Mechanik und Durchfluss
Durchfluss, Temperatur, Wärmeenergie

Willkommen im BEV
Bundesamt für Eich- und Vermessungswesen

Final report
Intercomparison of two electromagnetic meters

EUROMET Project no. 669

Coordinator and rapporteuer of the comparison

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1 General

At the EUROMET Fluid Flow contact persons meeting at Poiters/France/2002 the BEV proposed a European round robin test with two electromagnetic meters (MIDs), installed in series. The project was accepted and registered under project number 699.

The two MIDs were provided by the BEV and at first had been intensively examined (stability, dependency from temperature and pressure, etc.) . Prior to the real start of project 699 the meters had been tested in the course of a national intercomparison (see results annexed).

See also:
Table 1: detailed description of the MIDs
Table 2: chronology of this intercomparison in 4 cycles
Fig.1: meter housing
Fig.2: installation of the meters in the BEV-test rig
Fig.3: scheme of European participating countries
Fig.4: transport box.

Fig. 1*: Housing of meter*

Fig. 2*: Installation of the two meters in the test rig of the BEV*

Fig.4: Transport box for the meters including inlet and outlet piping

Fig. 3: European participating countries in comparison

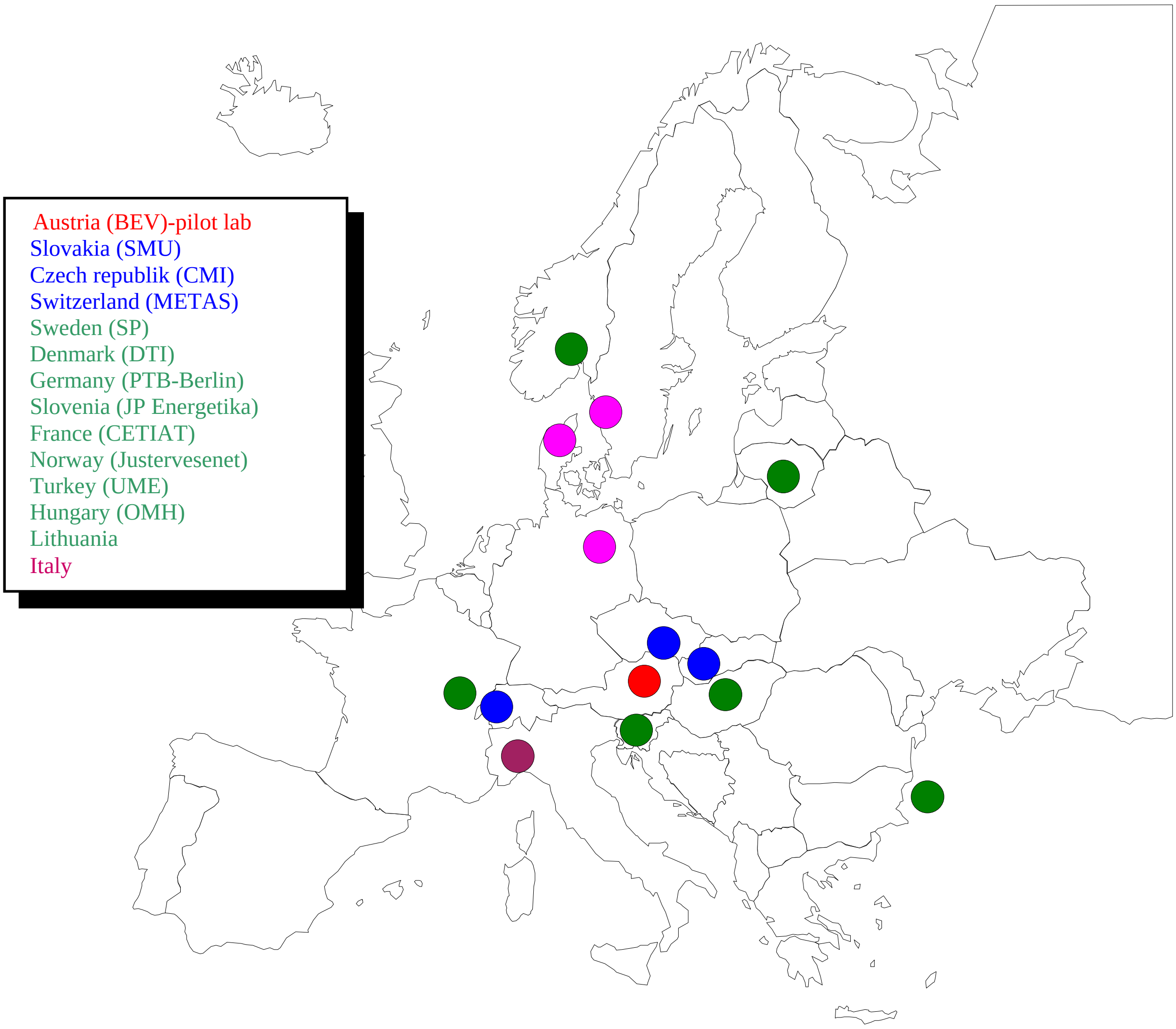


Table 1: Characteristics of used MIDs

Krohne	1.000	4,6767
	2.500	3,508
	5.000	2,338
	7.500	1,169
	10.000	0,468

Table2: Chronology of intercomparison

institute/country	time	remarks
Examinations at BEV	January - April 2002	
BEV/Austria	Mai 2002 May 2002	Start of intercomparison, 1st cycle
SMU/Slovakia	June2002	
CMI/Czec Republik	July 2002	
METAS/Switzerland	August 2002	
BEV/Austria	September 2002	2nd cycle
SP/Sweden	October 2002	
Delta/Denmark	November 2002	
PTB-IB/Germany	December 2002	
BEV/Austria	February 2003	3rd cycle
JP Energetika/Slovenia	March 2003	
CETIAT/France	April 2003	
Justervesenet/Norway	May 2003	
UME/Turkey	June 2003	
OMH/Hungary	September 2003	
Lithuania	October 2003	
BEV/Austria	December 2003	4th cycle
IMGC/Italy	January 2004	
BEV/Austria	February 2004	End of official intercomparison
Measurements in verification offices in Germany and Sweden	March 2004 – October 2004	
BEV/Austria – stability tests	November/December 2004	
Repeated measurements in Norway	January-March 2005	

Arrangement of meters under test

Fig.5 shows the arrangement of the meters under test. "Arrangement 1" stands for meter 857 upstream and 858 downstream, "Arrangement 2" is vice versa. These arrangements were chosen in order to apply the Youden plot, a graphical-statistical evaluation method.

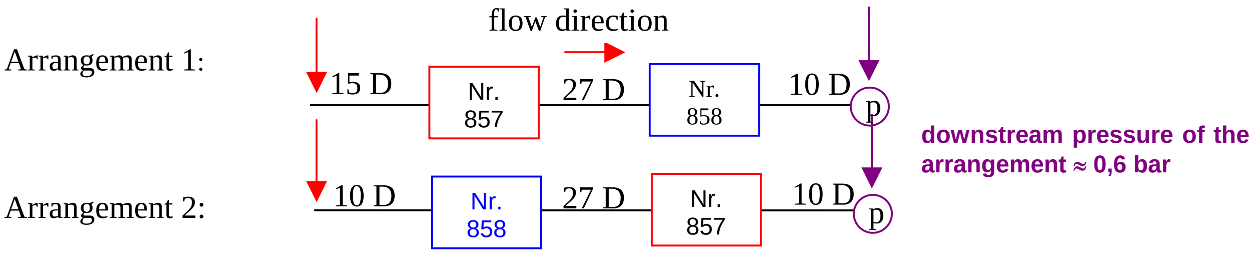


***Fig. 5**: Serial arrangement of the meters under test*

Fig.6 shows the complete meter with inlets and outlets installed, fig.7 shows the power supply stabilizer (provided for each meter).

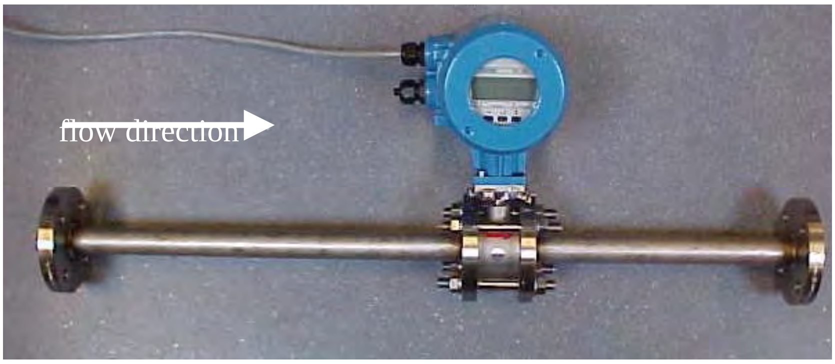


***Fig. 6:** Meter with connected inlet and outlet pipes*

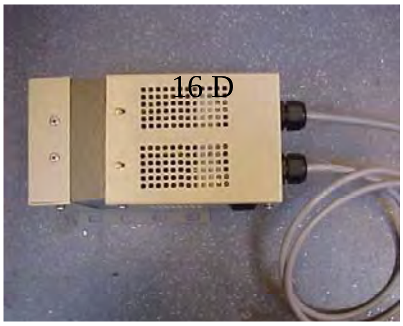


***Fig. 2**: Power supply stabilizer*

The nominal diameter of both meters is DN25 (D_i = 27,5 mm^{ø}). They are installed like sandwiches, with a given length for the inlet and outlet pipes. The power supply lines of both meters are connected to stabilizers.

The output pulse rate is 1 kHz at a flow rate of 10.000 l/h. The delivered volume had to be chosen as large as possible; this corresponds to about 3000 litres at the BEV. Table 3 shows the test conditions in an overview and fig.8 the arrangement of meter 857 and 858. The arrangement 1 sees the meter 857 upstream, and the arrangement 2 sees the meter 858 upstream. So both meters are in one case upstream and in the other case downstream.

Table 3: Test conditions

Flow rate *Q* [l/h]	Number *n* of repeated measurements	Temperature ***t*** [°C]
10.000	≥ 10	50 ± 1
7.500	≥ 10	50 ± 1
5.000	≥ 10	50 ± 1
2.500	≥ 10	50 ± 1
1.000	≥ 10	50 ± 1

Arrangement of meters

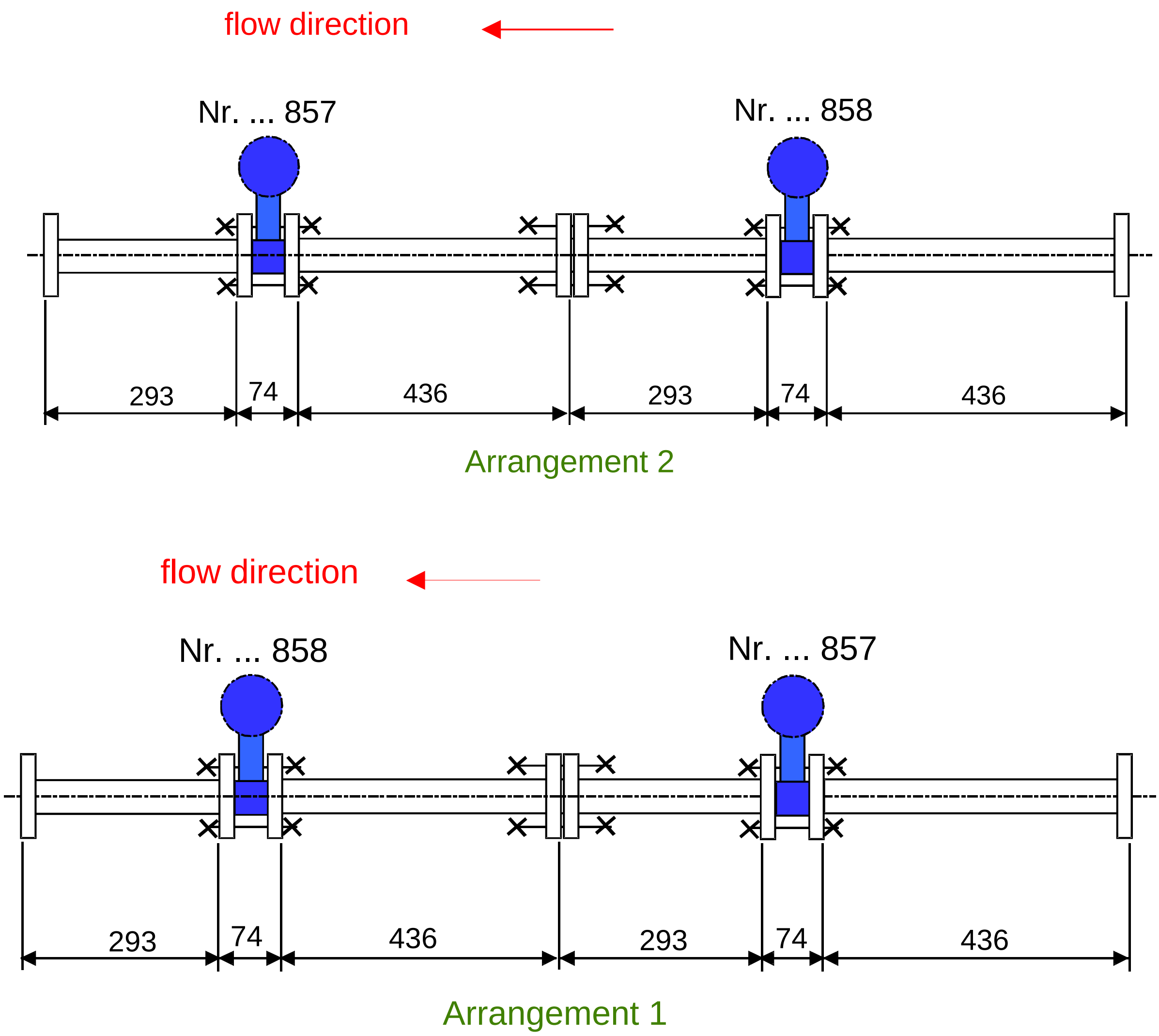


Fig.8*: Arrangement of meters 857 and 858 in both possible directions*

2 Measurement results

2.1 Results of intercomparisons

The following figures 8 - 12 show the measurement results of each participant. As mentioned above there were two arrangements, one with meter 857 upstream and one with meter 858 upstream. When considering the figures some of the participants came up with results of a definite systematic character; this will be examined more in detail.

Figures 13 - 16 show the expanded uncertainties claimed by the participants. Interesting that there are large differences of a ratio of 1:10 thus leading to problems with the statistical evaluation of the measurement results.

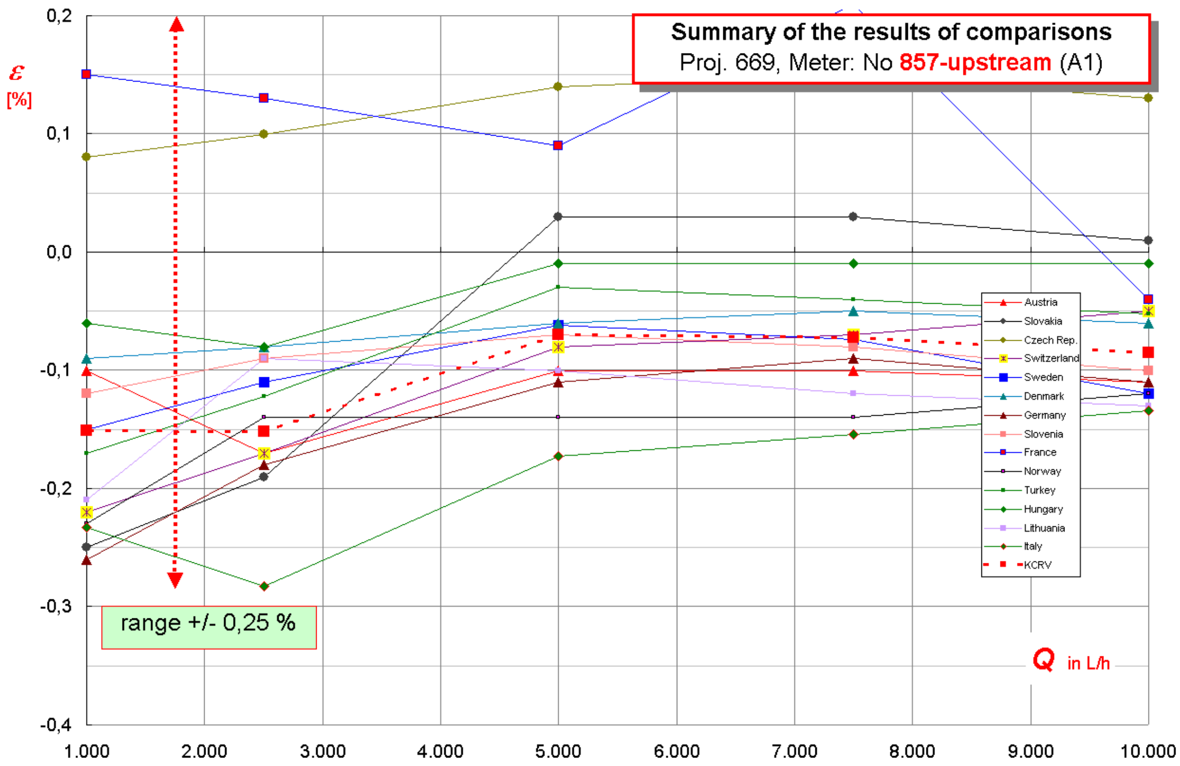


***Fig. 9**: measurement results for 857 upstream*

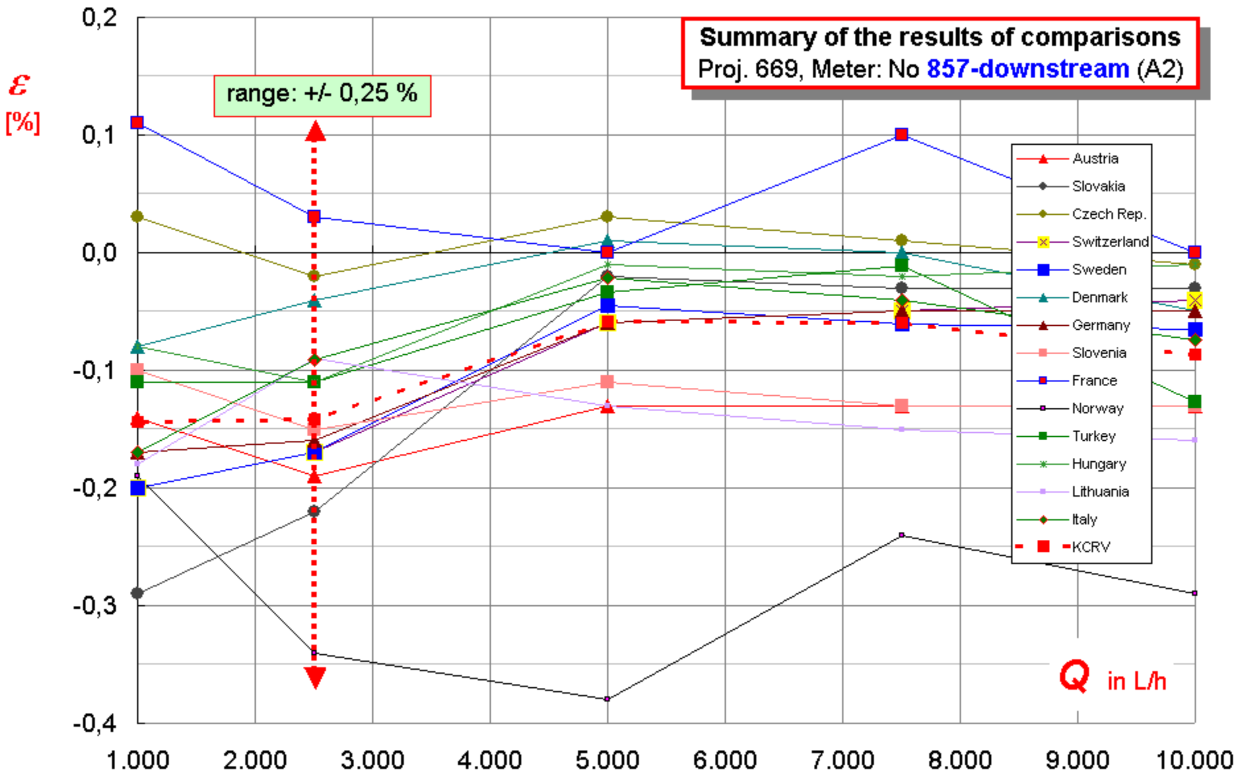


***Fig. 10**: measurement results for 857 downstreams*

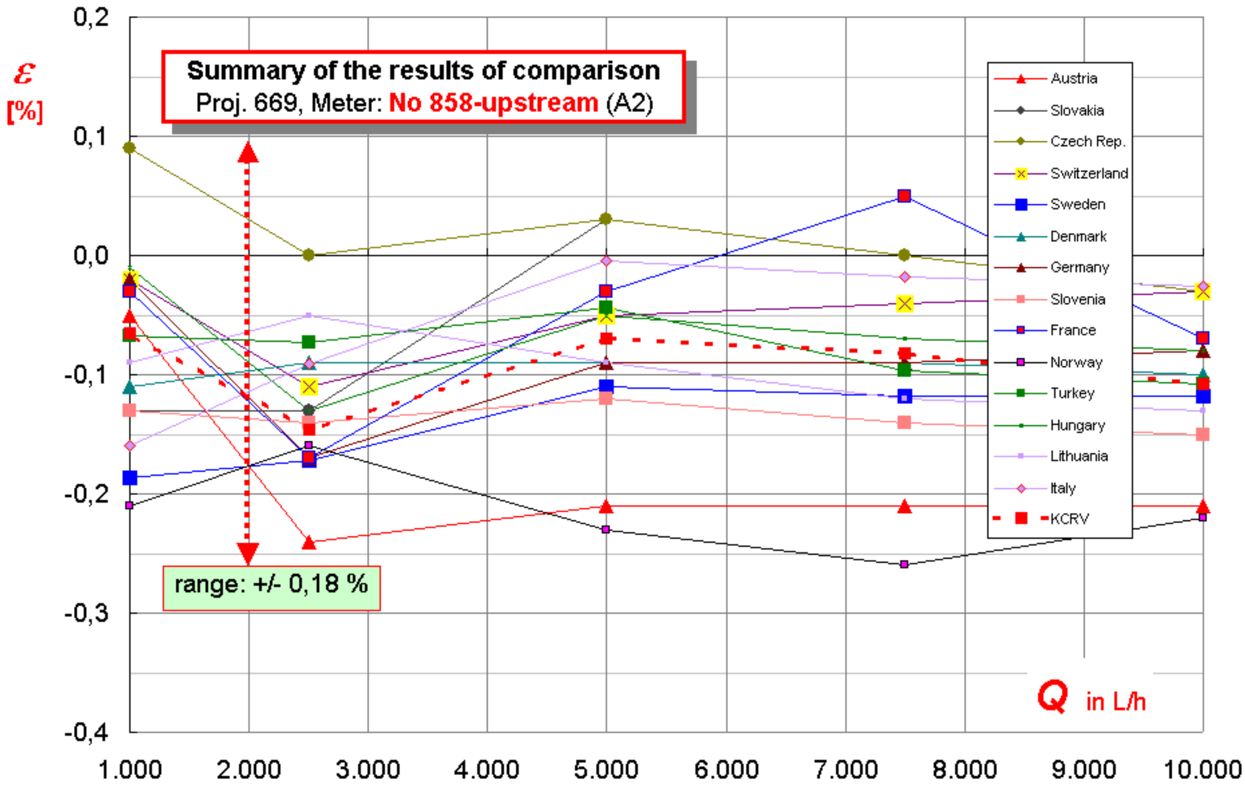


***Fig. 11**: measurement results for 858 upstream*

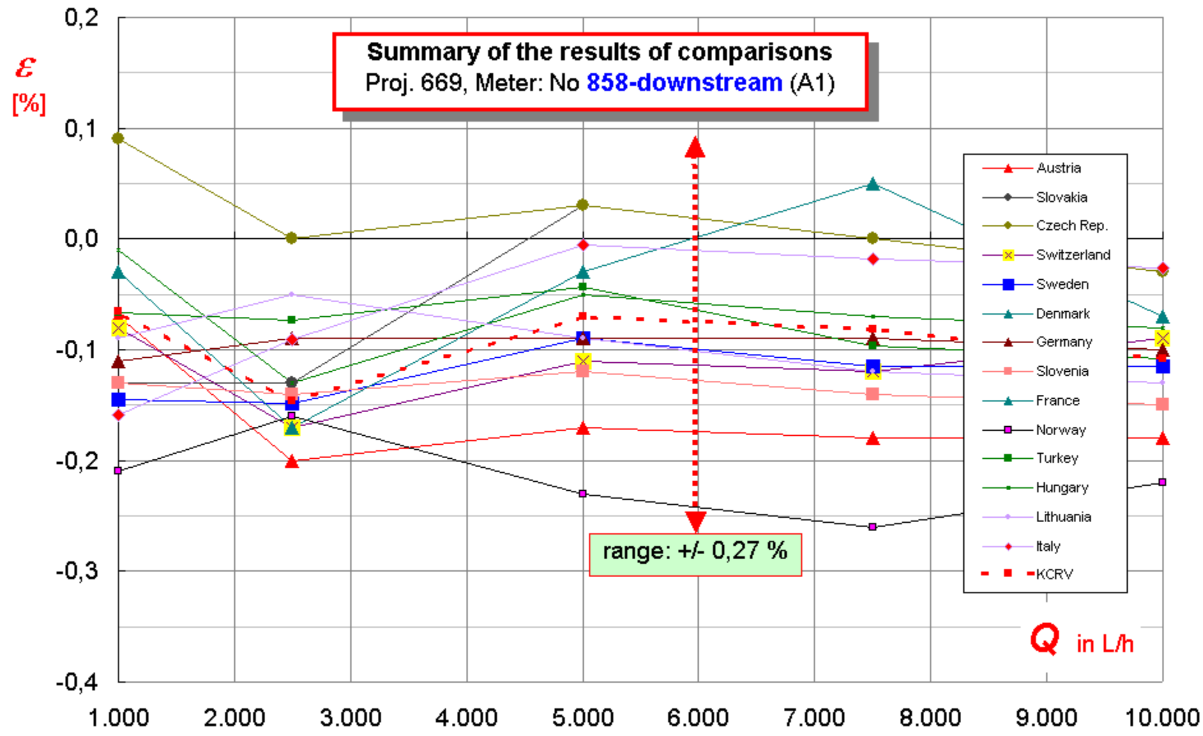


***Fig. 12**: measurement results for 858 downstream*

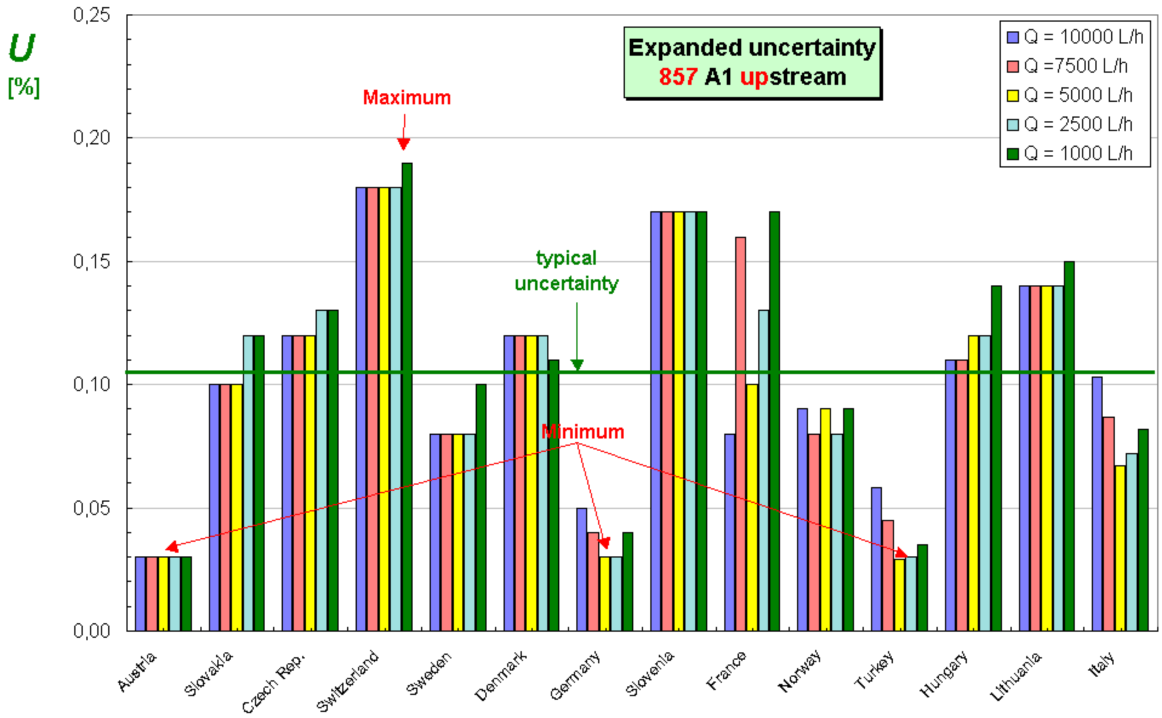


***Fig. 13**: Expanded uncertainties corresponding to fig.9*

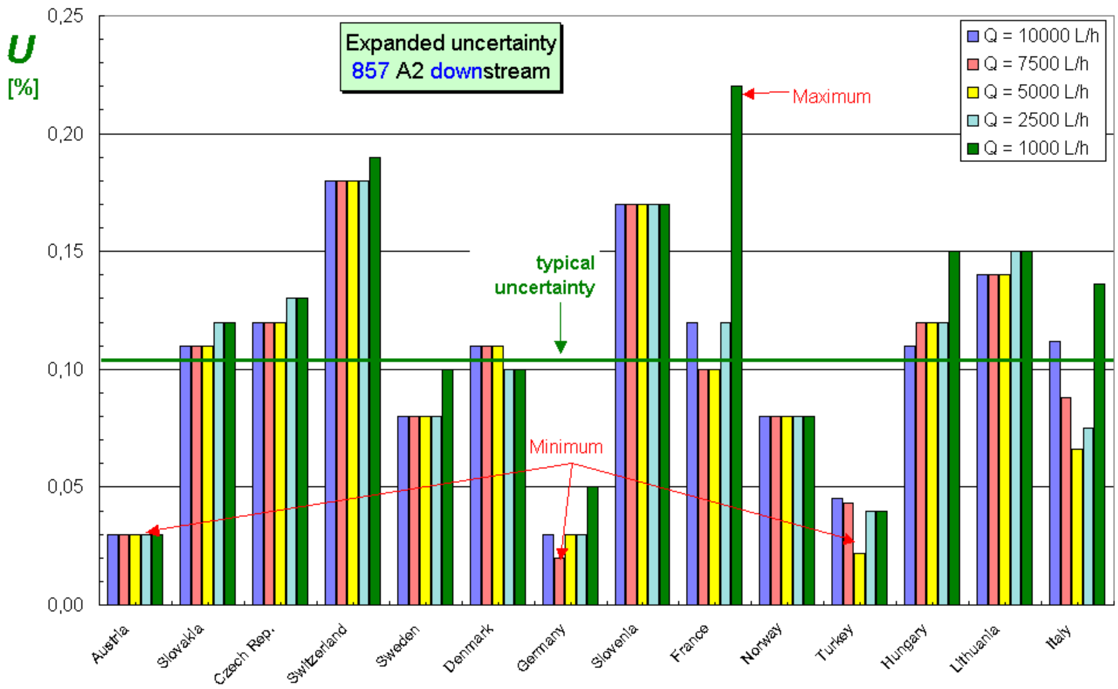


***Fig. 14**: Expanded uncertainties corresponding to fig.10*

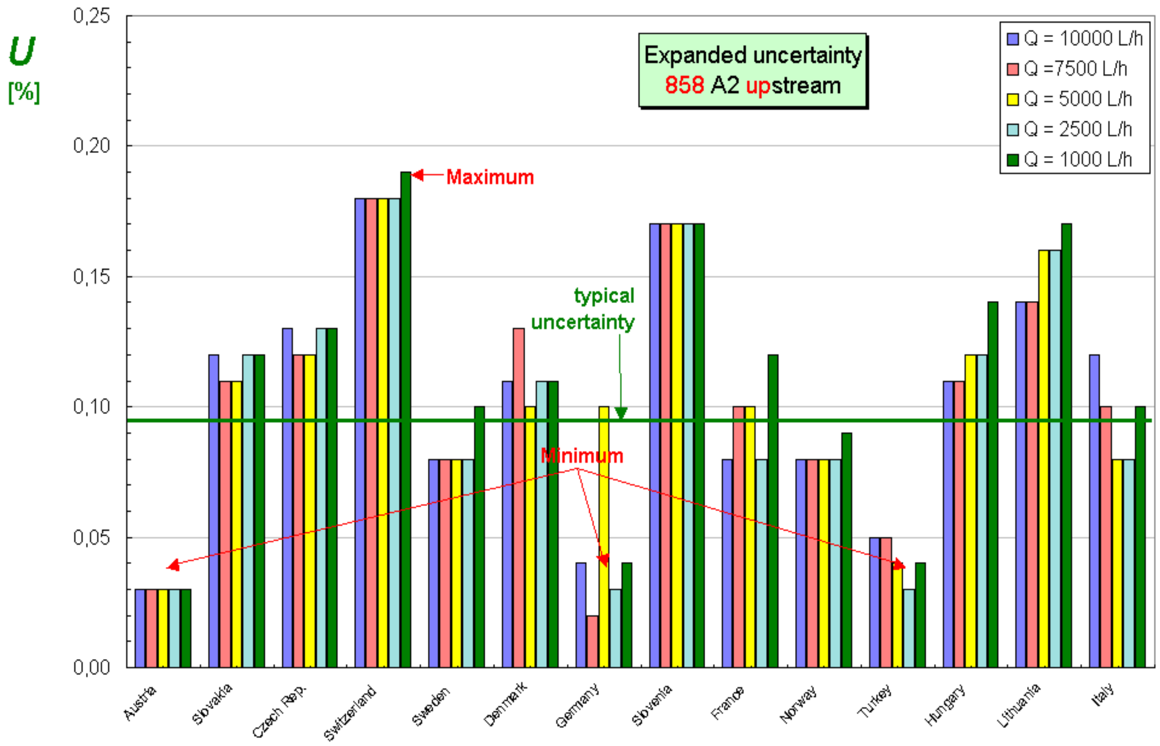


Fig. 15*: Expanded uncertainties corresponding to fig.11*

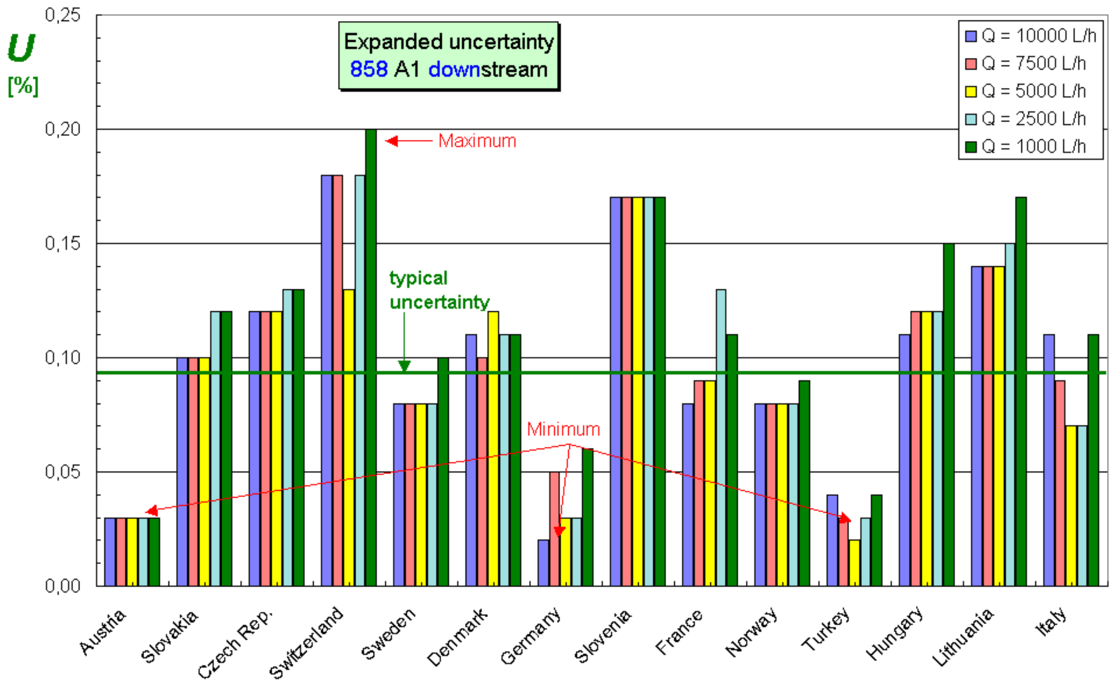


Fig. 16*: Expanded uncertainties corresponding to fig.12*

At the start of each measurement cycle, the BEV performed repeatability measurements (see fig.17 - 20). The typical changes during a 2 1/2 years period is ± 0,1 %. The installation of the meter might be the reason for this change (see also item on stability measurements), but also changes in the meters themselves.

All diagrams show the KCRV being assumed as the correct value for all these measurements; for explanation and giving reason to that see chapter 3 - evaluation of measurement results.

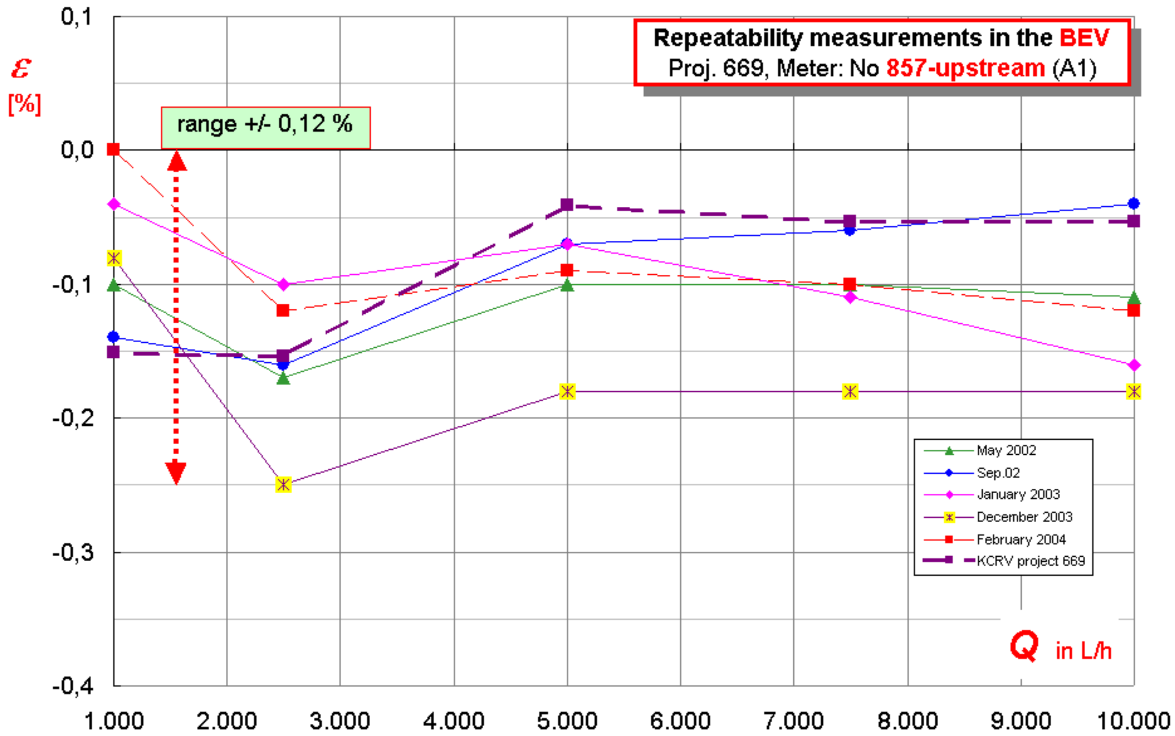


***Fig. 17**: repeatability measurements at BEV at the start and at the end of each cycle*

857-upstream

Remark: In fig.17 - 20 the KCRV is plotted. Its meaning in connection with the reported measurements will be discussed later (chapter 3 - evaluation of measurement results).

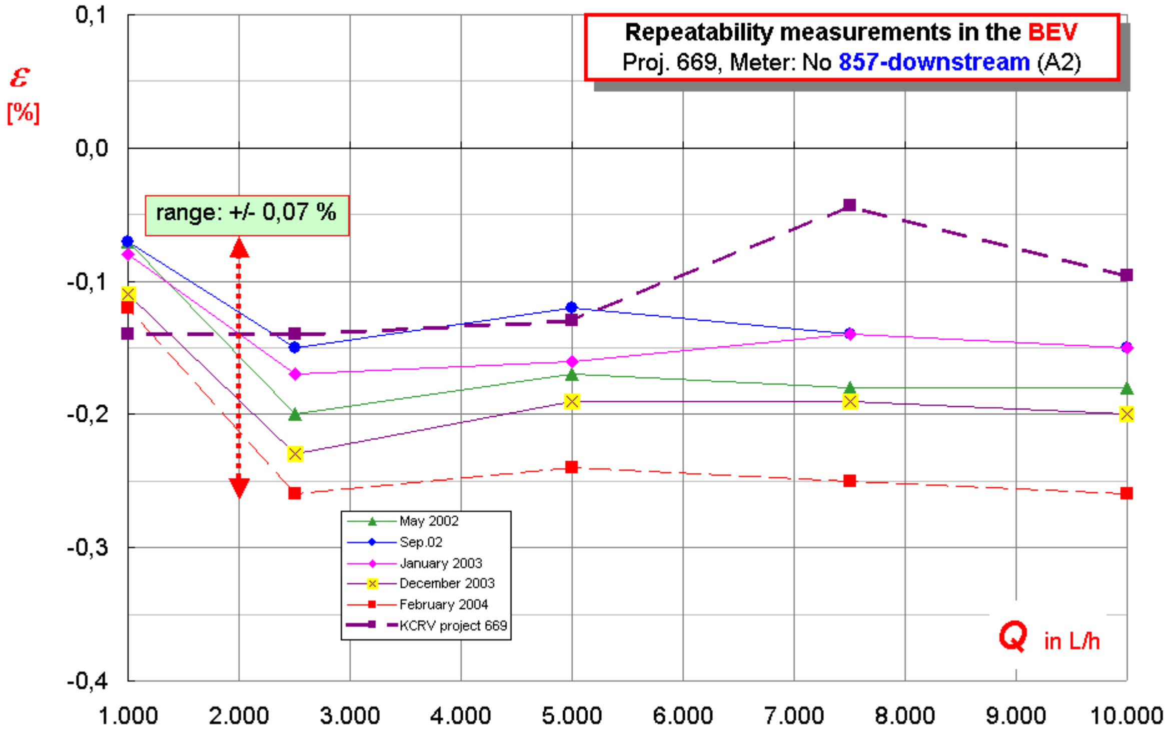


Fig. 18: *repeatability measurements at BEV at the start and at the end of each cycle.*
857 downstream

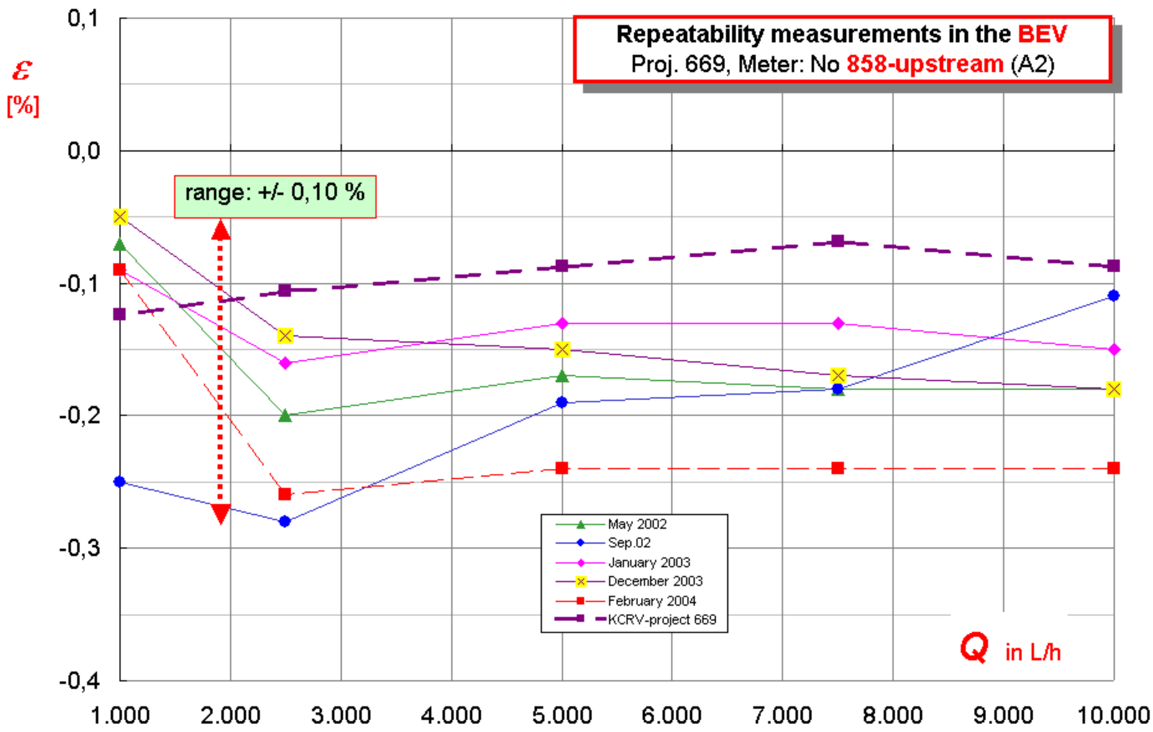


Fig. 19: *repeatability measurements at BEV at the start and at the end of each cycle*
858 upstream

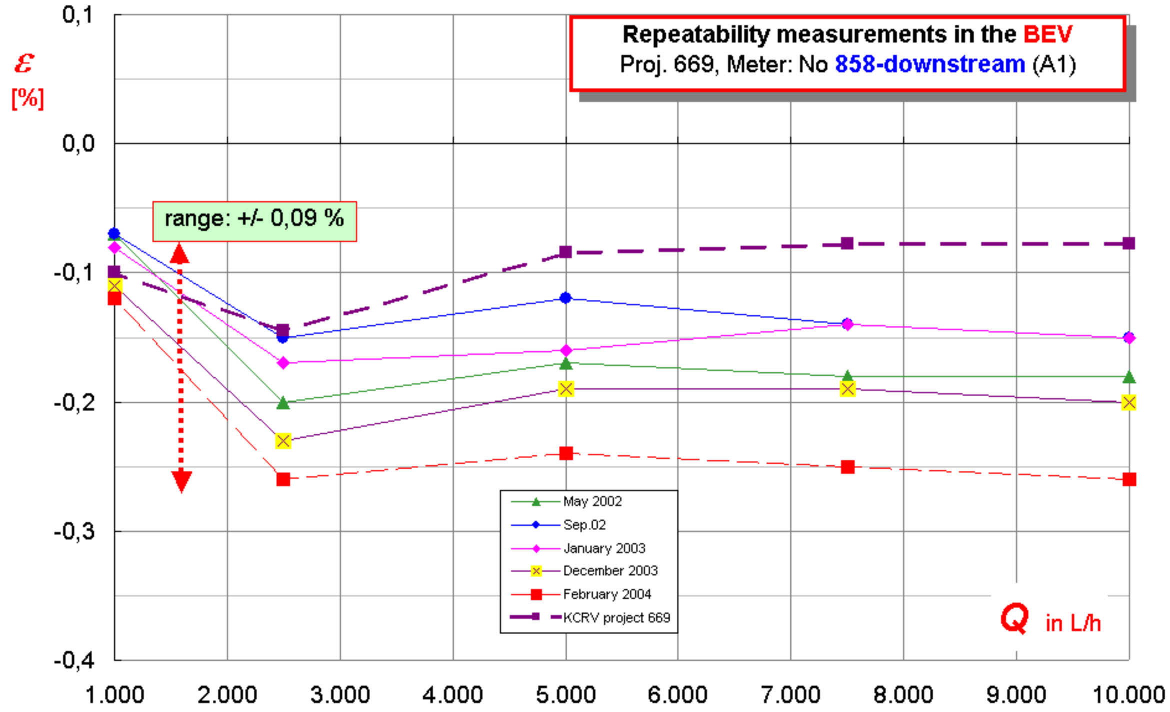


***Fig. 20**: repeatability measurements at BEV at the start and at the end of each cycle.*
858 downstream

2.2 Stability measurements

In spite of the relatively long inlet and outlet pipes there occurred some doubts upon the independency of the measurement results from the test rigs and their special installation conditions. Therefore at the end of the tests additional examinations had been carried out by loosening and then again fixing the flanges (see fig.21); the results of these actions are shown in fig.22-23.

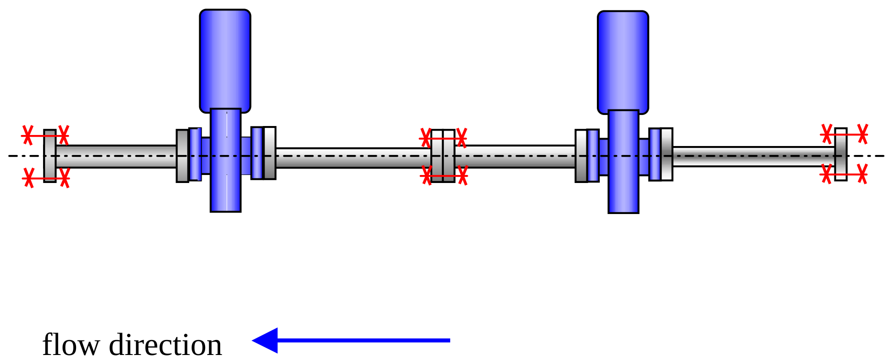


***Fig. 21**: Schematic arrangement of meters under test. At the postions marked red the screws of the flanges had been loosened and then fixed again.*

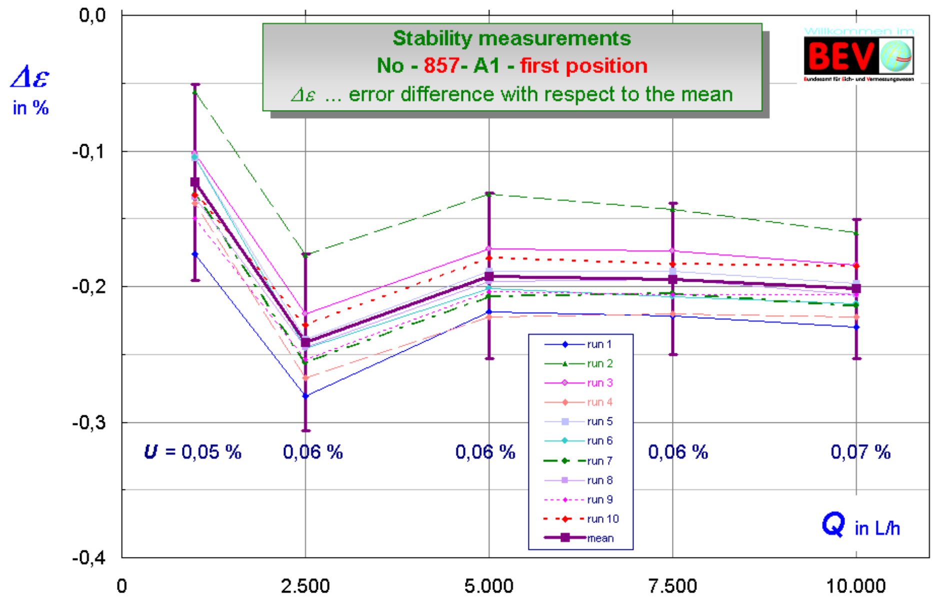


Fig. 22: *error curves of ten repeated measurements under the same conditions with relation to the mean of these measurements. One recognizes a strong scatter which might be interpretzed as an installation effect.*
857 upstream

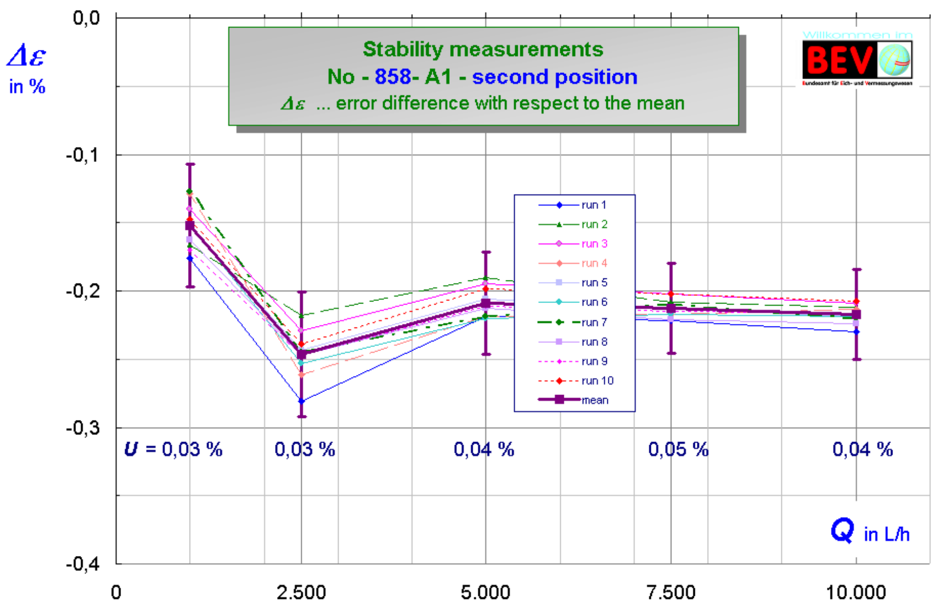


Fig. 23: *as-fig.22, but*
858 down-stream

Whereas under normal conditions the span d (difference between highest and lowest value of a measurement series) was not more than 0,02 %, the corresponding value d after loosening and re-fixing is 0,07 …0,12 %. The corresponding uncertainty contributions $u_{\mathrm{Install},1}$ generated by these installation effects are typically 0,03 % for meters upstream and for meters downstream $u_{\mathrm{Install},2} \approx 0{,}015$ %.[1]

This uncertainty contribution cannot be revealed by a participant unless he does not carry out the above procedure; but this is not assumed. So the uncertainty contributions of the par-

[1] The indicated values can be interpreted as a standard uncertainty, the data in fig.22 and fig.23 as an expanded measurement uncertainty.

ticipants according to fig.13-16 have to be enlarged by the amounts given above, a measure, which has been taken into account by calculating the KCRV (see point 3.2).

3 Evaluation of measurement results

3.1 General

The measurement results of point 2 reveal differences higher than it corresponds to the reported measurement uncertainties. So the conclusions might be:

The evaluation of the measurement uncertainty does not meet the reality, thus leading to several possibilities: some uncertainty contributions might be unknown or might have been under-estimated, existing correlations might have been neglected etc.

There are systematic contributions which are in general not known. Such contributions correspond to those given in point 2.2. Sometimes influences come from the test rig, but are unknown and therefore not regarded. In most cases the flow condition (flow profile) at the installation of the meter is unknown, that means whether the flow profile is fully developed or not.

Investigations were made at the BEV discovering a flow effect ("Borda-flow") generating a longitudinal wave and thus changes of the normally undisturbed profile[1]. The flow velocity in some cases may also have radial components (twist) which cause changes of the meter´s indication etc. A twist may also occur downstream of a pipe elbow or downstream of a meter introducing such a twist, e.g. with Woltman meters of type WP.

Investigations by the reporter have shown that downstream of certain disturbances very long undisturbed inlet pipes are necessary in order to restore a fully developed flow profile. E.g. a half open ball valve requires an undisturbed inlet pipe of 60 D, which is not present under normal conditions [2].

But anyway, because it can be assumed that the chosen meters are very accurate and the test rigs for the calibrations are located at NMIs, „high-level"-calibrations can be assumed. [2]

The intended measurement uncertainties of the test rigs taken from the CMC-tables are of the magnitude < 0,1 %. By looking at the results of chapter 2 there occur some doubts whether the CMC-values are realistic.

The reasons were drafted above and shall now be processed statistically. For this purpose first a conventional reference value has to be established denoted as " KCRV". It has been already plotted in the fig. 9-12 and 17-20.

3.2 Evaluation criteria for the reference value

When measurement values x_i correspond to a normal distribution then the arithmetic mean x_0 is the best estimate for the true value of the measurand X:

2 In some cases, e.g. in Slovenia, the primary standards for water flow are not located at the NMI, but at „JP Energetika", a supplier of energy

$$x_0 = \frac{1}{n}\sum_{i=1}^{n} x_i \ , \qquad (1)$$

The use of this mean is doubtful for the following reasons:

(1) The uncertainties claimed by the participants vary considerably, in the actual case by the factor 10. So it is necessary to attribute weights to the considered participants and to calculate a weighed mean. As the weight one normally uses the quantity $p = 1/u^2$ and then one writes for the weighed mean:[3]

$$x_{0,p} = \frac{\sum_{i=1}^{n} p_i \, x_i}{\sum_{i=1}^{n} p_i} \qquad (2)$$

(2) Sometimes it is not sure that all contributions can be assigned to the mean of a normal distribution, e.g. in cases when unknown systematic deviations are present in the single measurement values. In such a case two solutions are possible:

(2.1) The median is used as an emperic measure for the "mean": The values are lined up according to their magnitude and the value in the middle is taken or a mean is taken from the 2 values in the middle. The procedure is drafted in fig.24.
As it can be seen from fig.24 is the median an appropriate measure in the case of systematic deviations which cannot be easily qualified.

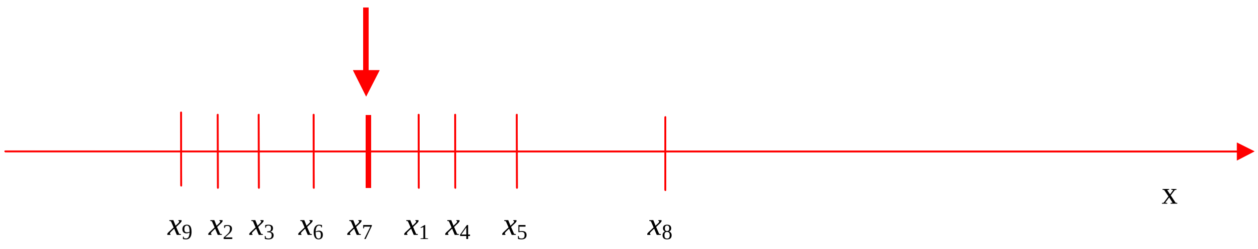


***Fig. 24**: The median as a "reference value" when systematic deviations are likely to occur. The values x_1, x_2 , x_3, … are lined up by their magnitude; the value in the middle (example: x_7) is the median.*

(2.2) A statistical procedure, the χ^2-test, helps to identify systematic deviations and to eliminate them before the calculation of the KCRV. The consideration is as follows: The χ^2-function is defined by [3]

3 It is not important, whether the combined variance or the expanded uncertainty is taken for the mean, because the denominator of equation (2) automatically performs a standardization. The only pre-condition is that the expansion factor =2 !

$$\chi^2 = \sum_{i=1}^{n} \frac{(\text{observed value} - \text{expected } value)^2}{\text{expected value}} = \sum_{i=1}^{n} \frac{(x_i - x_{ref})^2}{x_{ref}} \quad (3)$$

The χ^2-test means that for $\chi^2 = 0$ the observed and the expected distribution coincide. For $\chi^2 \leq n$ the coincidence is quite good, for $\chi^2 \gg n$ the assumption of coincidence fails (better: is very unlikely). In the metrological practice it is better to define the χ^2-function in a slightly different way:

$$\chi^2 = \sum_{i=1}^{n} \frac{(\text{observed value} - \text{expected value})^2}{\text{standard uncertainty}} = \sum_{i=1}^{n} \frac{(x_i - x_{ref})^2}{u^2(x_{ref})} \quad (4)$$

This is the starting point for the χ^2-test proposed by Cox [4]:

$$\chi^2_{obs} = \frac{(x_1 - x_{ref})^2}{u^2(x_1)} + \frac{(x_2 - x_{ref})^2}{u^2(x_2)} + \frac{(x_3 - x_{ref})^2}{u^2(x_3)} + \ldots + \frac{(x_n - x_{ref})^2}{u^2(x_n)} \quad (5)$$

In equation (5) χ^2_{obs} is the observed χ^2-function, which is now compared with the theoretical χ^2-function: This theoretical χ^2-function depends on the degree of freedom $\nu = n - 1$. When the uncertainty of the reference value is known and not neglectable, this can be regarded in equation (5). For $u^2(x_{ref})$ being the uncertainty of the reference value (for example according to equation (2)), one gets [4]:

$$\chi^2_{obs} = \frac{(x_1 - x_{ref})^2}{u^2(x_1) - u^2(x_{ref})} + \frac{(x_2 - x_{ref})^2}{u^2(x_2) - u^2(x_{ref})} + \frac{(x_3 - x_{ref})^2}{u^2(x_3) - u^2(x_{ref})} + \ldots + \frac{(x_n - x_{ref})^2}{u^2(x_n) - u^2(x_{ref})} \quad (6)$$

The Excel programme provides a function determining the coincidence between the observed and the theoretical χ^2-function:

$$P\{\chi^2(\nu) > \chi^2_{obs}\} > 5\% \quad (7)$$

As an example of the analysis by the χ^2-test, see tables 4 and 5. Table 4 shows all measurement values of the participants for a specials flow rate (Q = 10.000 L/h), for a special meter (Nr. 857) and for a special arrangement. Table 5 shows the effect of cancellation of some "suspicious" labs.

Table 4: Analysis of a measurement series by the χ^2-test

Labor	reported values x_i	abs deviation from mean d_i	reported uncertainties (k = 2) $U(x_i)$	reported uncertainties included installation effects (k = 2) $U(x_i)$	reported uncertainties (k = 1) with stability uncertainty $u(x_i)$	$x_i/u^2(x_i)$	$1/u^2(x_i)$	degree of equivalence d_i	normalized difference norm d_i	by Coc with $u^2(x_{ref})$ χ^2	by Coc without $u^2(x_{ref})$ χ^2
Austria	-0,13	0,04	0,03	0,07	0,034	-116	889	-0,04	1,16	1,35	1,12
Slovakia	-0,03	0,06	0,11	0,13	0,063	-8	255	0,06	1,06	1,12	1,06
Czech Rep.	-0,01	0,08	0,12	0,13	0,067	-2	222	0,08	1,29	1,66	1,59
Switzerland	-0,04	0,05	0,18	0,19	0,095	-4	111	0,05	0,58	0,34	0,33
Sweden	-0,07	0,02	0,08	0,10	0,050	-28	400	0,02	0,51	0,26	0,24
Denmark	-0,05	0,04	0,11	0,13	0,063	-13	255	0,04	0,73	0,53	0,50
Germany	-0,05	0,04	0,03	0,07	0,034	-44	889	0,04	1,46	2,13	1,76
Slovenia	-0,13	0,04	0,17	0,18	0,090	-16	123	-0,04	0,40	0,16	0,15
France	0,00	0,09	0,12	0,13	0,067	0	222	0,09	1,44	2,07	1,99
Norway	-0,29	0,35	0,08	0,10	0,050	-116	400	-0,20	4,07	16,57	15,28
Turkey	-0,13	0,04	0,05	0,08	0,038	-92	711	-0,04	1,02	1,04	0,90
Hungary	-0,01	0,08	0,11	0,13	0,063	-3	255	0,08	1,38	1,91	1,82
Lithuania	-0,16	0,07	0,14	0,15	0,076	-28	172	-0,07	0,87	0,76	0,74
Italy	-0,07	0,02	0,11	0,13	0,064	-17	248	0,02	0,40	0,16	0,15
mean = x_{ref}	**-0,084**				Summen =	**-487**				χ^2_{obs} =	χ^2_{obs} =
s	**0,079**				Summen =		**5152**			30,07	27,63
s_0	**0,026**								$P\{\chi^2(\nu)-\chi^2_{obs}\}$ =	**0,46%**	**1,02%**
ν =	**13**					$u^2(x_{ref})$ =	**1,941E-04** %²			level of significance	= 5 %
x_{ref} =	**-0,095**					$u(x_{ref})$ =	**0,014** %				

Remark: Without the cancellation of any participants

By comparing the 2 tables it is easy to be seen that the cancellation of 3 labs has a considerable effect, it is evident that the values of the cancelled labs did not fit into the distribution; their cancellation increases the adjustment from P = 0,46 % to 46,84 % (by regarding the uncertainty of the reference value $u(x_{ref})$).
Furthermore, in tables 4 and 5 that uncertainty of the meters (857 und 858, upstream und downstream), which was determined in chapter 2.2 (U = 0,06 % resp. 0,03 %) is regarded. Table 6 shows the single reference values x_{ref} = KCRV. In the annex the complete data for the calculation of the KCRV can be found.

Table 6 also indicates, which of the labs had been excluded when calculating the relevant KCRV = x_{ref}. In order to determine the influence of a single participant on the χ^2-test , with meter 858, downstream, the grew coloured cell had been varied according to the participants. Whereas only CZ and N had been excluded originally, some other labs were also excluded in order to increase the probability of the χ^2-adjustment. It can be observed that by that action the adjustment of χ^2_{obs} und $\chi^2(\nu)$ is getting better all the time.
It is also remarkable that the reference value shifts considerably (for example, in the above table by more than 0,016 %, which is of the magnitude of the measurement uncertainty). But by the cancellation of participants the degree of freedom decreases concurrently, which is problematic concerning the usefulness of the χ^2-tests ($n \geq 10$ resp. $\nu \geq 9$).

Table 5: Analysis of a (part of a) measurement series by the aid of the χ^2-test
Remark: <u>With</u> the cancellation of some participants

Labor	reported values x_i	abs deviation from mea[n] d_i	reported uncertainties (k = 2) $U(x_i)$	reported uncertainties included installation effects (k = 2) $U(x_i)$	reported uncertainties (k = 1) with stability uncertainty $u(x_i)$	$x_i/u^2(x_i)$	$1/u^2(x_i)$	degree of equivalence d_i	normalized difference norm d_i	by **Coc with $u^2(x_{ref})$** χ^2	by **Coc without $u^2(x_{ref})$** χ^2
Austria	-0,13	0,04	0,03	0,07	0,034	-116	889	-0,04	1,49	2,21	1,75
Slovakia	-0,03	0,06	0,11	0,13	0,063	-8	255	0,06	0,92	0,84	0,79
Switzerland	-0,04	0,05	0,18	0,19	0,095	-4	111	0,05	0,49	0,24	0,23
Sweden	-0,07	0,02	0,08	0,10	0,050	-28	400	0,02	0,33	0,11	0,10
Denmark	-0,05	0,04	0,11	0,13	0,063	-13	255	0,04	0,59	0,34	0,32
Germany	-0,05	0,04	0,03	0,07	0,034	-44	889	0,04	1,19	1,42	1,13
Slovenia	-0,13	0,04	0,17	0,18	0,090	-16	123	-0,04	0,50	0,25	0,24
Turkey	-0,13	0,04	0,05	0,08	0,038	-92	711	-0,04	1,30	1,68	1,40
Hungary	-0,01	0,08	0,11	0,13	0,063	-3	255	0,08	1,24	1,55	1,46
Lithuania	-0,16	0,07	0,14	0,15	0,076	-28	172	-0,07	1,00	0,99	0,95
Italy	-0,07	0,02	0,11	0,13	0,064	-17	248	0,02	0,25	0,06	0,06
mean = x_{ref}	**-0,079**				Summen =	**-369**				χ^2_{obs} =	χ^2_{obs} =
s	**0,050**				Summen =		**4308**			9,69	8,43
s_0	**0,017**								**$P\{\chi^2(\nu)-\chi^2_{obs}\}$ =**	**46,84%**	**58,66%**
ν =	**10**					**$u^2(x_{ref})$ = 2,321E-04**	%²		**level of significance**	**= 5 %**	
x_{ref} =	**-0,086**					**$u(x_{ref})$ = 0,015**	%				

Table 6: Reference values (KCRV = x_{ref}) for the calibrated meters (857 und 858) in dependency of flow rate and arrangement. Remark: d = span (maximal – minimal value). The table at the bottom shows the effect of the cancellation of single participants (meter Nr. 858, Q = 2500 L/h, downstream).

meter no 857

upstream						downstream					
Q	**x_{ref}**	**$u(x_{ref})$**	without	**P_1**	**P_2**	**Q**	**x_{ref}**	**$u(x_{ref})$**	without	**P_1**	**P_2**
L/h	%	%		%	%	L/h	%	%		%	%
10.000	-0,085	0,016	Cz, F, N	68,07	60,26	10.000	-0,086	0,015	Cz, F, N	58,66	46,84
7.500	-0,072	0,015	Cz, F, N	60,44	52,2	7.500	-0,060	0,015	Cz, F, N	44,86	31,94
5.000	-0,070	0,016	Cz, De, F, N	24,66	15,33	5.000	-0,058	0,014	Cz, F, N	49,33	36,49
2.500	-0,152	0,016	At, Cz, F, N	12,53	7,12	2.500	-0,142	0,015	Cz, F, N	45,69	35,44
1.000	-0,151	0,017	Cz, De, F, N	28,83	19,26	1.000	-0,144	0,015	F	16,79	12,73

meter no 858

upstream						downstream					
Q	**x_{ref}**	**$u(x_{ref})$**	without	**P_1**	**P_2**	**Q**	**x_{ref}**	**$u(x_{ref})$**	without	**P_1**	**P_2**
L/h	%	%		%	%	L/h	%	%		%	%
10.000	-0,108	0,015	N	20,47	10,71	10.000	-0,100	0,015	Cz, De	12,99	6,57
7.500	-0,082	0,017	At, Cz, F, N	87,08	83,65	7.500	-0,096	0,015	At	20,42	15,16
5.000	-0,070	0,015	At, Cz, F, N	8,33	5,08	5.000	-0,113	0,014	Cz, F, N	17,82	12,31
2.500	-0,146	0,014	Cz	13,66	6,27	2.500	-0,145	0,014	Cz, N	11,26	6,81
1.000	-0,065	0,015	N	17,82	13,19	1.000	-0,104	0,016	Cz, F	70,79	63,07

Influence of participants:

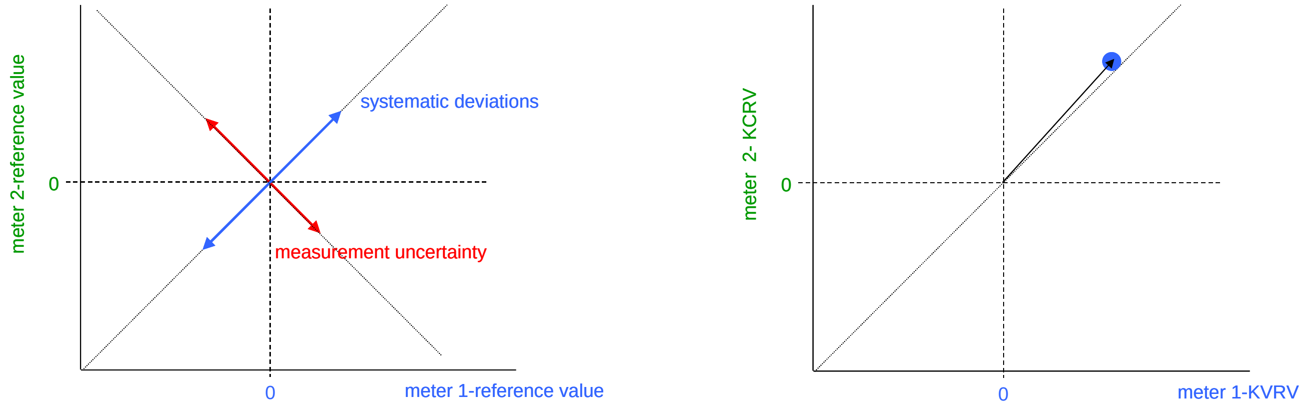
Q	**x_{ref}**	**$u(x_{ref})$**	without	**P_1**	**P_2**	**ν**
L/h	%	%	-	%	%	-
2.500	-0,145	0,014	Cz, N	11,26	6,81	11
2.500	-0,153	0,015	Cz, F, N	45,23	32,59	10
2.500	-0,142	0,016	At, Cz, F, N	59,11	47,25	9
2.500	-0,158	0,019	At, Cz, F, N, T	79,37	74,71	8
d =	**0,016**	**0,005**		**68,11**	**67,90**	

d = max-min

3.3 Youdenplot

The Youden plot (by Youden in 1959) is an excellent empirical procedure to plot graphically systematic deviations and measurement uncertainties of tandem measurements. The procedure is as follows (see also [5] - [7]):

For both meters the differences against the KCRV is plotted (e.g. at Q = 10 000 L/h), for one meter 857 upstream on the x-axis and for the other meter 858 upstream on the y-axis. By doing this a diagram is generated as shown in fig.25. The interpretation of the Youden plot can be taken from the comment on fig. 25.



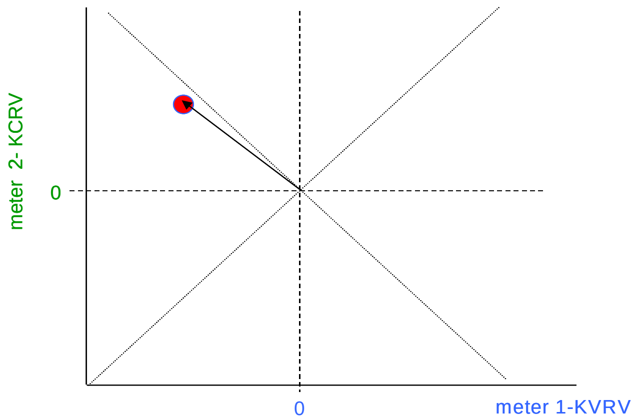
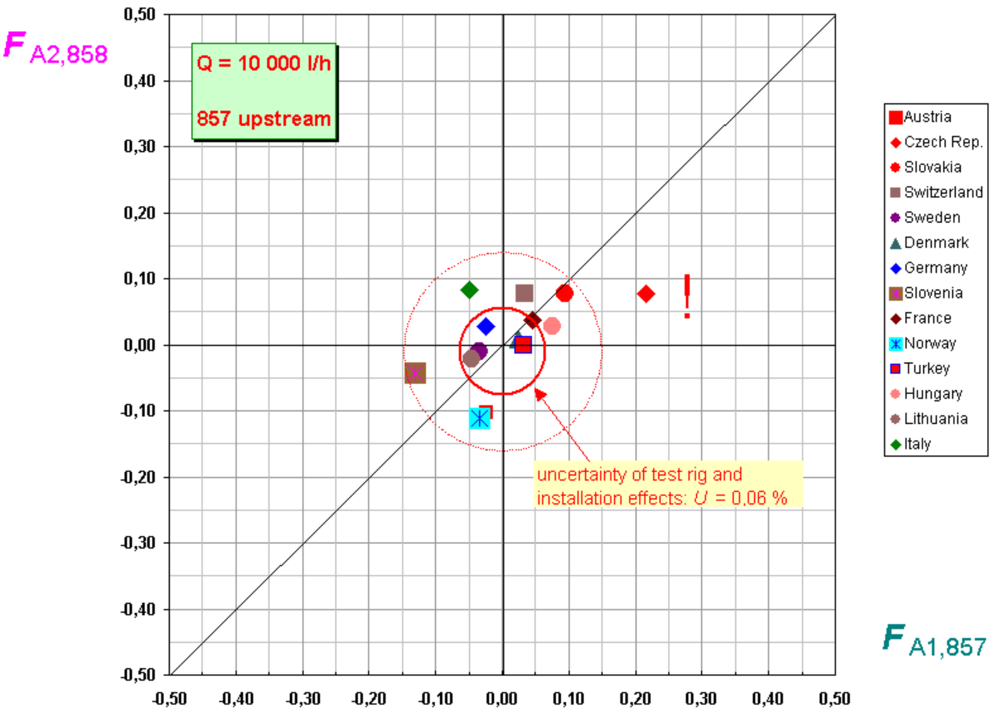


Fig. 25*: Principle of Youden plots. On left side up the arrangement is shown. The deviation from the KCRV (or another reference value e.g. the mean of all participant) of the first meter (upstream) is plotted on the x-axis and the deviation of the second meter (upstream) is plotted on the y-axis. Every measurement of a participant corresponds to one point in the x/y-plane. The systematic deviations are in blue, the measurement uncertainty is in red.*

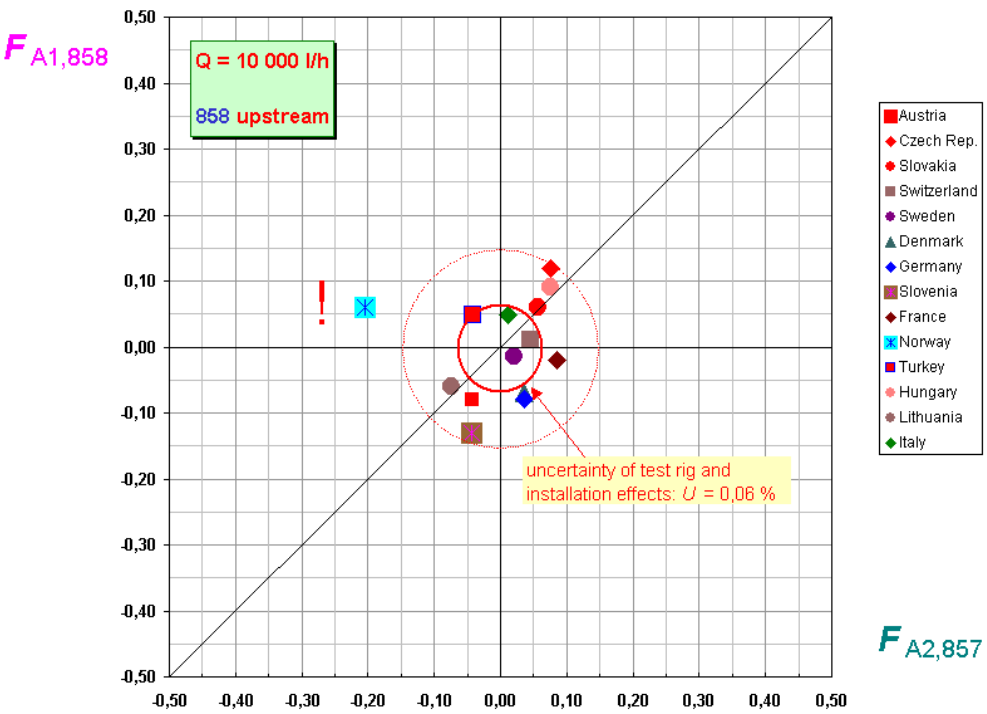
Quarter right side up: A measurement with small uncertainty, but with large systematic deviation.

Quarter left side down: A measurement with large uncertainty, but with small systematic deviation.

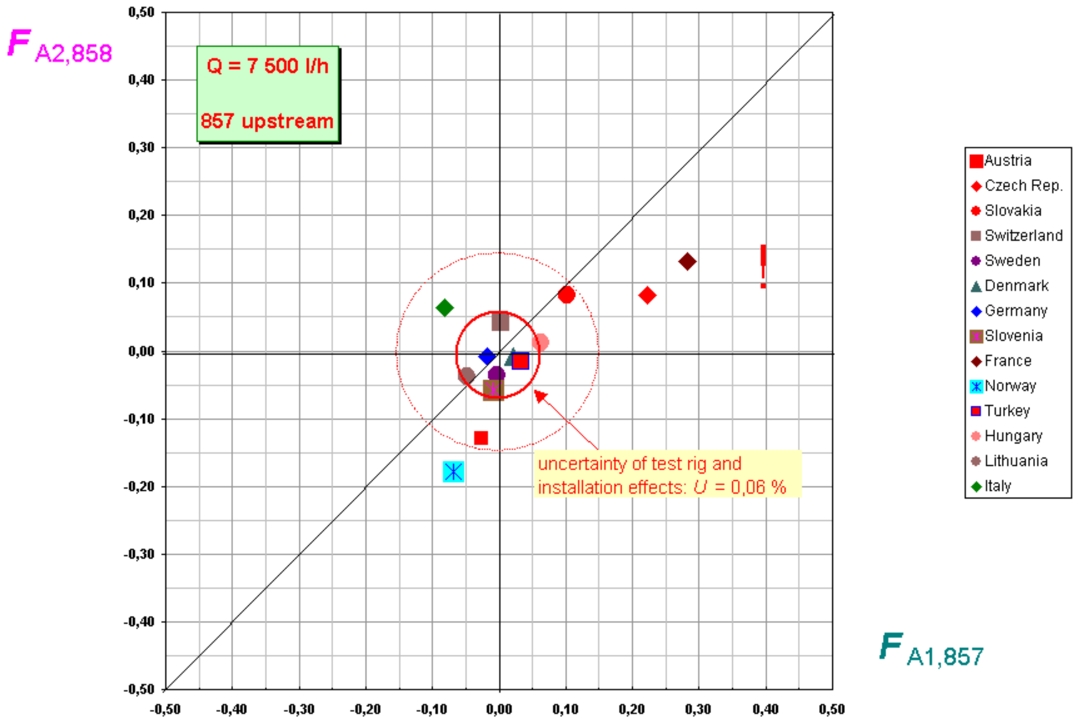
The following figures show the Youden plots for the different flow rates and the arrangements upstream und downstream.


F A2,858
Q = 10 000 l/h
857 upstream
uncertainty of test rig and installation effects: U = 0,06 %
F A1,857
Austria
Czech Rep.
Slovakia
Switzerland
Sweden
Denmark
Germany
Slovenia
France
Norway
Turkey
Hungary
Lithuania
Italy

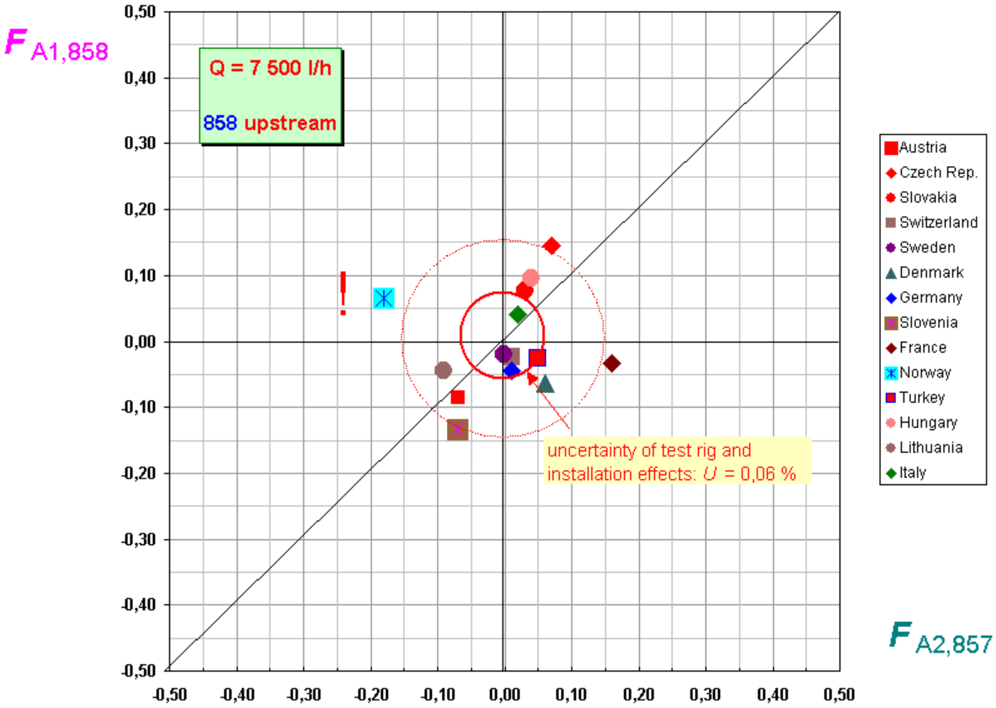
(a)


F A1,858
Q = 10 000 l/h
858 upstream
uncertainty of test rig and installation effects: U = 0,06 %
F A2,857
Austria
Czech Rep.
Slovakia
Switzerland
Sweden
Denmark
Germany
Slovenia
France
Norway
Turkey
Hungary
Lithuania
Italy

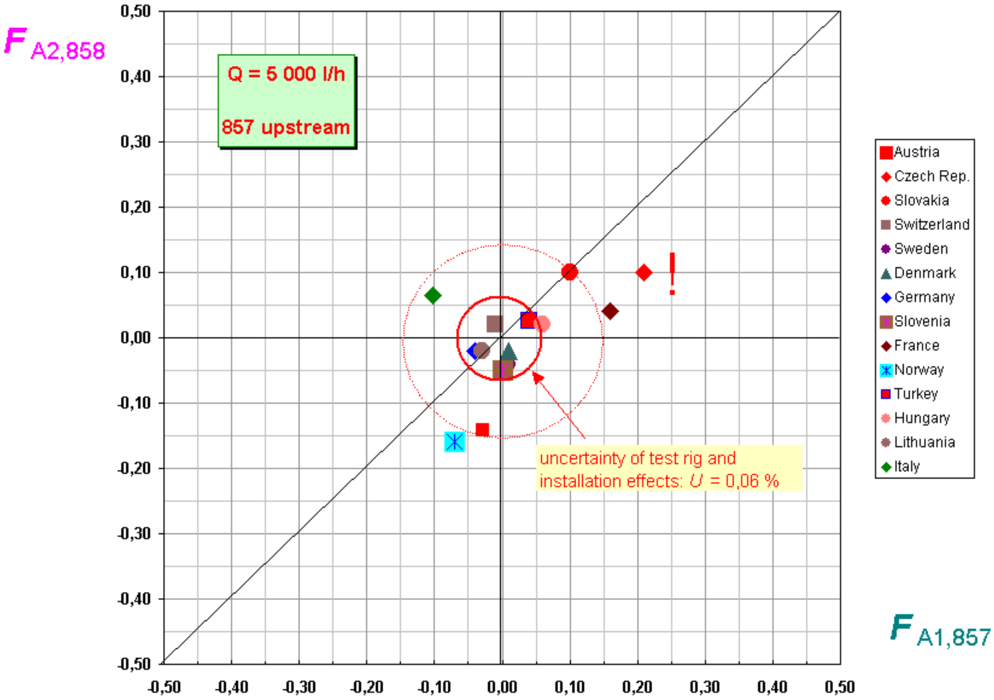
(b)


F A2,858
Q = 7 500 l/h
857 upstream
uncertainty of test rig and installation effects: U = 0,06 %
F A1,857
Austria
Czech Rep.
Slovakia
Switzerland
Sweden
Denmark
Germany
Slovenia
France
Norway
Turkey
Hungary
Lithuania
Italy

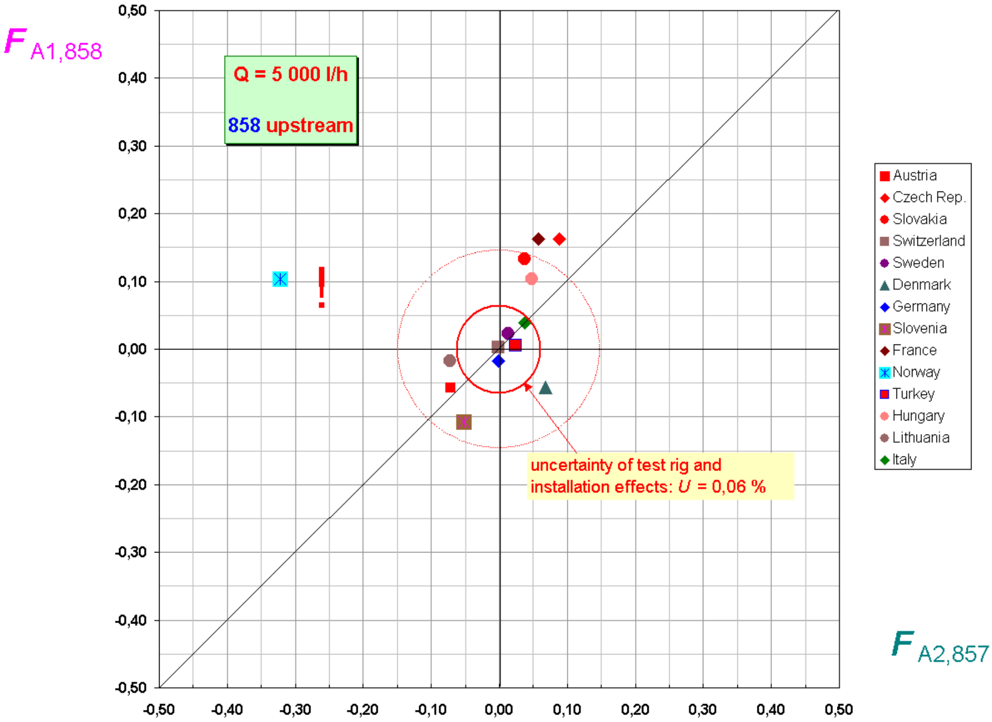
(c)


F A1,858
Q = 7 500 l/h
858 upstream
uncertainty of test rig and installation effects: U = 0,06 %
F A2,857
Austria
Czech Rep.
Slovakia
Switzerland
Sweden
Denmark
Germany
Slovenia
France
Norway
Turkey
Hungary
Lithuania
Italy

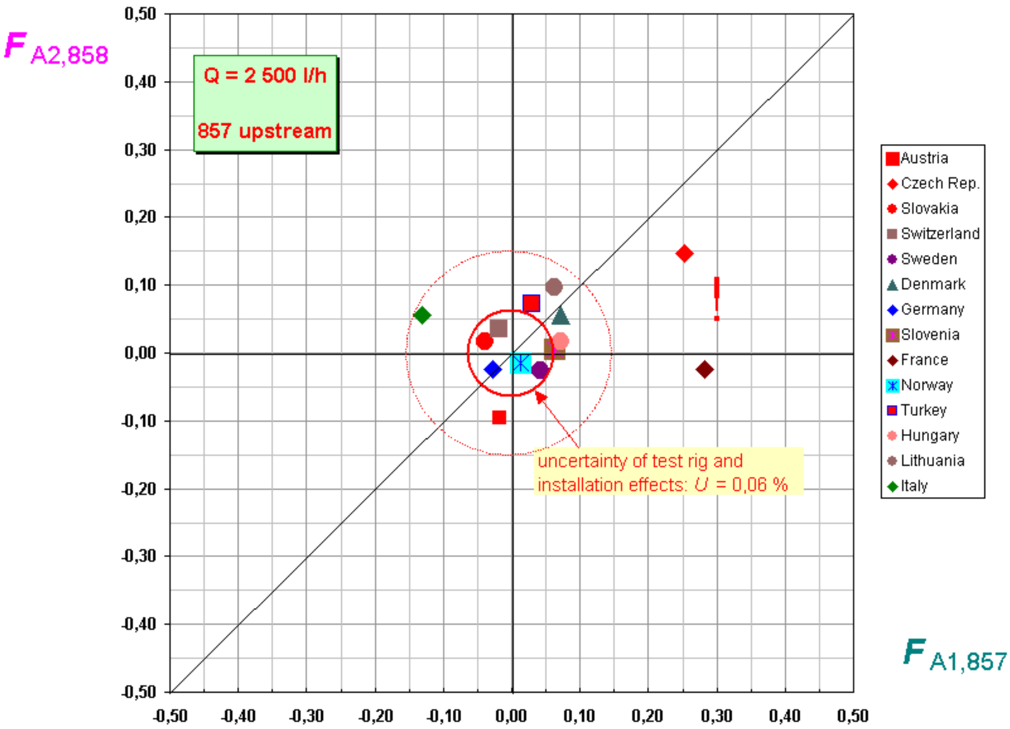
(d)


$F_{A2,858}$
Q = 5 000 l/h
857 upstream
uncertainty of test rig and installation effects: U = 0,06 %
Austria
Czech Rep.
Slovakia
Switzerland
Sweden
Denmark
Germany
Slovenia
France
Norway
Turkey
Hungary
Lithuania
Italy
$F_{A1,857}$

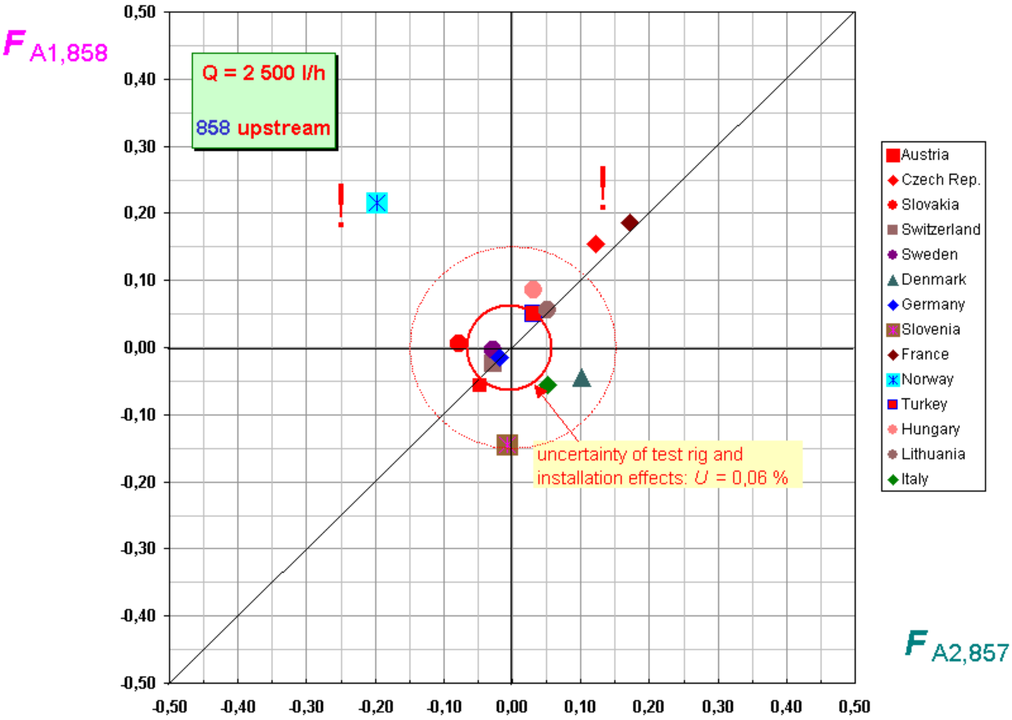
(e)


$F_{A1,858}$
Q = 5 000 l/h
858 upstream
uncertainty of test rig and installation effects: U = 0,06 %
Austria
Czech Rep.
Slovakia
Switzerland
Sweden
Denmark
Germany
Slovenia
France
Norway
Turkey
Hungary
Lithuania
Italy
$F_{A2,857}$

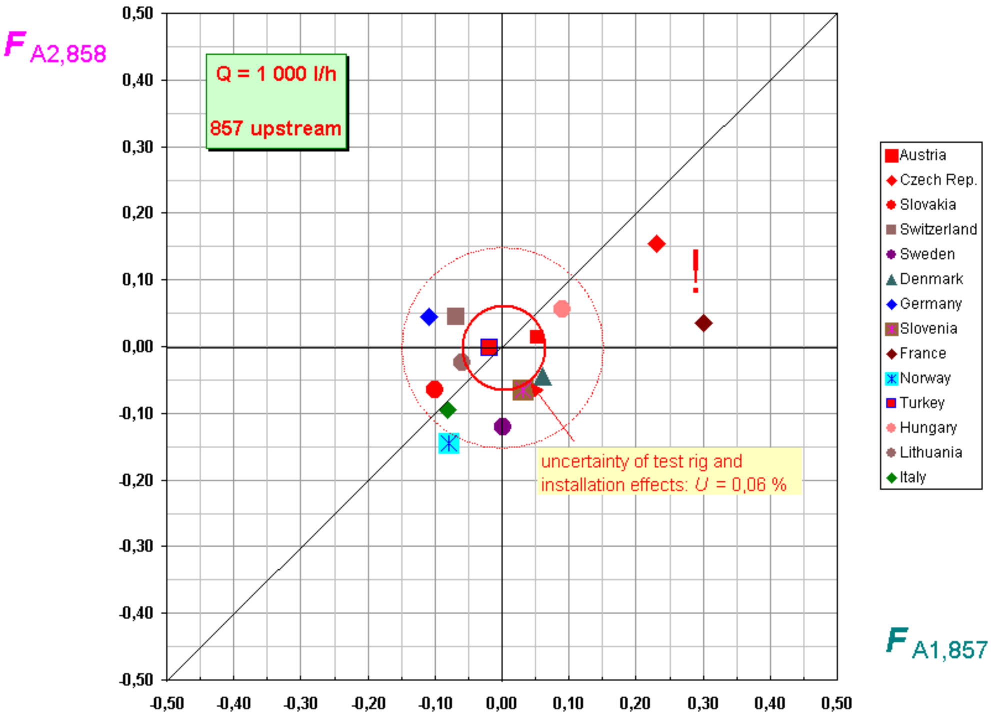
(f)


F A2,858
Q = 2 500 l/h
857 upstream
uncertainty of test rig and
installation effects: U = 0,06 %
Austria
Czech Rep.
Slovakia
Switzerland
Sweden
Denmark
Germany
Slovenia
France
Norway
Turkey
Hungary
Lithuania
Italy
F A1,857

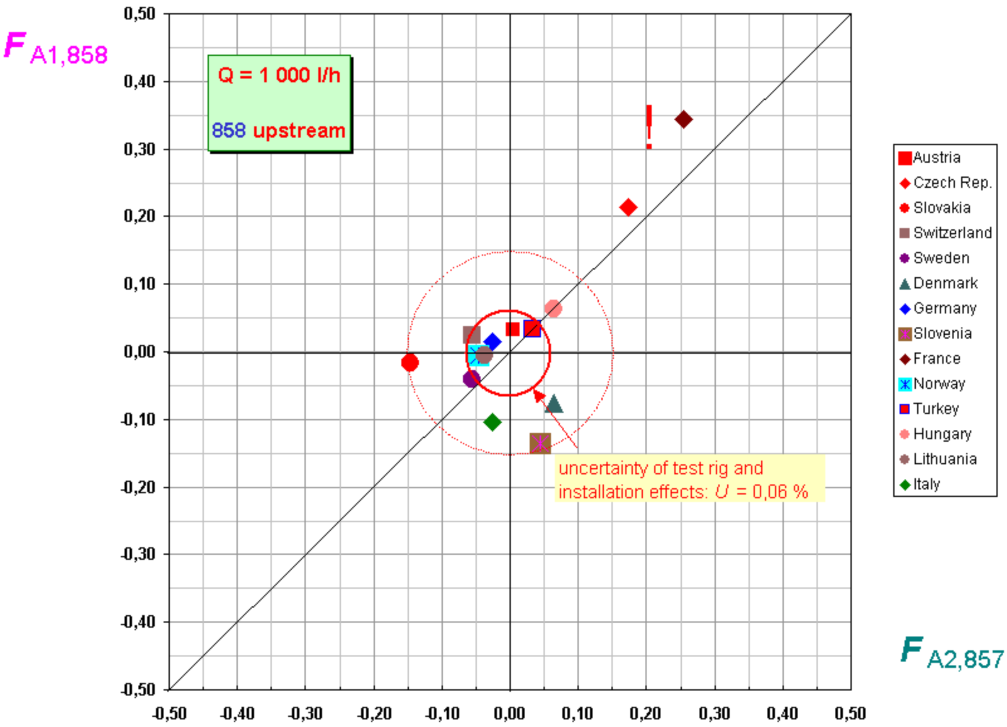
(g)


F A1,858
Q = 2 500 l/h
858 upstream
uncertainty of test rig and
installation effects: U = 0,06 %
Austria
Czech Rep.
Slovakia
Switzerland
Sweden
Denmark
Germany
Slovenia
France
Norway
Turkey
Hungary
Lithuania
Italy
F A2,857

(h)



(i)



(j)

Fig. 26*: Youden plots of different flow rates and arrangements of the meters*
a,c,e,g,i: meters in first position
b,d,f,h,j: meters in second position

From the Youden plots one is able to derive some characteristic values [5-7]:

- The eccentricity of the plotted values, which normally are supposed to lie within a circle around the zero point ($x = 0/y = 0$). In some cases these values are distributed like an ellipse, when there are considerable systematic deviations but small uncertainties. Table 7 shows such values with reference to fig.26. If one considers for one measurement point with the coordinates (x_i,y_i) in fig.27 the distance to the reference point (x_0,y_0), then the following variances can be calculated:

$$u_r^2 = \frac{1}{n-1}\sum_i N_i^2 \text{ and } u_s^2 = \frac{1}{n-1}\sum_i P_i^2 \quad (8)$$

which correspond to the quantities P_i und N_i defined by fig. 27.

$$P_i^2 = \frac{\left[(x_i - x_0) + (y_i - y_0)\right]^2}{2} \quad (9)$$

$$N_i^2 = \frac{\left[(x_i - x_0) - (y_i - y_0)\right]^2}{2} \quad (10)$$

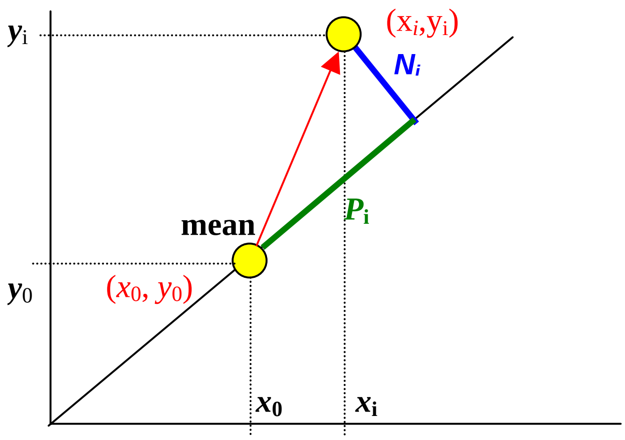


Fig. 27: Location of the measurement points with relation to the 45 °-straight line

u_r^2 can be interpreted as a variance in the sense of the GUM, u_s^2 as a systematic variance. If there were not any systematic deviations, 95 % of all points would lie within the 2 u_r-area of the mean,, i.e. within a circle with the centre (x_0/y_0) and a radius corresponding 2 times the standard deviation u_r. But the distribution of the points is generally such that a major part of all points lies outside the circle with the radius 2 u_r. Such outliers demonstrate that the labs had made additional systematic deviations; the distribution shows an elliptic shape. If the shape of the ellipse is defined by the ratio ε, with

$$\varepsilon = \frac{u_r}{u_s}, \quad (11)$$

then $\varepsilon < 1$ (deviation from the shape of a circle) can be interpreted in such a way that systematic deviations occur, which are larger than the statistical deviations.

If the measurement result of two meters 1 and 2 is present as n-times repeated deviations F_{1i} und F_{2i} on a test rig, then for the means $F_{1,0}$ and $F_{2,0}$ of the n measurements as well as for the standard deviations s_1 (resp. u_1) and s_2 (resp. u_2) of single measurements and for the correlation coefficient r_{12} of n pairs of deviations (F_{1i} and F_{2i}) follows:

$$F_{1,0} = \frac{1}{n}\sum_i F_{1i} \text{ and } F_{2,0} = \frac{1}{n}\sum_i F_{2i} \tag{12}$$

$$u_1 = s_1 = \sqrt{\frac{1}{n-1}\sum_i \left(F_{1i} - F_{1,0}\right)^2} \text{ and } u_2 = s_2 = \sqrt{\frac{1}{n-1}\sum_i \left(F_{2i} - F_{2,0}\right)^2} \tag{13}$$

$$r_{1,2} = \frac{u_{1,2}}{u_1 \times u_2} \tag{14}$$

$u_{1,2}$ in equation (14) is the covariance of the measurement series of meter 1 and of meter 2. $r_{1,2}^2$ can be - according to *Mattingly* [6,7] - interpreted as that part of the variance of the corresponding deviations, which can be assigned to that component of the measurement which is common for both meters, namely to the test rig.

$$r_{1,2} = \left(\frac{u_{1,\mathrm{PE}}}{u_1}\right)^2 \text{ and } 1 - r_{1,2} = \left(\frac{u_{1,Z}}{u_1}\right)^2 \tag{15}$$

$u_{1;\mathrm{PE}}$ ... component of the total variance of meter 1 (resp. $u_{2;\mathrm{PE}}$ of meter 2), generated by the test rig

$u_{1,\mathrm{z}}$ ... component of the total variance of meter 1 (resp. $u_{2;\mathrm{z}}$ of meter 2), generated by the corresponding meter

Table 7 shows the characteristic contributions according to the relations from above.
In table 7 it is remarkable that:

- the standard uncertainty of the test rig (columns with $u_{1(2),\mathrm{PE}}$) with meters mounted upstream or downstream is for all meters from the order ± 0,02 %,
- the standard uncertainty of the meters is about 5 times the uncertainty of the test rigs.

Table 7: Characteristic values from the Youden plot (in %).
Table above: Meter in first position, table below: Meters in second position

857, upstream, 858 downstream

Q l/h	s_1^2	s_2^2	$\upsilon_{1,2}$ =(Σ F_{1i}- mean) * (Σ F_{2i}- mean)/n(n-1)	r_{12}	$u_{1,PE}$	$u_{1,Z}$	$u_{2,PE}$	$u_{2,Z}$
10.000	0,005	0,006	0,0002	0,043	0,015	0,071	0,016	0,073
7.500	0,011	0,006	0,0002	0,023	0,016	0,104	0,012	0,076
5.000	0,007	0,007	0,0003	0,045	0,018	0,085	0,018	0,084
2.500	0,012	0,010	0,0005	0,041	0,022	0,106	0,021	0,100
1.000	0,015	0,015	0,0008	0,055	0,029	0,120	0,029	0,121

858, upstream, 857 downstream

Q l/h	s_1^2	s_2^2	$\upsilon_{1,2}$ =(Σ F_{1i}- mean) * (Σ F_{2i}- mean)/n(n-1)	r_{12}	$u_{1,PE}$	$u_{1,Z}$	$u_{2,PE}$	$u_{2,Z}$
10.000	0,006	0,004	0,00028	0,057	0,019	0,076	0,015	0,061
7.500	0,007	0,007	0,00043	0,062	0,021	0,080	0,021	0,081
5.000	0,011	0,006	0,00045	0,057	0,024	0,100	0,018	0,075
2.500	0,008	0,004	0,00018	0,032	0,017	0,090	0,011	0,059
1.000	0,010	0,007	0,00033	0,040	0,020	0,100	0,016	0,079

3.4 E_n-values

Tables 8 - 11 show the E_n-values for the intercomparisons, E_n being defined by:

$$E_n = \frac{x_i - x_j}{\sqrt{u^2(x_i) + u^2(x_j)}} \qquad (16)$$

E_n shall be ≤ 1.

Table 8: E_n-values for the intercomparisons with meter Nr. 857, **upstream**

857 upstream, Q = 10.000 L/h

	Austria	Slovakia	Czech Rep.	Switzerland	Sweden	Denmark	Germany	Slovenia	France	Norway	Turkey	Hungary	Lithuania	Italy
Austria		-0,9	-1,6	-0,3	0,1	-0,3	0,0	-0,1	-0,6	0,1	-0,5	-0,7	0,1	0,2
Slovakia			-0,7	0,3	0,8	0,4	0,9	0,5	0,3	0,8	0,4	0,1	0,7	0,9
Czech Rep.				0,8	1,5	1,0	1,5	1,0	1,0	1,5	1,2	0,8	1,3	1,5
Switzerland					0,3	0,0	0,3	0,2	0,0	0,3	0,0	-0,2	0,3	0,4
Sweden						-0,4	0,7	-0,1	-0,6	0,0	-0,5	-0,7	0,1	0,1
Denmark							0,3	0,2	-0,1	0,3	-0,1	-0,3	0,3	0,4
Germany								-0,1	-0,6	0,1	-0,5	-0,7	0,1	0,2
Slovenia									-0,3	0,1	-0,2	-0,4	0,1	0,2
France										0,5	0,1	-0,2	0,5	0,6
Norway											-0,5	-0,7	0,1	0,1
Turkey												-0,3	0,4	0,6
Hungary													0,6	0,0
Lithuania														0,0
Italy														

857 upstream, Q = 7.500 L/h

	Austria	Slovakia	Czech Rep.	Switzerland	Sweden	Denmark	Germany	Slovenia	France	Norway	Turkey	Hungary	Lithuania	Italy
Austria		-1,0	-1,7	-0,1	-0,2	-0,3	-0,1	-0,1	-1,7	0,3	-0,6	-0,6	0,1	0,4
Slovakia			-0,7	0,4	0,7	0,5	0,9	0,5	-0,9	1,1	0,5	0,2	0,8	1,2
Czech Rep.				0,9	1,3	1,1	1,6	1,0	-0,3	1,7	1,2	0,9	1,3	1,8
Switzerland					0,0	-0,1	0,1	0,0	-1,1	0,3	-0,1	-0,3	0,2	0,4
Sweden						-0,1	0,1	0,0	-1,4	0,5	-0,3	-0,4	0,3	0,5
Denmark							0,3	0,1	-1,2	0,5	-0,1	-0,2	0,3	0,6
Germany								-0,1	-1,6	0,4	-0,5	-0,6	0,2	0,5
Slovenia									-1,2	0,3	-0,2	-0,3	0,2	0,4
France										1,8	1,3	1,0	1,4	1,8
Norway											-0,8	-0,8	-0,1	0,1
Turkey												-0,2	0,5	0,9
Hungary													0,6	0,9
Lithuania														0,2
Italy														

857 upstream, Q = 5.000 L/h

	Austria	Slovakia	Czech Rep.	Switzerland	Sweden	Denmark	Germany	Slovenia	France	Norway	Turkey	Hungary	Lithuania	Italy
Austria		-1,0	-1,6	-0,1	-0,3	-0,3	0,1	-0,2	-1,4	0,3	-0,7	-0,6	0,0	0,7
Slovakia			-0,6	0,5	0,6	0,5	1,0	0,5	-0,4	1,1	0,4	0,2	0,7	1,4
Czech Rep.				0,9	1,3	1,2	1,5	1,0	1,2	1,3	1,5	1,2	1,1	1,4
Switzerland					-0,1	-0,1	0,1	0,0	-0,8	0,3	-0,2	-0,3	0,1	0,4
Sweden						0,0	0,4	0,0	-1,0	0,5	-0,3	-0,3	0,2	0,8
Denmark							0,3	0,0	-0,8	0,5	-0,2	-0,3	0,2	0,7
Germany								-0,2	-1,5	0,2	-0,8	-0,7	-0,1	0,6
Slovenia									-0,7	0,3	-0,2	-0,3	0,1	0,5
France										1,4	0,9	0,6	1,0	1,8
Norway											-0,9	-0,8	-0,2	0,2
Turkey												-0,8	-0,2	0,2
Hungary													0,4	1,0
Lithuania														0,4
Italy														

857 upstream, Q = 2.500 L/h

	Austria	Slovakia	Czech Rep.	Switzerland	Sweden	Denmark	Germany	Slovenia	France	Norway	Turkey	Hungary	Lithuania	Italy
Austria		0,1	-1,7	0,0	-0,5	-0,6	0,1	-0,4	-1,9	-0,2	-0,5	-0,6	-0,5	1,0
Slovakia			-1,5	-0,1	-0,5	-0,6	-0,1	-0,4	-1,6	-0,3	-0,5	-0,6	-0,5	0,6
Czech Rep.				1,1	1,2	0,9	1,8	0,8	-0,1	1,4	1,4	0,9	0,9	2,2
Switzerland					-0,3	-0,3	-0,3	-0,2	-0,3	-0,3	-0,3	-0,3	-0,2	-0,3
Sweden						-0,2	0,6	-0,1	-1,4	0,2	0,1	-0,2	-0,1	1,3
Denmark							0,7	0,0	-1,1	0,4	0,3	0,0	0,0	1,2
Germany								-0,5	-2,0	-0,3	-0,6	-0,7	-0,5	0,9
Slovenia									-1,0	0,2	0,2	0,0	0,0	0,9
France										1,5	1,6	1,1	1,1	2,4
Norway											-0,1	-0,4	-0,3	1,0
Turkey												-0,3	-0,2	1,4
Hungary													0,0	1,2
Lithuania														1,1
Italy														

857 upstream, Q = 1.000 L/h

	Austria	Slovakia	Czech Rep.	Switzerland	Sweden	Denmark	Germany	Slovenia	France	Norway	Turkey	Hungary	Lithuania	Italy
Austria		1,0	-1,1	0,6	0,4	-0,1	1,6	0,1	-1,3	1,0	0,7	-0,2	0,6	1,1
Slovakia			-1,7	-0,1	-0,6	-0,9	0,1	-0,6	-1,8	-0,1	-0,5	-0,9	-0,2	-0,1
Czech Rep.				1,2	1,2	0,9	2,1	0,9	-0,3	1,7	1,6	0,7	1,3	1,8
Switzerland					-0,3	-0,3	-0,3	-0,3	-0,3	-0,3	-0,3	-0,3	-0,3	-0,3
Sweden						-0,4	0,8	-0,1	-1,4	0,5	0,1	-0,5	0,3	0,5
Denmark							1,2	0,1	-1,1	0,8	0,6	-0,2	0,6	0,9
Germany								-0,7	-2,1	-0,2	-0,9	-1,2	-0,3	-0,2
Slovenia									-1,1	0,5	0,3	-0,3	0,4	0,5
France										0,5	0,3	-0,3	0,4	0,5
Norway											1,7	0,9	1,5	1,9
Turkey												-0,7	0,2	0,5
Hungary													0,7	0,9
Lithuania														0,1
Italy														

Table 9: E_n-values for the intercomparisons with meter Nr. 857, **downstream**

857 downstream, Q = 10.000 L/h

	Austria	Slovakia	Czech Rep.	Switzerland	Sweden	Denmark	Germany	Slovenia	France	Norway	Turkey	Hungary	Lithuania	Italy
Austria		-0,7	-0,8	-0,4	-0,5	-0,6	-0,8	0,0	-0,9	1,3	0,0	-0,8	0,2	-0,4
Slovakia			-0,1	0,0	0,2	0,1	0,1	0,5	-0,2	1,6	0,7	-0,1	0,7	0,2
Czech Rep.				0,1	0,3	0,2	0,3	0,5	-0,1	1,7	0,8	0,0	0,7	0,3
Switzerland					0,1	0,0	0,0	0,3	-0,2	1,2	0,4	-0,1	0,5	0,1
Sweden						-0,1	0,4	0,3	-0,4	1,6	0,5	-0,3	0,5	0,1
Denmark							0,0	0,4	-0,3	1,5	0,5	-0,2	0,6	0,1
Germany								0,4	-0,3	2,0	0,8	-0,3	0,7	0,2
Slovenia									-0,6	0,8	0,0	-0,5	0,1	-0,3
France										1,7	0,8	0,1	0,8	0,4
Norway											-1,3	-1,7	-0,7	-1,3
Turkey												-0,8	0,2	-0,4
Hungary													0,8	-0,4
Lithuania														-0,4
Italy														

857 downstream, Q = 7.500 L/h

	Austria	Slovakia	Czech Rep.	Switzerland	Sweden	Denmark	Germany	Slovenia	France	Norway	Turkey	Hungary	Lithuania	Italy
Austria		-0,7	-0,9	-0,4	-0,6	-0,9	-0,9	0,0	-1,7	0,9	-1,2	-0,7	0,1	-0,7
Slovakia			-0,2	0,1	0,2	-0,2	0,1	0,5	-0,8	1,3	-0,1	-0,1	0,6	0,1
Czech Rep.				0,3	0,4	0,1	0,4	0,6	-0,5	1,5	0,1	0,2	0,8	0,3
Switzerland					0,1	-0,2	0,0	0,3	-0,7	0,9	-0,2	-0,1	0,4	0,0
Sweden						-0,4	-0,1	0,3	-1,0	1,3	-0,4	-0,2	0,5	-0,1
Denmark							0,4	0,6	-0,6	1,5	0,1	0,1	0,8	0,2
Germany								0,4	-1,1	1,6	-0,4	-0,2	0,6	-0,1
Slovenia									-1,1	0,5	-0,6	-0,5	0,1	-0,4
France										2,2	0,8	0,7	1,3	0,9
Norway											-1,8	-1,3	-0,5	-1,4
Turkey												0,1	0,8	0,2
Hungary													0,6	0,1
Lithuania														-0,6
Italy														

857 downstream, Q = 5.000 L/h

	Austria	Slovakia	Czech Rep.	Switzerland	Sweden	Denmark	Germany	Slovenia	France	Norway	Turkey	Hungary	Lithuania	Italy
Austria		-0,8	-1,1	-0,3	-0,7	-1,0	-0,7	-0,1	-1,0	2,1	-1,0	-0,8	0,0	-1,0
Slovakia			-0,3	0,2	0,2	-0,2	0,3	0,4	-0,1	2,2	0,1	-0,1	0,6	0,0
Czech Rep.				0,4	0,5	0,5	0,6	0,4	0,5	0,5	0,6	0,5	0,4	0,6
Switzerland					-0,1	-0,3	0,0	0,2	-0,3	1,5	-0,1	-0,2	0,3	-0,2
Sweden						-0,3	0,1	0,3	-0,3	2,4	-0,1	-0,2	0,5	-0,2
Denmark							0,5	0,5	0,1	2,4	0,3	0,1	0,7	0,2
Germany								0,3	-0,4	2,7	-0,3	-0,3	0,4	-0,3
Slovenia									-0,5	1,3	-0,4	-0,4	0,1	-0,4
France										2,5	0,3	0,1	0,7	0,1
Norway											-2,9	-2,2	-1,4	-2,7
Turkey												-2,2	-1,4	-2,7
Hungary													0,6	0,1
Lithuania														-0,6
Italy														

857 downstream, Q = 2.500 L/h

	Austria	Slovakia	Czech Rep.	Switzerland	Sweden	Denmark	Germany	Slovenia	France	Norway	Turkey	Hungary	Lithuania	Italy
Austria		0,2	-1,1	-0,1	-0,2	-1,1	-0,3	-0,2	-1,5	1,2	-0,8	-0,5	-0,6	-0,8
Slovakia			-1,0	-0,2	-0,3	-1,0	-0,4	-0,3	-1,3	0,7	-0,7	-0,6	-0,6	-0,8
Czech Rep.				0,6	0,9	0,1	0,9	0,6	-0,3	1,8	0,6	0,5	0,3	0,4
Switzerland					0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Sweden						-0,8	-0,1	-0,1	-1,2	1,2	-0,5	-0,4	-0,4	-0,6
Denmark							0,9	0,5	-0,4	2,0	0,5	0,4	0,3	0,3
Germany								-0,1	-1,3	1,5	-0,5	-0,3	-0,4	-0,6
Slovenia									-0,8	0,9	-0,2	-0,2	-0,2	-0,3
France										2,2	0,9	0,7	0,6	0,7
Norway											-1,9	-1,4	-1,3	-1,8
Turkey												0,0	-0,1	-0,2
Hungary													-0,1	-0,1
Lithuania														0,0
Italy														

857downstream, Q = 1.000 L/h

	Austria	Slovakia	Czech Rep.	Switzerland	Sweden	Denmark	Germany	Slovenia	France	Norway	Turkey	Hungary	Lithuania	Italy
Austria		1,0	-1,1	0,3	0,4	-0,4	0,3	-0,2	-1,1	0,4	-0,3	-0,3	0,2	0,2
Slovakia			-1,6	-0,4	-0,5	-1,2	-0,8	-0,8	-1,5	-0,6	-1,2	-1,0	-0,5	-0,6
Czech Rep.				0,9	1,2	0,6	1,2	0,6	-0,3	1,3	0,9	0,5	1,0	1,0
Switzerland					0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Sweden						-0,7	-0,2	-0,5	-1,2	-0,1	-0,7	-0,6	-0,1	-0,2
Denmark							0,6	0,1	-0,7	0,7	0,2	0,0	0,5	0,5
Germany								-0,4	-1,2	0,2	-0,6	-0,5	0,1	0,0
Slovenia									-0,7	0,4	0,1	-0,1	0,3	0,3
France										0,4	0,1	-0,1	0,3	0,3
Norway											0,9	0,7	1,0	1,0
Turkey												-0,2	0,4	0,4
Hungary													0,4	0,4
Lithuania														0,0
Italy														

Table 10: E_n-values for the intercomparisons with meter Nr. 858, upstream

858 upstream, Q = 10.000 L/h

	Austria	Slovakia	Czech Rep.	Switzerland	Sweden	Denmark	Germany	Slovenia	France	Norway	Turkey	Hungary	Lithuania	Italy
Austria		-1,2	-1,1	-0,9	-0,8	-0,8	-1,3	-0,3	-1,2	0,1	-1,0	-0,9	-0,5	-1,2
Slovakia			0,0	0,0	0,5	0,4	0,3	0,5	0,2	1,1	0,5	0,3	0,5	0,0
Czech Rep.				0,0	0,5	0,4	0,3	0,5	0,2	1,1	0,5	0,3	0,5	0,0
Switzerland					0,4	0,3	0,2	0,5	0,2	0,9	0,4	0,2	0,4	0,0
Sweden						-0,1	0,6	0,2	-0,3	0,7	-0,1	-0,2	0,1	-0,5
Denmark							-0,1	0,2	-0,2	0,7	0,1	-0,1	0,2	-0,4
Germany								0,4	-0,1	1,1	0,3	0,0	0,3	-0,4
Slovenia									-0,4	0,3	-0,2	-0,3	-0,1	-0,6
France										1,1	0,3	0,1	0,3	-0,3
Norway											-0,9	-0,9	-0,5	-1,2
Turkey												-0,2	0,1	-0,5
Hungary													0,3	-0,5
Lithuania														-0,5
Italy														

858 upstream, Q = 7.500 L/h

	Austria	Slovakia	Czech Rep.	Switzerland	Sweden	Denmark	Germany	Slovenia	France	Norway	Turkey	Hungary	Lithuania	Italy
Austria		-1,5	-1,4	-0,8	-0,8	-0,8	-1,3	-0,4	-1,9	0,4	-1,1	-1,0	-0,5	-1,4
Slovakia			0,0	0,2	0,7	0,5	0,6	0,6	-0,3	1,6	0,7	0,4	0,6	0,1
Czech Rep.				0,2	0,7	0,5	0,6	0,6	-0,3	1,6	0,6	0,4	0,6	0,1
Switzerland					0,4	0,2	0,3	0,4	-0,4	1,0	0,3	0,1	0,3	-0,1
Sweden						-0,2	-0,2	0,1	-1,1	1,0	-0,2	-0,3	0,0	-0,7
Denmark							0,0	0,2	-0,8	1,0	0,0	-0,1	0,1	-0,4
Germany								0,3	-1,1	1,4	0,1	-0,1	0,2	-0,5
Slovenia									-0,9	0,6	-0,2	-0,3	-0,1	-0,6
France										2,0	1,0	0,7	0,9	0,4
Norway											-1,3	-1,2	-0,8	-1,6
Turkey												-0,2	0,1	-0,6
Hungary													0,3	-0,3
Lithuania														-0,5
Italy														

858 upstream, Q = 5.000 L/h

	Austria	Slovakia	Czech Rep.	Switzerland	Sweden	Denmark	Germany	Slovenia	France	Norway	Turkey	Hungary	Lithuania	Italy
Austria		-1,7	-1,6	-0,8	-0,8	-0,9	-0,9	-0,5	-1,3	0,2	-1,7	-1,1	-0,7	-1,7
Slovakia			0,0	0,4	0,9	0,7	0,7	0,7	0,4	1,6	0,5	0,4	0,6	0,2
Czech Rep.				0,3	0,5	0,5	0,5	0,4	0,5	0,5	0,5	0,4	0,4	0,5
Switzerland					0,3	0,2	0,2	0,3	-0,1	0,8	0,0	0,0	0,2	-0,2
Sweden						-0,1	-0,1	0,0	-0,5	0,8	-0,5	-0,4	-0,1	-0,7
Denmark							0,0	0,1	-0,4	0,9	-0,3	-0,2	0,0	-0,6
Germany								0,1	-0,4	0,9	-0,3	-0,2	0,0	-0,6
Slovenia									-0,4	0,5	-0,4	-0,3	-0,1	-0,6
France										1,3	0,1	0,1	0,3	-0,2
Norway											-1,5	-1,1	-0,7	-1,6
Turkey												-1,1	-0,7	-1,6
Hungary													0,2	-0,3
Lithuania														-0,4
Italy														

858 upstream, Q = 2.500 L/h

	Austria	Slovakia	Czech Rep.	Switzerland	Sweden	Denmark	Germany	Slovenia	France	Norway	Turkey	Hungary	Lithuania	Italy
Austria		-0,7	-1,5	-0,6	-0,6	-1,1	-0,7	-0,5	-0,6	-0,7	-1,8	-0,7	-1,0	-1,2
Slovakia			-0,7	-0,1	0,3	-0,2	0,3	0,0	0,2	0,2	-0,4	0,0	-0,4	-0,2
Czech Rep.				0,5	1,0	0,5	1,1	0,6	1,0	0,9	0,5	0,7	0,2	0,5
Switzerland					0,3	0,3	0,3	0,2	0,3	0,3	0,3	0,3	0,2	0,3
Sweden						-0,5	0,0	-0,2	0,0	-0,1	-0,8	-0,3	-0,6	-0,6
Denmark							0,6	0,2	0,5	0,4	-0,1	0,2	-0,2	0,0
Germany								-0,2	0,0	-0,1	-1,0	-0,3	-0,7	-0,7
Slovenia									0,1	0,1	-0,3	0,0	-0,4	-0,2
France										-0,1	-0,8	-0,2	-0,6	-0,6
Norway											-0,7	-0,2	-0,6	-0,5
Turkey												0,4	-0,1	0,1
Hungary													-0,4	-0,2
Lithuania														0,2
Italy														

858 upstream, Q = 1.000 L/h

	Austria	Slovakia	Czech Rep.	Switzerland	Sweden	Denmark	Germany	Slovenia	France	Norway	Turkey	Hungary	Lithuania	Italy
Austria		0,5	-0,9	-0,1	1,0	0,4	-0,3	0,4	-0,1	1,3	0,2	-0,2	0,2	0,8
Slovakia			-1,1	-0,5	0,3	-0,1	-0,7	0,0	-0,5	0,5	-0,4	-0,6	-0,2	0,2
Czech Rep.				0,4	1,5	1,1	0,7	1,0	0,6	1,7	1,0	0,5	0,8	1,3
Switzerland					0,7	0,7	0,8	0,6	0,7	0,7	0,8	0,7	0,6	0,7
Sweden						-0,4	-1,2	-0,3	-0,9	0,2	-0,9	-0,9	-0,4	-0,2
Denmark							-0,6	0,1	-0,4	0,6	-0,3	-0,5	-0,1	0,3
Germany								0,6	0,1	1,5	0,5	-0,1	0,4	1,0
Slovenia									-0,4	0,4	-0,3	-0,5	-0,2	0,1
France										0,4	-0,3	-0,5	-0,2	0,1
Norway											0,2	-0,1	0,3	0,7
Turkey												-0,3	0,1	0,7
Hungary													0,3	0,8
Lithuania														0,3
Italy														

Table 11: E_n-values for intercomparisons with meter Nr. 858, downstream

858 downstream, Q = 10.000 L/h

	Austria	Slovakia	Czech Rep.	Switzerland	Sweden	Denmark	Germany	Slovenia	France	Norway	Turkey	Hungary	Lithuania	Italy
Austria		-1,0	-1,3	-0,4	-0,5	-0,1	0,0	0,3	-0,5	-1,2	-1,3	-1,2	-0,1	-0,9
Slovakia			-0,3	0,2	0,5	0,8	1,1	0,9	0,5	0,0	0,1	-0,2	0,6	0,1
Czech Rep.				0,5	0,8	1,0	1,3	1,1	0,8	0,4	0,5	0,2	0,9	0,4
Switzerland					0,1	0,4	0,5	0,5	0,1	-0,2	-0,2	-0,4	0,3	-0,2
Sweden						0,3	1,3	0,6	0,0	-0,5	-0,5	-0,7	0,2	-0,4
Denmark							0,1	0,3	-0,3	-0,8	-0,8	-0,9	-0,1	-0,7
Germany								0,3	-0,5	-1,2	-1,3	-1,2	-0,1	-0,9
Slovenia									-0,5	-0,9	-0,9	-1,0	-0,3	-0,8
France										-0,6	-0,6	-0,7	0,2	-0,4
Norway											0,1	-0,2	0,7	0,1
Turkey												-0,3	0,6	0,0
Hungary													0,8	-0,5
Lithuania														-0,5
Italy														

858 downstream, Q = 7.500 L/h

	Austria	Slovakia	Czech Rep.	Switzerland	Sweden	Denmark	Germany	Slovenia	France	Norway	Turkey	Hungary	Lithuania	Italy
Austria		-1,2	-1,5	-0,3	-0,5	-0,1	-0,4	0,3	-0,4	-1,2	-0,6	-1,2	-0,2	-1,0
Slovakia			-0,4	0,4	0,6	0,8	0,9	1,0	0,7	0,1	0,8	-0,1	0,6	0,2
Czech Rep.				0,7	1,0	1,2	1,2	1,2	1,0	0,5	1,1	0,3	0,9	0,6
Switzerland					0,0	0,2	0,1	0,4	0,0	-0,4	0,0	-0,5	0,1	-0,3
Sweden						0,3	0,2	0,6	0,1	-0,6	0,0	-0,7	0,1	-0,4
Denmark							-0,1	0,3	-0,2	-0,8	-0,3	-0,9	-0,1	-0,7
Germany								0,5	-0,1	-0,9	-0,2	-0,9	0,0	-0,6
Slovenia									-0,5	-1,0	-0,6	-1,0	-0,4	-0,8
France										-0,7	-0,1	-0,8	0,1	-0,5
Norway											0,8	-0,2	0,6	0,2
Turkey												-0,8	0,1	-0,5
Hungary													0,7	0,3
Lithuania														-0,5
Italy														

858 downstream, Q = 5.000 L/h

	Austria	Slovakia	Czech Rep.	Switzerland	Sweden	Denmark	Germany	Slovenia	France	Norway	Turkey	Hungary	Lithuania	Italy
Austria		-1,4	-1,5	-0,4	-0,7	0,0	-0,4	0,3	-1,7	-1,3	-0,7	-1,1	-0,2	-0,8
Slovakia			-0,2	0,7	0,7	1,1	1,1	1,1	-0,2	0,2	1,0	0,2	0,8	0,6
Czech Rep.				0,8	1,0	0,8	1,1	0,7	0,9	1,0	1,1	0,8	0,8	1,0
Switzerland					-0,1	0,3	0,1	0,5	-0,9	-0,6	0,0	-0,5	0,1	-0,2
Sweden						0,5	0,3	0,6	-1,0	-0,6	0,2	-0,5	0,2	-0,1
Denmark							-0,3	0,2	-1,3	-1,0	-0,4	-0,8	-0,2	-0,6
Germany								0,5	-1,4	-1,0	-0,2	-0,8	0,0	-0,5
Slovenia									-1,3	-1,0	-0,6	-0,9	-0,4	-0,7
France										0,4	1,3	0,3	1,0	0,9
Norway											0,8	0,0	0,7	0,5
Turkey												0,0	0,7	0,5
Hungary													0,6	0,4
Lithuania														-0,3
Italy														

858 downstream, Q = 2.500 L/h

	Austria	Slovakia	Czech Rep.	Switzerland	Sweden	Denmark	Germany	Slovenia	France	Norway	Turkey	Hungary	Lithuania	Italy
Austria		-0,4	-1,3	-0,1	-0,4	-0,1	-0,4	0,5	-1,5	-2,2	-1,1	-0,9	-0,6	0,0
Slovakia			-0,8	0,1	0,1	0,3	0,1	0,7	-0,9	-1,3	-0,3	-0,4	-0,2	0,4
Czech Rep.				0,8	0,9	1,1	1,1	1,3	-0,1	-0,3	0,7	0,4	0,5	1,2
Switzerland					-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1
Sweden						0,3	0,1	0,7	-1,1	-1,5	-0,4	-0,5	-0,3	0,4
Denmark							-0,2	0,5	-1,2	-1,6	-0,7	-0,7	-0,5	0,1
Germany								0,7	-1,3	-1,9	-0,7	-0,7	-0,4	0,4
Slovenia									-1,4	-1,7	-1,0	-1,0	-0,8	-0,4
France										-0,2	0,9	0,5	0,6	1,4
Norway											1,4	0,8	0,8	2,0
Turkey												-0,2	0,0	0,9
Hungary													0,1	0,9
Lithuania														0,6
Italy														

858 downstream, Q = 1.000 L/h

	Austria	Slovakia	Czech Rep.	Switzerland	Sweden	Denmark	Germany	Slovenia	France	Norway	Turkey	Hungary	Lithuania	Italy
Austria		0,3	-1,1	0,0	0,6	0,8	0,2	0,9	-2,2	0,3	0,0	-0,2	0,2	1,0
Slovakia			-1,2	-0,2	0,1	0,3	-0,2	0,5	-2,0	-0,1	-0,3	-0,4	0,0	0,5
Czech Rep.				0,8	1,4	1,5	1,2	1,5	-0,7	1,2	1,1	0,7	1,0	1,7
Switzerland					0,3	0,3	0,3	0,2	0,3	0,3	0,3	0,2	0,2	0,3
Sweden						0,2	-0,4	0,4	-2,2	-0,2	-0,5	-0,5	-0,2	0,4
Denmark							-0,6	0,3	-2,4	-0,4	-0,8	-0,7	-0,3	0,2
Germany								0,8	-2,2	0,1	-0,2	-0,3	0,1	0,8
Slovenia									-2,2	-0,6	-0,9	-0,8	-0,5	-0,1
France										-0,6	-0,9	-0,8	-0,5	-0,1
Norway											2,2	1,4	1,6	2,5
Turkey												-0,2	0,2	1,0
Hungary													0,3	0,8
Lithuania														0,5
Italy														

4 Summary and final considerations

The prescribed intercomparisons should have served the purpose to investigate the measurement accuracy of water meter test rigs of highest capability at NMIs in Europe by means of two preselected master meters. Two electromagnetic meters had been chosen, installed in series and then cyclically changed in their position. The results fell short of expectations. The following phenomena occurred:

1. Most labs show deviations which are normally distributed. Some labs show large deviations, which can be by means of statistics classified as systematic. Definitely spoken lie
   - 11 participants (77 %) in an area of ± 0,15 %
   - 1 participant (7,6 %) in an area of ± 0,25 %
   - 1 participant (7,6 %) in an area of ± 0,30 %

   around the KCRV, the reference value of all measurements having been adjusted statistically.

2. After the intercomparison, stability tests had been carried out to determine the "installation error", i.e. the influence of the pipes connected to the meters. It showed up that it is not irrelevant whether a meter is installed upstream on first or second position. So, measurement uncertainties had been assigned to these installation effects of the magnitude of uncertainties indicated by the CMC-tables.

3. The E_n-values are surprisingly high, which can be attributed to the fact that the indicated uncertainties of the participants are rather small and that installation effects increase the real uncertainty considerably.

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Annex

Original measurement results of the concerned laboratories at the European NMIs

Results of the paticipating institutes, Project 669, meter No 857

arrangement A1: 857 at first position - upstream

Q [L/h]	10.000	7.500	5.000	2.500	1.000	Date
Austria	-0,11	-0,10	-0,10	-0,17	-0,10	May 02
Slovakia	0,01	0,03	0,03	-0,19	-0,25	June 02
Czech Rep.	0,13	0,15	0,14	0,10	0,08	July 02
Switzerland	-0,05	-0,07	-0,08	-0,17	-0,22	Aug. 98
Sweden	-0,120	-0,074	-0,062	-0,110	-0,150	Okt. 98
Denmark	-0,06	-0,05	-0,06	-0,08	-0,09	Nov. 98
Germany	-0,110	-0,090	-0,110	-0,180	-0,260	Dec 02
Slovenia	-0,10	-0,08	-0,07	-0,09	-0,12	Jän. 99
France	-0,04	0,21	0,09	0,13	0,15	Mär. 99
Norway	-0,12	-0,14	-0,14	-0,14	-0,23	May 03
Turkey	-0,052	-0,040	-0,030	-0,122	-0,170	June 03
Hungary	-0,010	-0,010	-0,010	-0,080	-0,060	July 03
Lithuania	-0,130	-0,120	-0,100	-0,090	-0,210	Aug. 99
Italy	-0,134	-0,154	-0,173	-0,283	-0,233	Jan 04
KCRV	-0,085	-0,072	-0,070	-0,152	-0,151	
mean	-0,064	-0,038	-0,048	-0,105	-0,133	
median	-0,080	-0,072	-0,066	-0,116	-0,160	
weighted mean	-0,082	-0,068	-0,065	-0,137	-0,148	
average	-0,075	-0,059	-0,060	-0,119	-0,147	

arrangement A2: 857 at second position - downstream

Q [L/h]	10.000	7.500	5.000	2.500	1.000
Austria	-0,13	-0,13	-0,13	-0,19	-0,14
Slovakia	-0,03	-0,03	-0,02	-0,22	-0,29
Czech Rep.	-0,01	0,01	0,03	-0,02	0,03
Switzerland	-0,04	-0,05	-0,06	-0,17	-0,20
Sweden	-0,065	-0,061	-0,045	-0,170	-0,200
Denmark	-0,05	0,00	0,01	-0,04	-0,08
Germany	-0,050	-0,050	-0,060	-0,160	-0,170
Slovenia	-0,13	-0,13	-0,11	-0,15	-0,10
France	0,00	0,10	0,00	0,03	0,11
Norway	-0,29	-0,24	-0,38	-0,34	-0,19
Turkey	-0,127	-0,011	-0,034	-0,110	-0,110
Hungary	-0,010	-0,020	-0,010	-0,110	-0,080
Lithuania	-0,160	-0,150	-0,130	-0,090	-0,180
Italy	-0,074	-0,040	-0,021	-0,091	-0,170
KCRV	-0,086	-0,060	-0,058	-0,142	-0,144
mean	-0,083	-0,057	-0,069	-0,131	-0,126
median	-0,058	-0,045	-0,040	-0,130	-0,155
weighted mean	-0,094	-0,064	-0,067	-0,151	-0,136
average	-0,078	-0,056	-0,058	-0,137	-0,139

measurement uncertainty

arrangement A1: 857 at first position - upstream

Q [L/h]	Austria	Slovakia	Czech Rep.	Switzerland	Sweden	Denmark	Germany	Slovenia	France	Norway	Turkey	Hungary	Lithuania	Italy	u(xref)
10.000	0,03	0,10	0,12	0,18	0,08	0,12	0,05	0,17	0,08	0,09	0,06	0,11	0,14	0,10	0,016
7.500	0,03	0,10	0,12	0,18	0,08	0,12	0,04	0,17	0,16	0,08	0,05	0,11	0,14	0,09	0,016
5.000	0,03	0,10	0,12	0,18	0,08	0,12	0,03	0,17	0,10	0,09	0,03	0,12	0,14	0,07	0,016
2.500	0,03	0,12	0,13	0,18	0,08	0,12	0,03	0,17	0,13	0,08	0,03	0,12	0,14	0,07	0,016
1.000	0,03	0,12	0,13	0,19	0,10	0,11	0,04	0,17	0,17	0,09	0,04	0,14	0,15	0,08	0,020

arrangement A2: 857 at second position - downstream

Q [L/h]	Austria	Slovakia	Czech Rep.	Switzerland	Sweden	Denmark	Germany	Slovenia	France	Norway	Turkey	Hungary	Lithuania	Italy	u(xref)
10.000	0,03	0,11	0,12	0,18	0,08	0,11	0,03	0,17	0,12	0,08	0,05	0,11	0,14	0,11	0,015
7.500	0,03	0,11	0,12	0,18	0,08	0,11	0,02	0,17	0,10	0,08	0,04	0,12	0,14	0,09	0,017
5.000	0,03	0,11	0,12	0,18	0,08	0,11	0,03	0,17	0,10	0,08	0,02	0,12	0,14	0,07	0,014
2.500	0,03	0,12	0,13	0,18	0,08	0,10	0,03	0,17	0,12	0,08	0,04	0,12	0,15	0,08	0,015
1.000	0,03	0,12	0,13	0,19	0,10	0,10	0,05	0,17	0,22	0,08	0,04	0,15	0,15	0,14	0,015

Results of the paticipating institutes, Project 669, meter No 858

arrangement A1: 858 at second position - downstream

Q [L/h]	Date	1.000	2.500	5.000	7.500	10.000
Austria	May 02	-0,07	-0,20	-0,17	-0,18	-0,18
Slovakia	June 02	-0,12	-0,14	0,02	-0,02	-0,04
Czech Rep.	July 02	0,11	0,01	0,05	0,05	0,02
Switzerland	Aug. 98	-0,08	-0,17	-0,11	-0,12	-0,09
Sweden	Okt. 98	-0,15	-0,15	-0,09	-0,12	-0,12
Denmark	Nov. 98	-0,18	-0,19	-0,17	-0,16	-0,17
Germany	Dec 02	-0,09	-0,16	-0,13	-0,14	-0,18
Slovenia	Jän. 99	-0,24	-0,29	-0,22	-0,23	-0,23
France	Mär. 99	0,24	0,04	0,05	-0,13	-0,12
Norway	May 03	-0,11	0,07	-0,01	-0,03	-0,04
Turkey	June 03	-0,07	-0,10	-0,11	-0,12	-0,05
Hungary	July 03	-0,04	-0,06	-0,01	0,00	-0,01
Lithuania	Aug. 99	-0,11	-0,09	-0,13	-0,14	-0,16
Italy	Jan 04	-0,21	-0,20	-0,07	-0,06	-0,05
KCRV	KCRV	-0,104	-0,145	-0,113	-0,096	-0,100

arrangement A2: 858 at first position - upstream

Q [L/h]	1.000	2.500	5.000	7.500	10.000
Austria	-0,05	-0,24	-0,21	-0,21	-0,21
Slovakia	-0,13	-0,13	0,03	0,00	-0,03
Czech Rep.	0,09	0,00	0,03	0,00	-0,03
Switzerland	-0,02	-0,11	-0,05	-0,04	-0,03
Sweden	-0,19	-0,17	-0,11	-0,12	-0,12
Denmark	-0,11	-0,09	-0,09	-0,09	-0,10
Germany	-0,02	-0,17	-0,09	-0,09	-0,08
Slovenia	-0,13	-0,14	-0,12	-0,14	-0,15
France	-0,03	-0,17	-0,03	0,05	-0,07
Norway	-0,21	-0,16	-0,23	-0,26	-0,22
Turkey	-0,07	-0,07	-0,04	-0,10	-0,11
Hungary	-0,01	-0,13	-0,05	-0,07	-0,08
Lithuania	-0,09	-0,05	-0,09	-0,12	-0,13
Italy	-0,16	-0,09	-0,01	-0,02	-0,03
KCRV	-0,065	-0,146	-0,070	-0,082	-0,108

measurement uncertainty

arrangement A1: 858 at second position - downstream

Q [L/h]	10.000	7.500	5.000	2.500	1.000
Austria	0,03	0,03	0,03	0,03	0,03
Slovakia	0,10	0,10	0,10	0,12	0,12
Czech Rep.	0,12	0,12	0,12	0,13	0,13
Switzerland	0,18	0,18	0,13	0,18	0,20
Sweden	0,08	0,08	0,08	0,08	0,10
Denmark	0,11	0,10	0,12	0,11	0,11
Germany	0,02	0,05	0,03	0,03	0,06
Slovenia	0,17	0,17	0,17	0,17	0,17
France	0,08	0,09	0,09	0,13	0,11
Norway	0,08	0,08	0,08	0,08	0,09
Turkey	0,04	0,03	0,02	0,03	0,04
Hungary	0,11	0,12	0,12	0,12	0,15
Lithuania	0,14	0,14	0,14	0,15	0,17
Italy	0,11	0,09	0,07	0,07	0,11
u(xref)	0,017	0,017	0,015	0,014	0,015

arrangement A2: 858 at first position - upstream

Q [L/h]	10.000	7.500	5.000	2.500	1.000
Austria	0,03	0,03	0,03	0,03	0,03
Slovakia	0,12	0,11	0,11	0,12	0,12
Czech Rep.	0,13	0,12	0,12	0,13	0,13
Switzerland	0,18	0,18	0,18	0,18	0,19
Sweden	0,08	0,08	0,08	0,08	0,10
Denmark	0,11	0,13	0,10	0,11	0,11
Germany	0,04	0,02	0,10	0,03	0,04
Slovenia	0,17	0,17	0,17	0,17	0,17
France	0,08	0,10	0,10	0,08	0,12
Norway	0,08	0,08	0,08	0,08	0,09
Turkey	0,05	0,05	0,04	0,03	0,04
Hungary	0,11	0,11	0,12	0,12	0,14
Lithuania	0,14	0,14	0,16	0,16	0,17
Italy	0,12	0,10	0,08	0,08	0,10
u(xref)	0,040	0,015	0,014	0,013	0,022