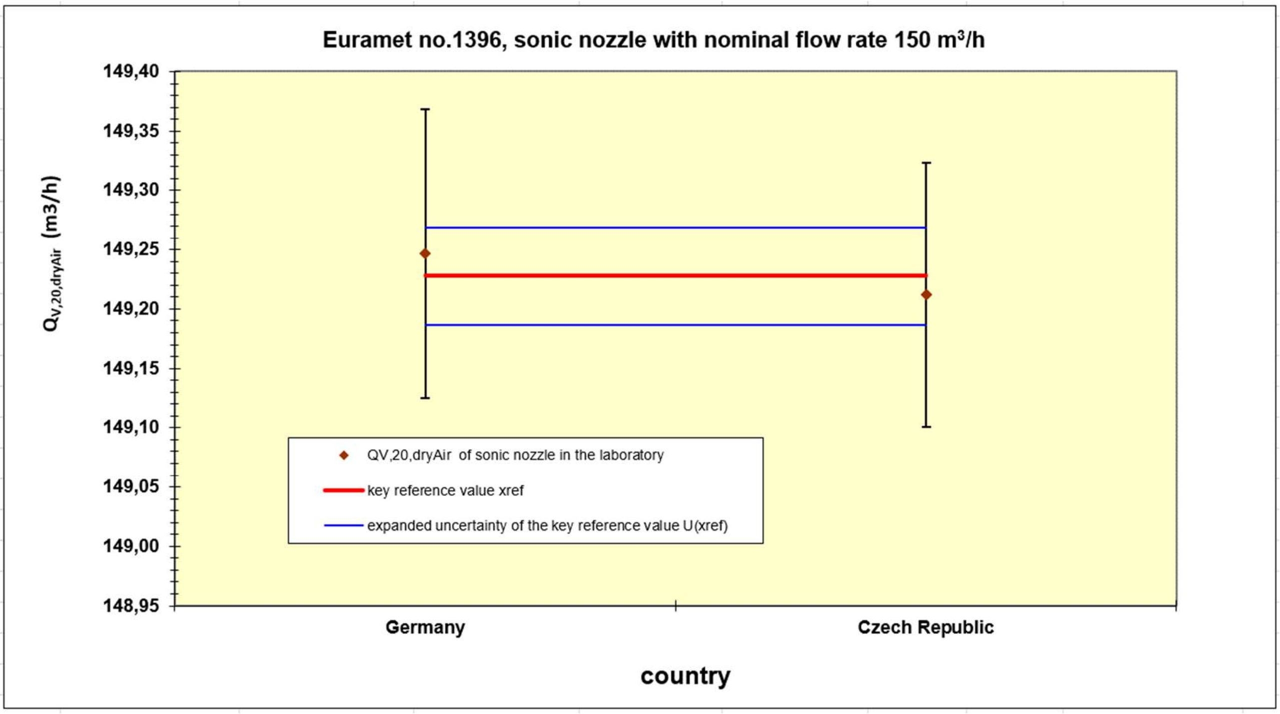
The first and last round of evaluation:

Country	$Q_{V,20,\mathrm{dryAir}}$ x	Uncertainty $U(k=2)$	Uncertainty +stability $U(k=2)$	$\frac{(x_i - y)^2}{\left(\frac{U(x_i)}{2}\right)^2}$	*1/u^2*
	(m³/h)	(%)	(m³/h)		
Germany	149.247	0.080	0.12176	0.098	269.796
Czech Republic	149.212	0.073	0.11151	0.082	321.683

WME = y = 149.22796 m³/h
U(y)= 0.04112 m³/h
CHIINV 3.84
χ^2_{obs} = 0.179

The consistency check passed because CHIINV > χ^2_{obs}

Country	$Q_{V.20.\mathrm{dryAir}}$ x	Uncertainty $U(k=2)$	Uncertainty +stability $U(k=2)$	*di*	*U(di)*	*Ei*
	(m³/h)	(%)	(m³/h)	(m³/h)		
Germany	149.247	0.080	0.12176	0.019	0.0898	0.21
Czech Republic	149.212	0.073	0.11151	-0.016	0.0753	-0.21



6.4. Sonic nozzle with nominal flow rate 75 m³/h

The first and last round of evaluation:

Country	$Q_{V,20,\mathrm{dryAir}}$ x	Uncertainty $U(k=2)$	Uncertainty +stability $U(k=2)$	$\frac{(x_i-y)^2}{\left(\frac{U(x_i)}{2}\right)^2}$	$1/u^2$
	(m³/h)	(%)	(m³/h)		
Germany	74.522	0.080	0.06478	0.434	953.233
Czech Republic	74.504	0.073	0.06000	0.012	1111.196
Russia	74.485	0.060	0.05137	0.382	1515.943

WME = y = 74.50066 m³/h

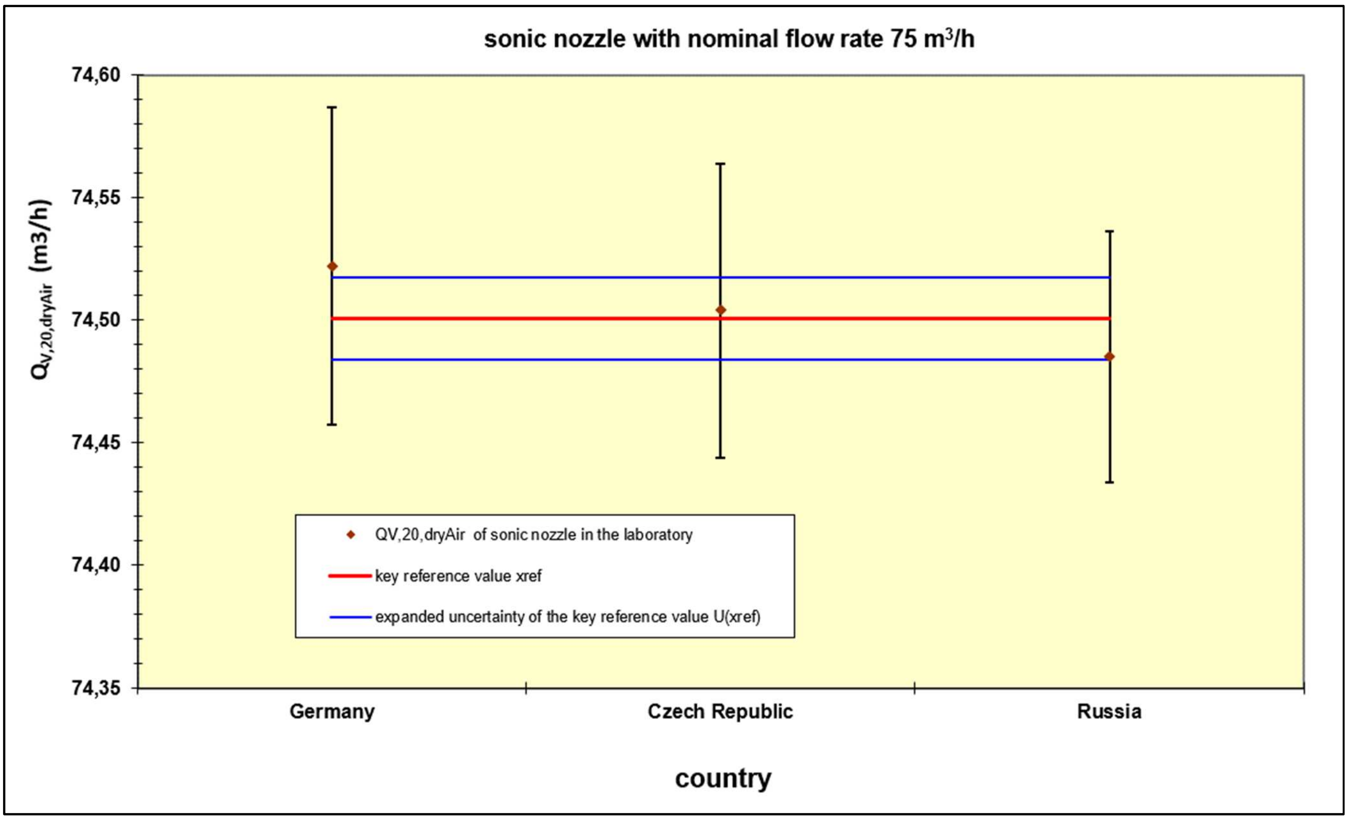
U(y)= 0.0167 m³/h

CHIINV 5.991

χ^2_{obs} = 0.828

The consistency check passed because CHIINV > χ^2_{obs}

Country	$Q_{V.20.\mathrm{dryAir}}$ x	Uncertainty $U(k=2)$	Uncertainty +stability $U(k=2)$	*di*	*U(di)*	*Ei*
	(m³/h)	(%)	(m³/h)	(m³/h)		
Germany	74.522	0.080	0.06478	0.0213	0.0555	0.38
Czech Republic	74.504	0.073	0.06000	0.0033	0.0498	0.07
Russia	74.485	0.060	0.05137	-0.0159	0.0390	-0.41



6.5. Sonic nozzle with nominal flow rate 12.5 m^3/h

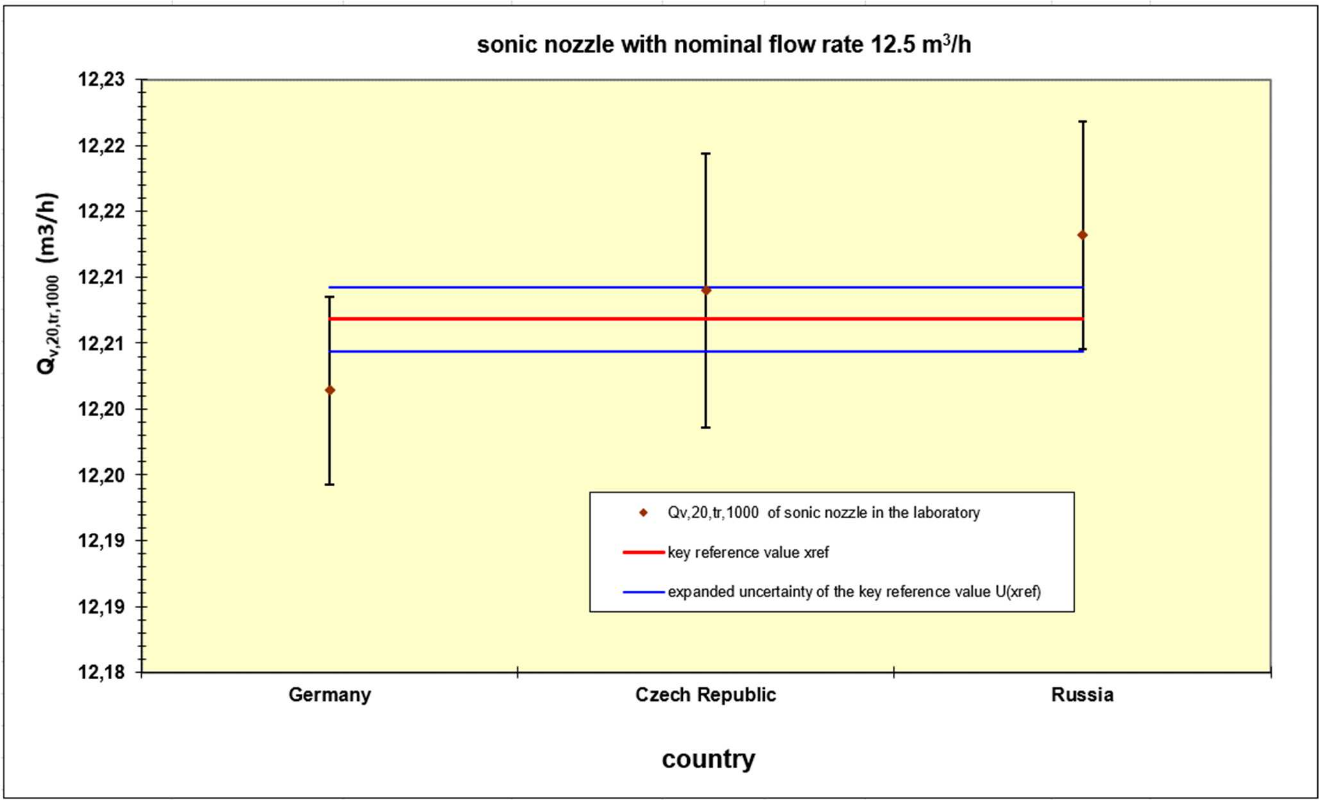
The first and last round of evaluation:

Country	$Q_{v,20,tr,1000}$ x	Uncertainty $U(k=2)$	Uncertainty +stability $U(k=2)$	$\frac{(x_i-y)^2}{\left(\frac{U(x_i)}{2}\right)^2}$	$1/u^2$
	(m^3/h)	(%)	(m^3/h)		
Germany	12.2014	0.045	0.00711	2.276	79163
Czech Republic	12.2090	0.077	0.01043	0.178	36770
Russia	12.2132	0.060	0.00861	2.189	53967

WME = y = 12.2068 m^3/h
U(y)= 0.00243 m^3/h
CHIINV 4.64
χ^2_{obs} = 5.99

The consistency check passed because CHIINV > χ^2_{obs}

Country	$Q_{v.20.tr.1000}$ x	Uncertainty $U(k=2)$	Uncertainty +stability $U(k=2)$	di	$U(di)$	Ei
	(m^3/h)	(%)	(m^3/h)	(m^3/h)		
Germany	12.2014	0.045	0.00711	-0.0054	0.0052	-1.03
Czech Republic	12.2090	0.077	0.01043	0.0022	0.0092	0.24
Russia	12.2132	0.060	0.00861	0.0064	0.0071	0.90



6.6. Sonic nozzle with nominal flow rate 2.5 m^3/h

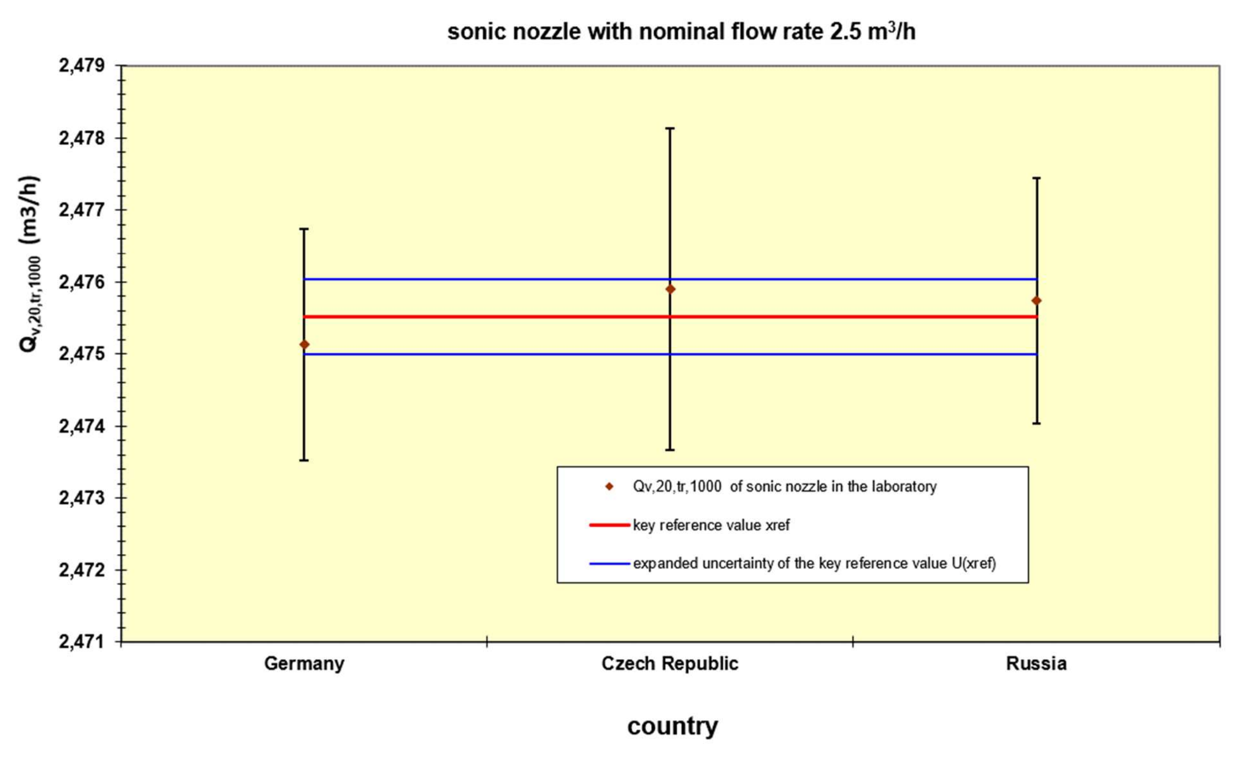
The first and last round of evaluation:

Country	$Q_{v,20,tr,1000}$ x	Uncertainty $U(k=2)$	Uncertainty +stability $U(k=2)$	$\frac{(x_i - y)^2}{\left(\frac{U(x_i)}{2}\right)^2}$	*1/u^2*
	(m^3/h)	(%)	(m^3/h)		
Germany	2.47513	0.045	0.00161	0.234	1542102
Czech Republic	2.47590	0.077	0.00223	0.116	801818
Russia	247574	0.060	0.00171	0.064	1372175

WME = y = 2.475522 m^3/h
U(y)= 0.000519 m^3/h
CHIINV 5.99
χ^2_{obs} = 0.4141

The consistency check passed because CHIINV > χ^2_{obs}

Country	$Q_{v.20.tr.1000}$ x	Uncertainty $U(k=2)$	Uncertainty +stability $U(k=2)$	*di*	*U(di)*	*Ei*
	(m^3/h)	(%)	(m^3/h)	(m^3/h)		
Germany	2.47513	0.045	0.00161	-0.0004	0.0012	-0.32
Czech Republic	2.47590	0.077	0.00223	0.0004	0.0020	0.19
Russia	2.47574	0.060	0.00171	0.0002	0.0014	0.16



6.7. Sonic nozzle with nominal flow rate 1.0 m³/h

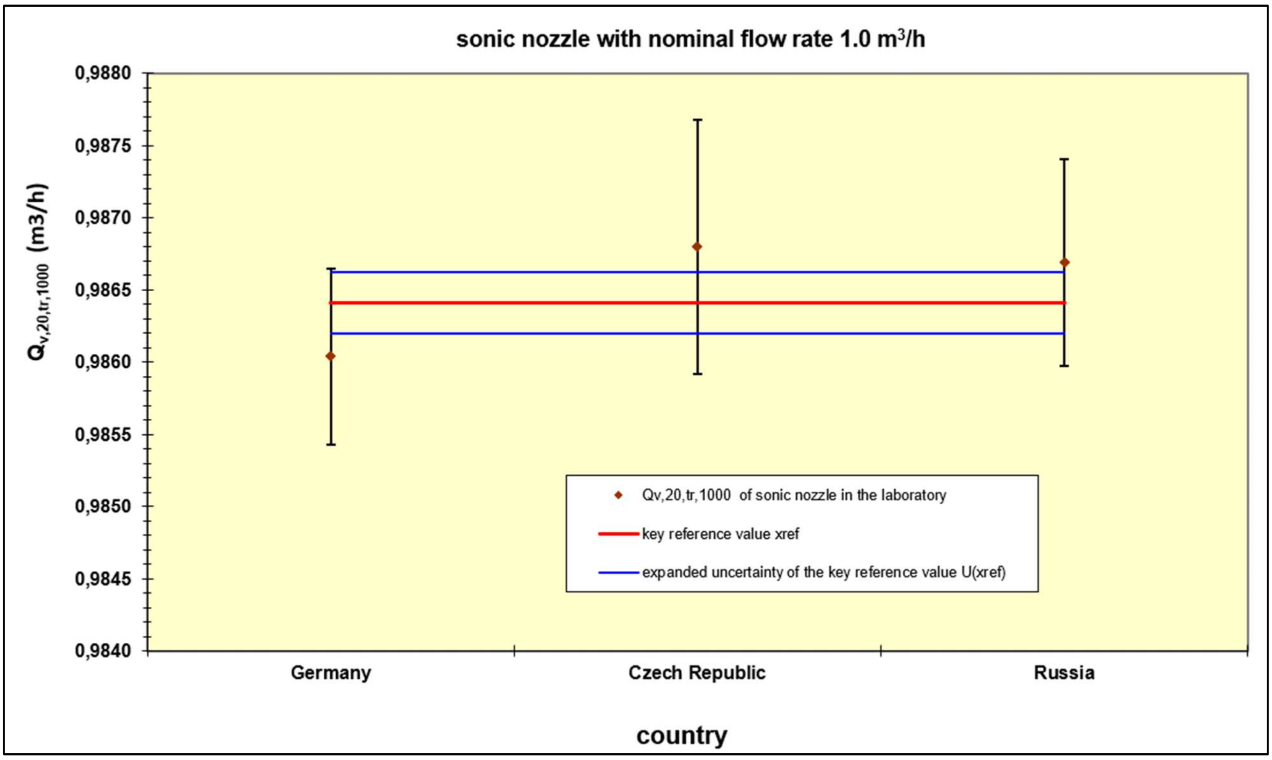
The first and last round of evaluation:

Country	$Q_{v,20,tr,1000}$ x	Uncertainty $U(k=2)$	Uncertainty +stability $U(k=2)$	$\frac{(x_i-y)^2}{\left(\frac{U(x_i)}{2}\right)^2}$	*1/u^2*
	(m^3/h)	(%)	(m^3/h)		
Germany	0.98604	0.045	0.00061	1.524	10857912
Czech Republic	0.98680	0.079	0.00088	0.762	5131453
Russia	0.98669	0.060	0.00072	0.570	7659705

WME = y = 0.98641 m^3/h
U(y)= 0.00021 m^3/h
CHIINV 5.99
χ^2_{obs} = 2.86

The consistency check passed because CHIINV > χ^2_{obs}

Country	$Q_{v.20.tr.1000}$ x	Uncertainty $U(k=2)$	Uncertainty +stability $U(k=2)$	*di*	*U(di)*	*Ei*
	(m^3/h)	(%)	(m^3/h)	(m^3/h)		
Germany	0.98604	0.045	0.00061	-0.00037	0.00045	-0.84
Czech Republic	0.98680	0.079	0.00088	0.00039	0.00078	0.49
Russia	0.98669	0.060	0.00072	0.00027	0.00059	0.46



7. Results

7.1. Germany

Sonic nozzle nominal flow rate	$Q_{V,20,dryAir}$ or $Q_{v,20,tr,1000}$	uncertainty U(k=2)	uncertainty declared in CMC U(k=2)	uncertainty of the error including stability of the meter U(k=2)	key reference value x_{ref}	expanded uncertainty of the key refrence value U(x_{ref})	consistency check	di	Ei	result
m³/h	m³/h	%	%	m³/h	m³/h	m³/h				
250	248.849	0.080	0.080	0.19964	248.814	0.069	inside	0.035	0.24	passed
150	149.247	0.080	0.080	0.12176	149.228	0.041	inside	0.019	0.21	passed
75	74.5220	0.080	0.080	0.06478	74.5007	0.017	inside	0.0213	0.38	passed
12.5	12.2014	0.045	0.045	0.00711	12.2068	0.0024	inside	-0.0054	-1.03	warning
2.5	2.4751	0.045	0.045	0.00161	2.47552	0.00052	inside	-0.0004	-0.32	passed
1	0.98604	0.045	0.045	0.00061	0.98641	0.00021	inside	-0.00037	-0.84	passed
							mean		**-0,23**	**passed**

7.2. Czech Republic

Sonic nozzle nominal flow rate	$Q_{V,20,dryAir}$ or $Q_{v,20,tr,1000}$	uncertainty U(k=2)	uncertainty declared in CMC U(k=2)	uncertainty of the error including stability of the meter U(k=2)	key reference value x_{ref}	expanded uncertainty of the key refrence value U(x_{ref})	consistency check	di	Ei	result
m³/h	m³/h	%	%	m³/h	m³/h	m³/h				
250	248.783	0.076	0.07	0.18966	248.814	0.069	inside	-0.031	-0.24	passed
150	149.212	0.073	0.07	0.11151	149.228	0.041	inside	-0.016	-0.21	passed
75	74.5040	0.073	0.07	0.06000	74.5007	0.017	inside	0.0033	0.07	passed
12.5	12.2090	0.077	0.07	0.01043	12.2068	0.0024	inside	0.0022	0.24	passed
2.5	2.4759	0.077	0.07	0.00223	2.47552	0.00052	inside	0.0004	0.19	passed
1	0.98680	0.079	0.07	0.00088	0.98641	0.00021	inside	0.00039	0.49	passed
							mean		**0.09**	**passed**

7.3. Russia

Sonic nozzle nominal flow rate	**$Q_{V,20,dryAir}$ or $Q_{v,20,tr,1000}$**	**uncertainty U(k=2)**	**uncertainty declared in CMC U(k=2)**	**uncertainty of the error including stability of the meter U(k=2)**	**key reference value x_{ref}**	**expanded uncertainty of the key refrence value U(x_{ref})**	**consistency check**	**di**	**Ei**	**result**
m^3/h	**m^3/h**	**%**	**%**	**m^3/h**	**m^3/h**	**m^3/h**				
75	74.4848	0.06	0.15	0.05137	74.5007	0.017	inside	-0.0159	-0.41	passed
12.5	12.2132	0.06	0.15	0.00861	12.2068	0.0024	inside	0.0064	0.90	passed
2.5	2.4757	0.06	0.15	0.00171	2.47552	0.00052	inside	0.0002	0.16	passed
1	0.98669	0.06	0.15	0.00072	0.98641	0.00021	inside	0.00027	0.46	passed
							mean		**0.28**	**passed**

8. Degree of equivalence between laboratories

The 14th CCM meeting (February, 2013) recommended that pair-wise degrees of equivalence no longer to be published in the KCDB and that information on pair-wise degrees of equivalence published in KC reports 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.

9. Other results from pressure department of CMI

Another independent test facility for sonic nozzles in Czech Metrology Institute is placed at the address:
Czech Metrology Institute
Pressure Department
Okružní 31
63800 Brno

This test facility consists of Laminar Flow Elements traceable to the primary gravimetric weighting device (gravimetric flow system, GFS). In this test facility there absolute pressure sensors are traceable to the primary standard of pressure and Pt1000 thermometers are traceable to the CMI OI Brno department of temperature. Due to the range limit of this test facility only three sonic nozzles were tested in this laboratory.

Results

Sonic nozzle		$Q_{v,20,tr,1000}$	U (k=2)	c_{PE}:	CMC	Internal NMI service identifier:
Serial number	Nominal flow rate	m^3/h	%	1/mbar		
01505	1.0	0.9861	0.146%	1.3E-05	0.10%	CZ9
01506	2.5	2.4766	0.215%	1.3E-05	0.20%	CZ11
01507	12.5	12.221	0.229%	1.2E-05	0.20%	CZ11

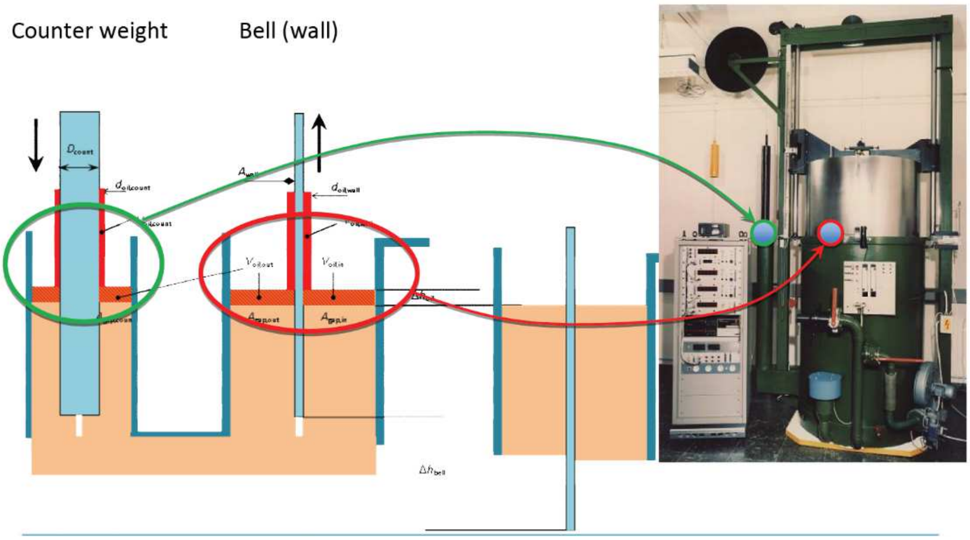
Evaluation of the results of the pressure department of CMI without contribution to KCRV (*Key Comparison Reference Value*):

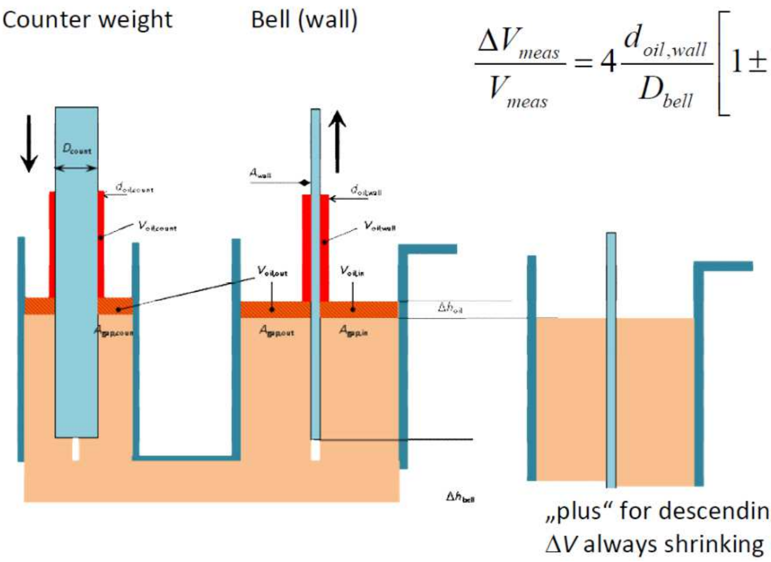
Sonic nozzle nominal flow rate	$Q_{v,20,tr,1000}$	uncertainty U(k=2)	uncertainty declared in CMC U(k=2)	uncertainty of the error including stability of the meter U(k=2)	key reference value x_{ref}	expanded uncertainty of the key refrence value U(x_{ref})	di	Ei	result
m³/h	m³/h	%	%	m³/h	m³/h	m³/h			
1.0	0.98614	0.15	0.10	0.001498	0.98641	0.000210	-0.000269	-0.18	passed
2.5	2.47662	0.22	0.20	0.005450	2.47552	0.000520	0.001098	0.20	passed
12.5	12.22078	0.23	0.20	0.028349	12.20680	0.002400	0.013980	0.49	passed
							mean	**0.28**	**passed**

10. Oil film thickness

During this project the oil film thickness on the wall of bell of Bell Prover was investigated in PTB, too. This similar investigation was performed approximately 20 years ago. The oil film thickness is one of source of uncertainty because it influences the inside diameter of the bell and consequently the volume of air that is pressed out from the bell. Oil Shell Morlina 5 (Shell Morlina S2 BL 5) is used in all the Bell Provers used in this project.

The way of evaluation and results are mentioned down in the pictures.



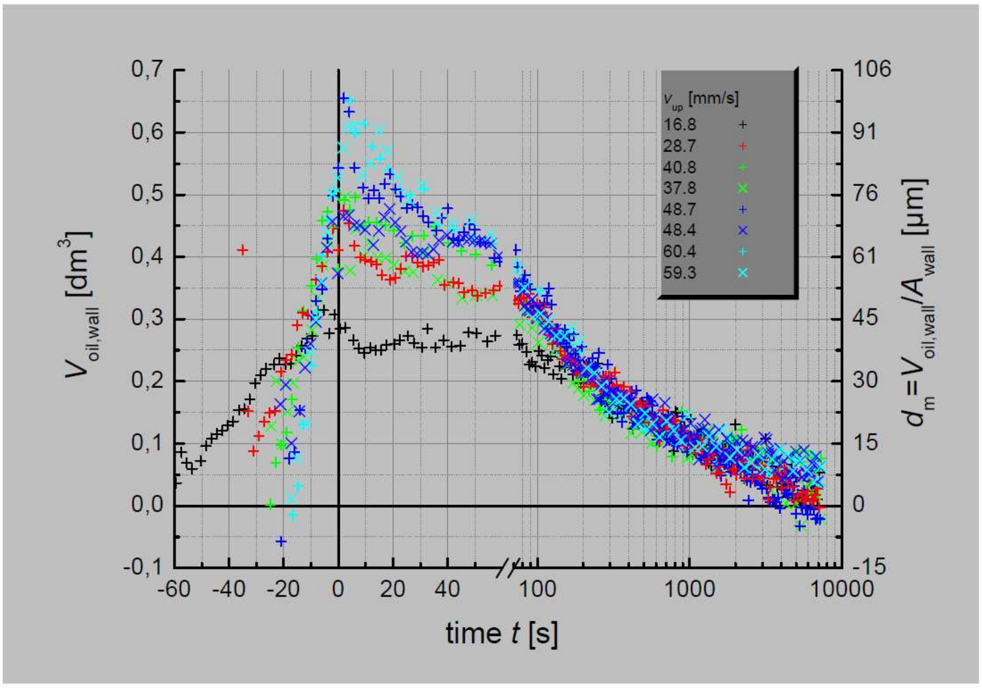


$$\frac{\Delta V_{meas}}{V_{meas}} = 4\frac{d_{oil,wall}}{D_{bell}}\left[1 \pm 2\alpha\left(1-\beta\frac{d_{oil,count}}{d_{oil,wall}}\right)\right]$$

$$\frac{1}{1+\frac{A_{gap,out,total}}{A_{gap,in}}} = \alpha \approx 0.5$$

$$\sqrt{\frac{d_{wall,bell}}{D_{bell}}} = \beta \approx 0.14$$

„plus“ for descending; „minus“ rising mode;
ΔV always shrinking V_{meas}



The last picture shows that a good waiting time between two measurements in sinking mode of Bell Prover is 300 seconds and to calculate with the thickness of oil film d=30 µm in the uncertainty budget.

11. Summary and conclusion

The summary of inter-comparison results is mentioned down in the table:

Sonic nozzle		Laboratory		
Serial number	Nominal flow rate (m^3/h)	**Germany (PTB)**	**Czech Republic (CMI)**	**Russia (VNIIR)**
01510	250	passed	passed	-
01509	150	passed	passed	-
01508	75	passed	passed	passed
01507	12.5	warning	passed	passed
01506	2.5	passed	passed	passed
01505	1.0	passed	passed	passed
Mean		**passed**	**passed**	**passed**