Final Report on the CIPM Key Comparisons for Compressed Air and Nitrogen Conducted in November 2004 / June 2005 CCM.FF-5.b

Authors:
D. Dopheide, B. Mickan, R. Kramer, H-J Hotze, (PTB-***pigsar***^{TM}), Dietrich.Dopheide@ptb.de
J.- P. Vallet, (LNE-LADG), Cesame@univ-poitier.fr
M. R. Harris; mreader@tuvnel.com
Jiunn-Haur Shaw, CMS/ITRI; jiunn-haur.shaw@itri.org.tw
Kyung-Am Park, KRISS; kapark@kriss.re.kr

This Report has been approved by the Consultative Committee for Mass and Related Quantities (CCM)

Physikalisch-Technische Bundesanstalt (PTB)
Bundesallee 100, 38116 Braunschweig, Germany
Dietrich.Dopheide@ptb.de

CCM.FF-5.b Final Report for KCRVs for Compressed Air and Nitrogen

CCM.FF-5.b; Pilot laboratories: PTB and LNE-LADG in cooperation with pilot KRISS (APMP)

D. Dopheide, B. Mickan, R. Kramer, H.-J. Hotze; (PTB-***pigsar***^{TM}), Dietrich.Dopheide@ptb.de
J.- P. Vallet, (LNE-LADG), Cesame@univ-poitier.fr
M. R. Harris; mreader@tuvnel.com
Jiunn-Haur Shaw, ITRI/CMS; jiunn-haur.shaw@itri.org.tw
Kyung-Am Park, KRISS; kapark@kriss.re.kr

1 INTRODUCTION

The CIPM decided, in accordance with the CIPM Mutual Recognition Arrangement (MRA) [2], to conduct Key Comparisons (KCs) [1] among national primary standards of selected NMIs in the subject field high-pressure gas flow. This includes natural gas and compressed air and/or Nitrogen. The members of the responsible CCM Working Group for Fluid Flow (WGFF) elected PTB and LNE-LADG as the pilot laboratories for this Key Comparison (KC) for compressed Air and Nitrogen. In parallel, the same transfer standard has been used to conduct a KC among APMP partners KRISS and CMS. This final report comprises the results for both KC and has been approved by all participants and the CCM.

Participants for the Compressed air loop:
PTB-***pigsar***^{TM}, initial and final calibration
LNE-LADG, Poitier
Since January 25$^{th\ 2005}$, LNE is the former BNM. LNE stands for **Laboratoire National de métrologie et d'Essais**. For this reason in this paper, the previous abbreviation BNM is still used in the figures.

NEL, Scotland, NMI
KRISS, Korea, and CMS/ITRI as members of APMP.

It shall be mentioned here, that all potential facilities worldwide have been invited to participate (at least as guests), but all of them have refrained from any activity in the CIPM Key Comparison for high-pressure compressed air and nitrogen.

The KC-5.b has been conducted during Nov. 2004 / June 2005 successfully.

2 GENERAL INFORMATION

This draft was prepared in accordance to the *Guidelines for CIPM Key Comparisons* [1]. The KCs described here, have been performed to fulfill the requirements of the CIPM MRA [2] and the requirements from the CIPM Committee Consultative for Mass and Related Quantities [3]. The aim of these KCs is to verify the claimed Calibration and Measurement Capabilities (CMCs) of the NMIs and to quantify the degree of equivalence of the national flow standards as maintained in the participating NMIs. In addition, a CIPM Key Comparison Reference Value (KCRV) should be the outcome of a key comparison. To achieve the intended quantification, these KCs are intended to produce a set of tabulated results: the first set of tables presents the measured differences between the participants and the KCRV and the second set will quantify the laboratory-to-laboratory equivalencies with the associated uncertainties of these differences, and the last set shall comprise the degree of equivalence of all laboratories to the KCRV. The KC 5.b participants will give visual presentation of the degree of equivalence En as recommended recently [4, 5, 6].

In these En tables all measured data (meter readings) will be associated with the values of degree of equivalence $E_n = |d| / U(d)$. d means the bias between KCRV and measured value and $U(d)$ is the corresponding uncertainty of this bias between KCRV and the measured value as explained in chapter 5. Following this recommendation, it will be possible to describe the degree of equivalence of a laboratory to the KCRV using a dimensionless number. E_n should be between 0 and 1 and may go up to 1.2

Organization of the high-pressure gas and nitrogen comparison loop

The high-pressure KC comprises the circulation of a tandem meter travel standard among all participants in a single loop. As the number of participants was finally very low, only one of the originally proposed four tandem packages has been used finally.

Loop: PTB-***pigsar***TM => LNE-LADG => NEL => PTB-***pigsar***TM => KRISS => ITRI/CMS => KRISS => PTB-***pigsar***TM => LNE-LADG end of loop.
According to wishes of the international flow community, the pilot lab has organized a detour in Asia in order to include CMS into the APMP-KC as an invited guest of pilot lab into the comparison loop. This detour does not affect the CIPM KC, as it turns out during the evaluation procedure, that all the participating labs are extremely close together and are completely equivalent to each other. In addition, the results will be presented in separate tables. The flow community wants to achieve good metrological effort by analysing the data all together, so that a truly good metrological

KCRV can be reached. The result has succeeded all expectations. Secondly it shall be pointed out here, that the measurements at 1 bar have not been included into the KCRV, as they are only necessary to do meter tests in advance and in order to get a future link between these KCs and natural gas.

As it has been decided during the KC 5 meetings, transfer package #3 has been applied. This package comprises of two turbine meters (DN150) put in series, compare Fig. 2. For the pressure ranges and flow rate samples, see Fig. 1.

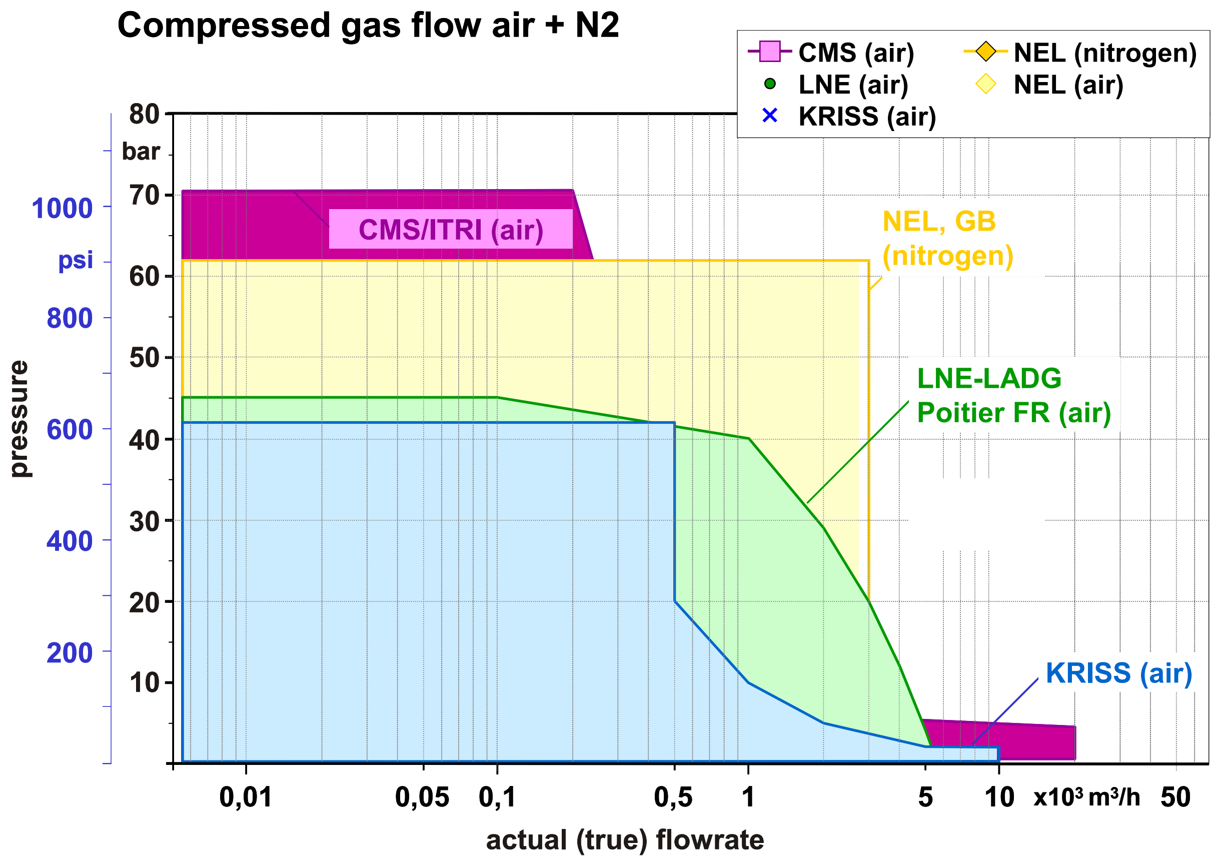

Fig.1: Visualized pressure and flow ranges of potential participants in the CIPM Key Comparison for compressed air and Nitrogen. The suggested calibration points are indicated as dots. The suggested G650 (package #3) can cover the flow ranges of the final KC5b-participants best.

The selected calibration points for the finally participating facilities are visualized in Figure 11 below.

It shall be explicitly pointed out here, that all appropriate facilities worldwide have been invited to participate, but only European and Asian facilities have been ready for a KC.

3 THE TRANSFER PACKAGE

The transfer packages for this KC consist of two commercial G650 meters put in series. Due to generous donations from the manufacturer Elster /Instromet, an appropriate selection of two turbines has been made by the pilot laboratory. The meters have been optimized in the meantime by the pilots and the manufacturers to provide for meters with smooth error curves.
The basic arrangement and geometry of each transfer package can be seen below in Fig. 2a

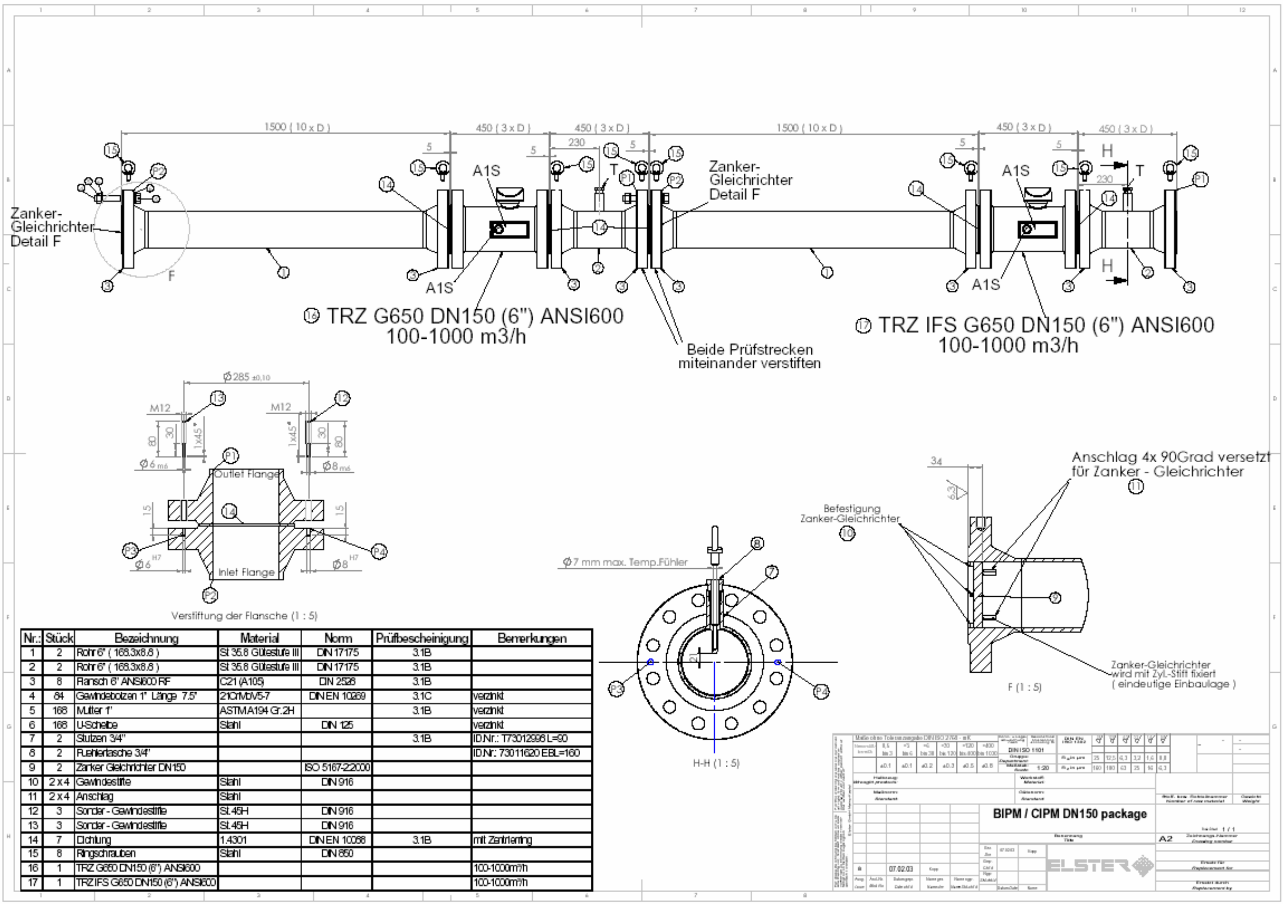

Fig. 2a: Drawing of the tandem meters for compressed air and Nitrogen (package #3), compare also Fig. 2b.

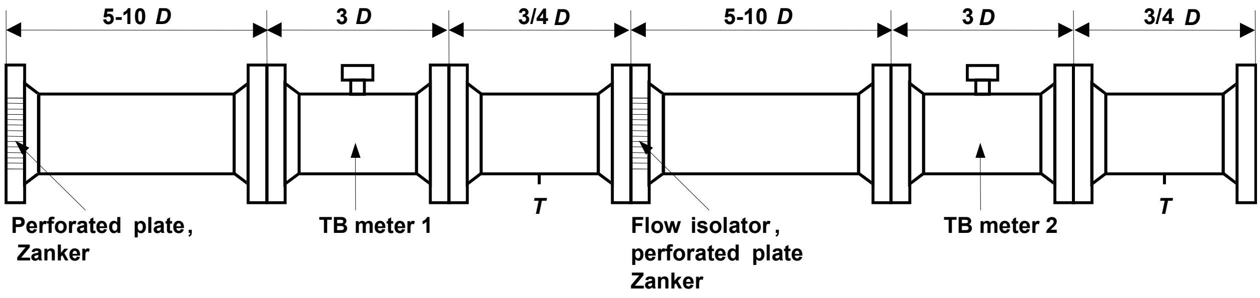

Fig. 2b: Principal arrangement of the tandem meters for compressed air and Nitrogen according to the drawing in Fig. 2a. (package #3).

The main properties of these meters are:

- Flanges: ANSI 600 pressure up to 90 bar
- Temperature tabs T 1,5 D downstream of meters
- Selected Reynolds-balanced meters with flat error curves
  The pilot laboratories have done this selection in close collaboration with the manufacturers.
- Output signals: high frequency pulses, NAMUR signals, open collector adapter
- Inlet lengths: 10 for turbines

Each meter is provided with its own inlet and outlet sections, referred to as part #1 and part #2. Both meters are equipped with Zanker flow straighteners.

Package No. #3

Loop:	**High pressure natural gases**
Size (Q_{max}, Diameter):	650 m^3/h; DN = 150 mm (= 6 “)
Total length of package:	35 D = 5,3 m
Type of meter 1:	turbine G650
Manufacturer:	Elster
Length of part 1: (inlet, meter 1, outlet)	10D; 3D; 3D;
Type of meter 2:	turbine G650
Manufacturer:	Elster
Length of part 2: (inlet, meter 2, outlet)	10D; 3D; 3D;

A full documentation of the transfer package #3 DN 150 mm (=6’’) for compressed air and Nitrogen is presented in the following Fig. 3

Package No. #3.

Loop: Elevated pressures air and Nitrogen

Size (Q_{max}, Diameter): 650 m^3/h; DN = 150 mm = 6 "

total length of package: 32 D = 4,810 m

type of meter 1: turbine G650

manufacturer: Elster

Nr 83034940

Length of part 1: 10D; 3D; 3D; 2405mm

(inlet, meter 1, outlet) Flanschd.355mm

Weight 350kg

type of meter 2: turbine G650

manufacturer: Elster G650

Nr. 83034960

Length of part 2: 10D; 3D; 3D; 2405mm

(inlet, meter 2, outlet) Flanschd.356mm

Weight 350kg

Fig.3: The file above presents the drawing of package #3 DN 150 mm consisting of two turbines in series for a full documentation.

In the following chapter, the detailed investigations on reproducibility of the transfer meter and the facilities will be summarized to demonstrate that the transfer package (and both meters) fulfills the prerequisites to compare facilities with claimed uncertainties between 0.16 % and 0.30 %.

3.1 Reproducibility of the transfer packages and facilities

In this chapter the impact of reproducibility/repeatability of the transfer package as well as the reproducibility of the facilities on the KC comparisons will be considered and conclusions will be drawn.

The investigation of the reproducibility of the transfer meter led here also to a reliable statement about the amount of installation effects *at the pilot lab*. The measurements at the pilot lab covered following conditions:

- Measurements had been done before, at the beginning, during and at the end of the time interval of the key comparison.
- The meters have been swapped several times at the pilot lab.
- The meters were used at different locations (three different test rooms/test lines).
- The meters were tested at five different pressure stages.

All measurement results of these tests were used to define an overall base line. The reproducibility stated below is the doubled standard deviation of the single measurement results with respect to this base line. Therefore the phrase “overall reproducibility” covers here following influences:

- repeatability at one test point (flow rate, pressure)
- hysteresis (low-to-high flow rates and high-to-low flow rates)
- reproducibility (repeated tests at different dates, build in build out, transport)
- installation effects (flow profiles, ambient influences of test rooms)

One of the outcomes of the overall reproducibility was that the indication of the transfer meters was not affected significantly by any installation *effect at the pilot lab*. In the following we use the phrases “installation effects are affecting the meter indication in a negligible level” and “no installation effect” synonymously. .

The investigation of reproducibility of the transfer meters are based on the evaluation of correlated meter readings as it is described in detail by [Pöschel], see [7]. Prerequisites for this procedure are:

- Two independent results of two meters under test (MuT, 1 and MuT, 2) simultaneously measured at the same reference (facility *fac*);
- normality of the stochastic process;

- sufficient Degree of Freedom (DOF), i.e. number of measurements;
- flow rates indicated by MuT Q_{MuT} and facility Q_{fac} are nearly the same (i.e. meter deviation is not far from zero, e.g. 1 %).

The measurand for the meter readings is the meter deviation ***f*** defined as following:

$$\boldsymbol{f} = \left(\frac{\boldsymbol{Q}_{\mathbf{MuT}}}{\boldsymbol{Q}_{\mathbf{fac}}} - \mathbf{1} \right) \cdot \mathbf{100\%} \tag{1}$$

where Q are the flow rates indicated by the MuT or the facility.

As the meter deviation is a function of flow rate, it is useful to refer the result of each measurement relative to the mean meter deviation $\boldsymbol{f}_{\mathbf{m}}$ as a new zero line:

$$\mathbf{d}\boldsymbol{f} = \left(\frac{\boldsymbol{Q}_{\mathbf{MuT}}}{\boldsymbol{Q}_{\mathbf{fac}}} - \mathbf{1} \right) \cdot \mathbf{100\%} - \boldsymbol{f}_{\mathbf{m}} \tag{2}$$

With that, all results **d*f*** determined at different flow rates are comparable.

Using the rules for propagation of uncertainty according to GUM we get for the stochastic part of uncertainty (i.e. the standard deviation of results ***s***):

$$\boldsymbol{s}^{\mathbf{2}}_{\mathbf{d}\boldsymbol{f}\mathbf{,abs}} = \boldsymbol{s}^{\mathbf{2}}_{\boldsymbol{Q}_{\mathbf{MuT}}\mathbf{,rel}} + \boldsymbol{s}^{\mathbf{2}}_{\boldsymbol{Q}_{\mathbf{fac}}\mathbf{,rel}} \tag{3}$$

Please note that the absolute standard deviation $s_{\mathrm{d}f\mathrm{,abs}}$ (expressed in %) is the quadratic sum of the relative standard deviation $s_{Q\mathrm{MuT,rel}}$ and $s_{Q\mathrm{fac,rel}}$ (also expressed in %)!

Further on the name of variables in eq. (3) will be reduced to:

$$\boldsymbol{s}^{\mathbf{2}}_{\mathbf{d}\boldsymbol{f}} = \boldsymbol{s}^{\mathbf{2}}_{\mathbf{MuT}} + \boldsymbol{s}^{\mathbf{2}}_{\mathbf{fac}} \tag{4}$$

For the evaluation of the correlated results of two MuT simultaneously measured we calculate two more terms:

$$\Delta_{p,\mathrm{i}} = \mathrm{d}f_{1,\mathrm{i}} + \mathrm{d}f_{2,\mathrm{i}} \tag{5}$$

and

$$\Delta_{m,\mathrm{i}} = \mathrm{d}f_{1,\mathrm{i}} - \mathrm{d}f_{2,\mathrm{i}} \tag{6}$$

Using again the rules of uncertainty propagation with the requirements mentioned above we get:

$$\boldsymbol{s}^{\mathbf{2}}_{\boldsymbol{\Delta_m}} = \boldsymbol{s}^{\mathbf{2}}_{\mathbf{MuT,1}} + \boldsymbol{s}^{\mathbf{2}}_{\mathbf{MuT,2}} \tag{7}$$

and

$$s_{\Delta_p}^2 = s_{\mathrm{MuT,1}}^2 + s_{\mathrm{MuT,2}}^2 + 4 \cdot s_{\mathrm{fac}}^2 \quad (8)$$

Finally, with eq. (4), (7) and (8) we can determine:

$$s_{\mathrm{fac}}^2 = \frac{1}{4} \cdot \left(s_{\Delta_p}^2 - s_{\Delta_m}^2 \right) \quad (9)$$

$$s_{\mathrm{MuT}}^2 = s_{df}^2 - s_{\mathrm{fac}}^2 \quad (10)$$

Eq. (9) and (10) are the final outcome for the estimations of reproducibility. As the estimates are based on a finite number of samples, the results of eq. (9) and (10) have also a confidence interval. It can be calculated as:

$$s_{\mathrm{LCL}}^2 = \frac{DOF}{ChiInv\left(\frac{\alpha}{2}, DOF\right)} \cdot s^2 \quad (11)$$

$$s_{\mathrm{UCL}}^2 = \frac{DOF}{ChiInv\left(1 - \frac{\alpha}{2}, DOF\right)} \cdot s^2 \quad (12)$$

(LCL – Lower Confidence Level; UCL - Upper Confidence Level; α – probability of error)

Because the standard deviation estimated from a number of samples follows a Chi-Square probability function, the confidence interval calculated with eq. (11) and (12) is not symmetrically!

The meaning of the standard deviation (calculated with eq. 9 and 10) depends on the sample of measurements. Roughly we can discuss three situations:

1. The sample is taken only at one flow rate and one pressure with a number of repetitions. Here we get the pure repeatability.
2. The sample contains measurements at different working points which where used in one experiment going up and down with the flow rate and/or pressure. Here, with the standard deviation, we get information about the repeatability and the hysteresis.
3. The measurements cover also a build-in-build-out (and a transport may be) and were done at different days. In this case the standard deviation includes information on the complete reproducibility also on the repeatability and the hysteresis.

Note that within an intercomparison, the impact of the first two contributions (repeatability, hysteresis) to the average result of an experiment can easily be reduced by a higher number of individual measurements / repeats / samples.

3.2 Results for transfer meters used in KC.5.b at pilot lab

Using the background from gathered experience within harmonization it was the aim for the KC pilots to provide for transfer meters with a reproducibility equal or better than 0,06 % (k=2). For this purpose the chosen meters were tested at ***pigsar***^{TM} in Dorsten several times and the corresponding values were calculated according to eq. (9) and (10). The Table 1 below presents an overview on all measurements done at pilot lab.

Date	pressure	order of meters	location	Symbol in Legend (Fig. 4 to 7)
Pre-Tests				
20.08.2003	17 bar	swapped (M2/M1)	Pigsar, testroom 1, testline 2	●
20.08.2003	50 bar	swapped (M2/M1)		▲
22.08.2003	17 bar	regular (M1/M2)		●
22.08.2003	50 bar	regular (M1/M2)		▲
KC5b				
11.11.2004	20 bar	regular (M1/M2)	Pigsar, testroom 2, testline 4	●
11.11.2004	40 bar	regular (M1/M2)		▲
28.01.2005	1 bar	regular (M1/M2)	PTB sonic nozzle test rig (Braunschweig)	■
31.01.2005	1 bar	regular (M1/M2)		■
08.06.2005	1 bar	swapped (M2/M1)		■
09.06.2005	1 bar	regular (M1/M2)		■
17.06.2005	40 bar	regular (M1/M2)	Pigsar, testroom 2, testline 4	▲
17.06.2005	20 bar	regular (M1/M2)		●
17.06.2005	40 bar	swapped (M2/M1)		▲

Table 1: Summary of all measurements and test at different meter runs at pilot lab

In most cases regular calibrations have been done in order to get the repeatability and reproducibility of the two transfer meters M1 and M2 in series. In a few cases the meters have been swapped.

Fig. 4 visualizes all measured error curves of the pre-tests at atmospheric pressure (1bar) as well as at high-press nat. gas at 20 bar and 40 bar for meter 1 (M1). The excellent agreement for all meters at all pressures can be seen. Meter swapping does not affect the readings. (No installation effects).

The claimed uncertainties of the pilot lab at 1 bar and high-press gas has been indicated and it can be concluded that all measurements are within these uncertainties.

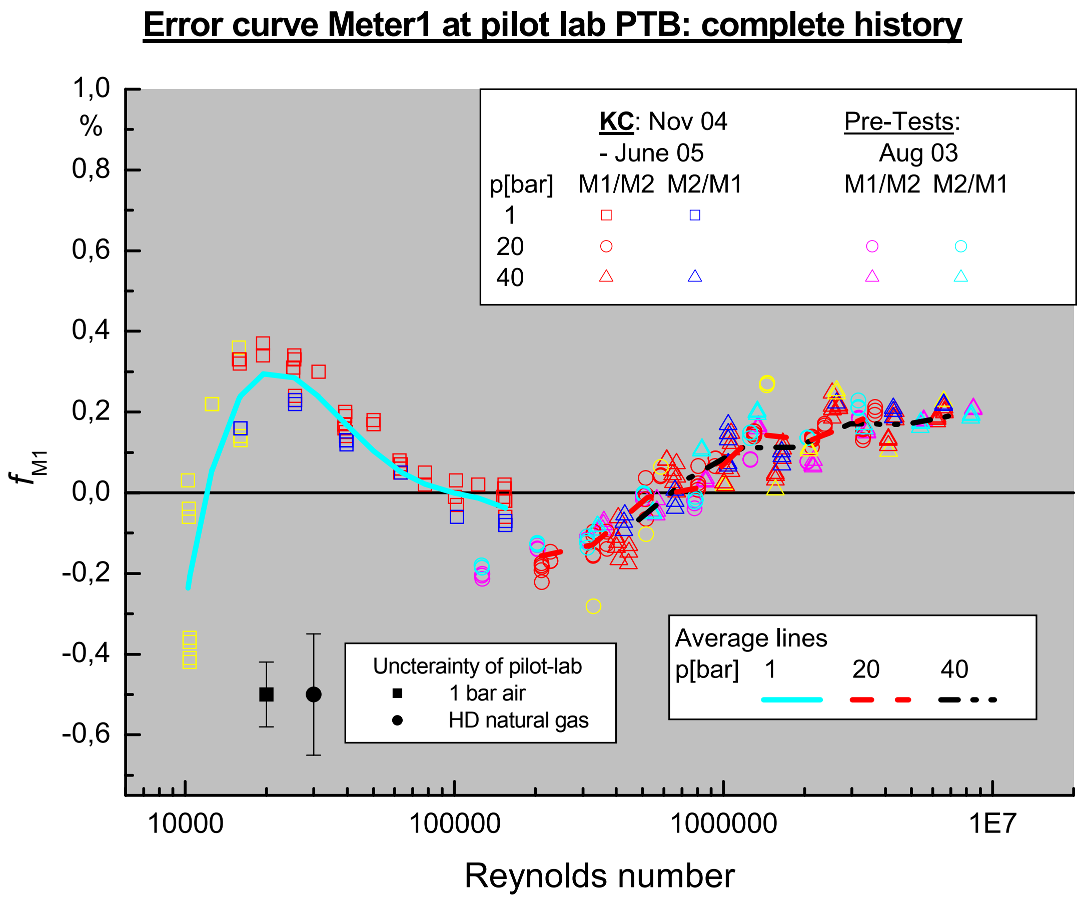

Fig 4: Visualization of all measured error curves of meter 1 (M1) of the transfer package used in KC5b. All valid data are within the claimed uncertainties of pilot lab. The yellow marked data in the diagram are outliers. The were determined by a two dimensional 2-sigma test, see also Fig. 7.

As a comparison, the uncertainties of the air facility at 1 bar and the uncertainty of the natural gas facility have been indicated by black error bars in Figure 4. All results are very well within these limits.

Fig. 5 visualizes all measured error curves of the pre-tests of meter 2 (M2) at atmospheric pressure (1bar) as well as at high-press nat. gas at 20 bar and 40 bar. Meter swapping does not affect the readings. (No installation effects).
The excellent agreement for all meters at all pressures can be seen.

The claimed uncertainties of the pilot lab at 1 bar and high-press gas has been indicated and it can be concluded that all measurements are within these uncertainties.

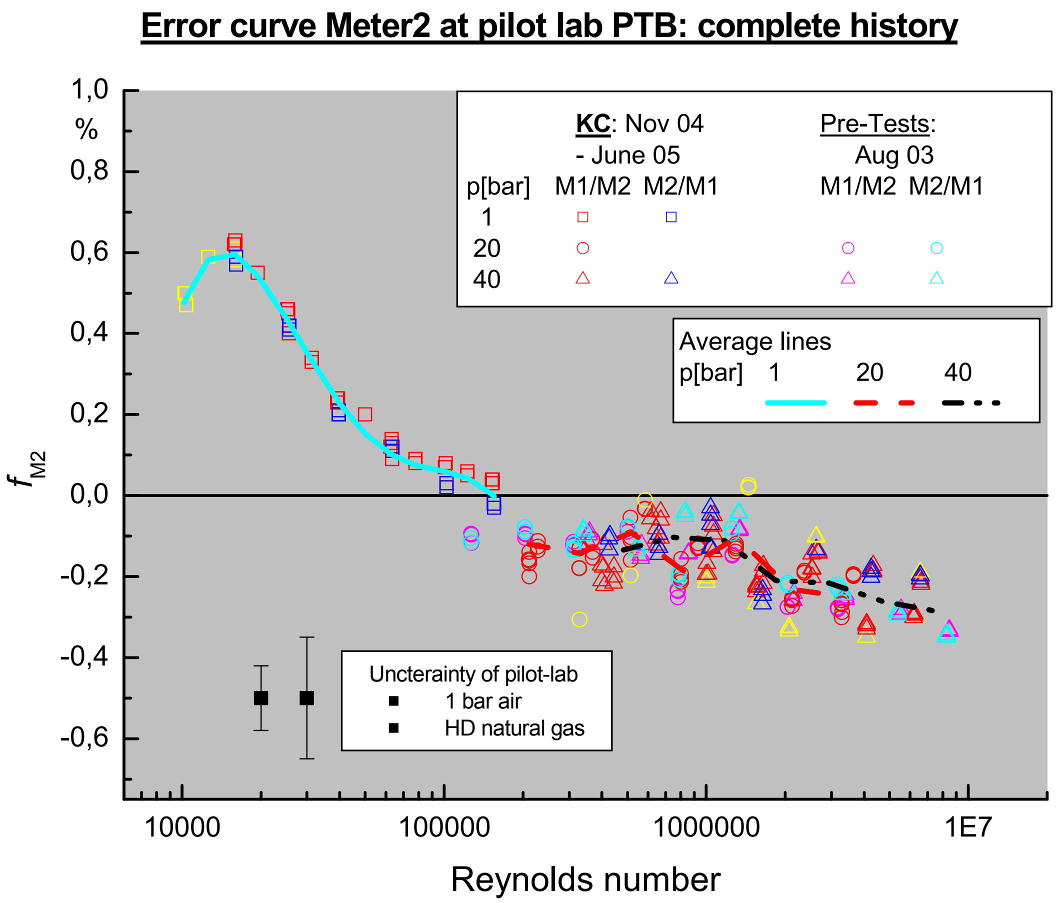

Fig 5: Visualization of all measured error curves of meter 2 (M2) of the transfer package used in KC5b. All valid data are within the claimed uncertainties of pilot lab. The yellow marked data in the diagram are outliers. The were determined by a two dimensional 2-sigma test, see also Fig. 7.

Again we have shown for comparison, the uncertainties of the air facility at 1 bar and the uncertainty of the natural gas facility have been indicated by black error bars in Figure 5. All results for meter 2 are very well within these limits.

In order to check the reproducibility of the meters 1 and 2 it is useful to look to the difference of the meter readings of meter 1 and meter 2 during all measurements. If these differences scatter very little at all pressure stages as well at flow rates, it can be concluded that they are very stable. These differences are presented in Fig. 6.

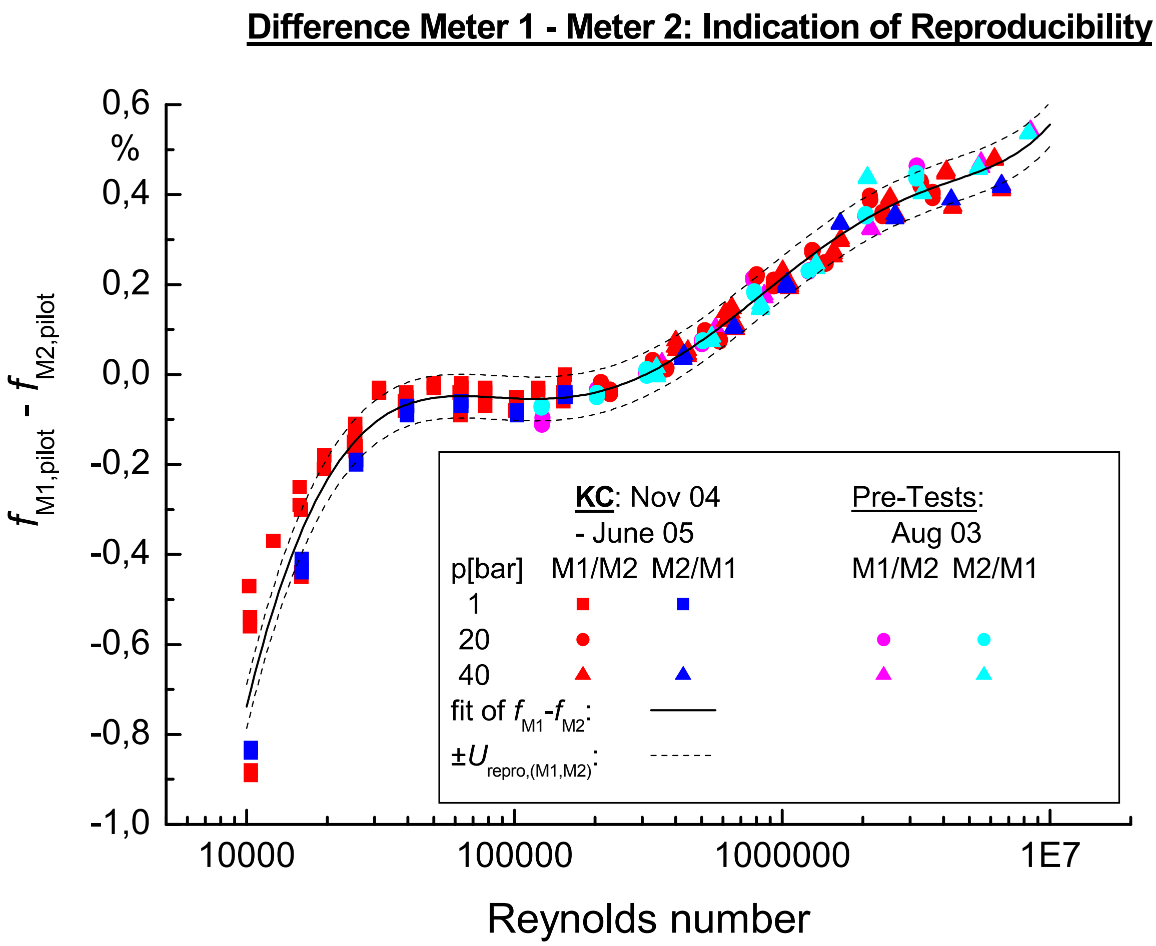

Fig 6: Visualization of all measured differences between M1 and M2 during all pre-tests as well as in the KC data. As the scatter of the differences remains very little, the meters have good reproducibility.

In order to quantify the reproducibility and the repeatability in a quantitative way, correlation plots of the differences d*f* for the transfer package #3 DN150 (Meter 1: Turbine; Meter 2: Turbine meter) designed for KC-5.b have been calculated, see Fig. 7.

The differences of meter 2 minus the average of meter 2 (=df $_{M2,\ pilot}$) have been plotted on the vertical axis and the horizontal axis shows the differences of meter 1 minus the average of meter 1 (=df $_{M1,\ pilot}$). These results have been obtained at the pilot lab PTB.

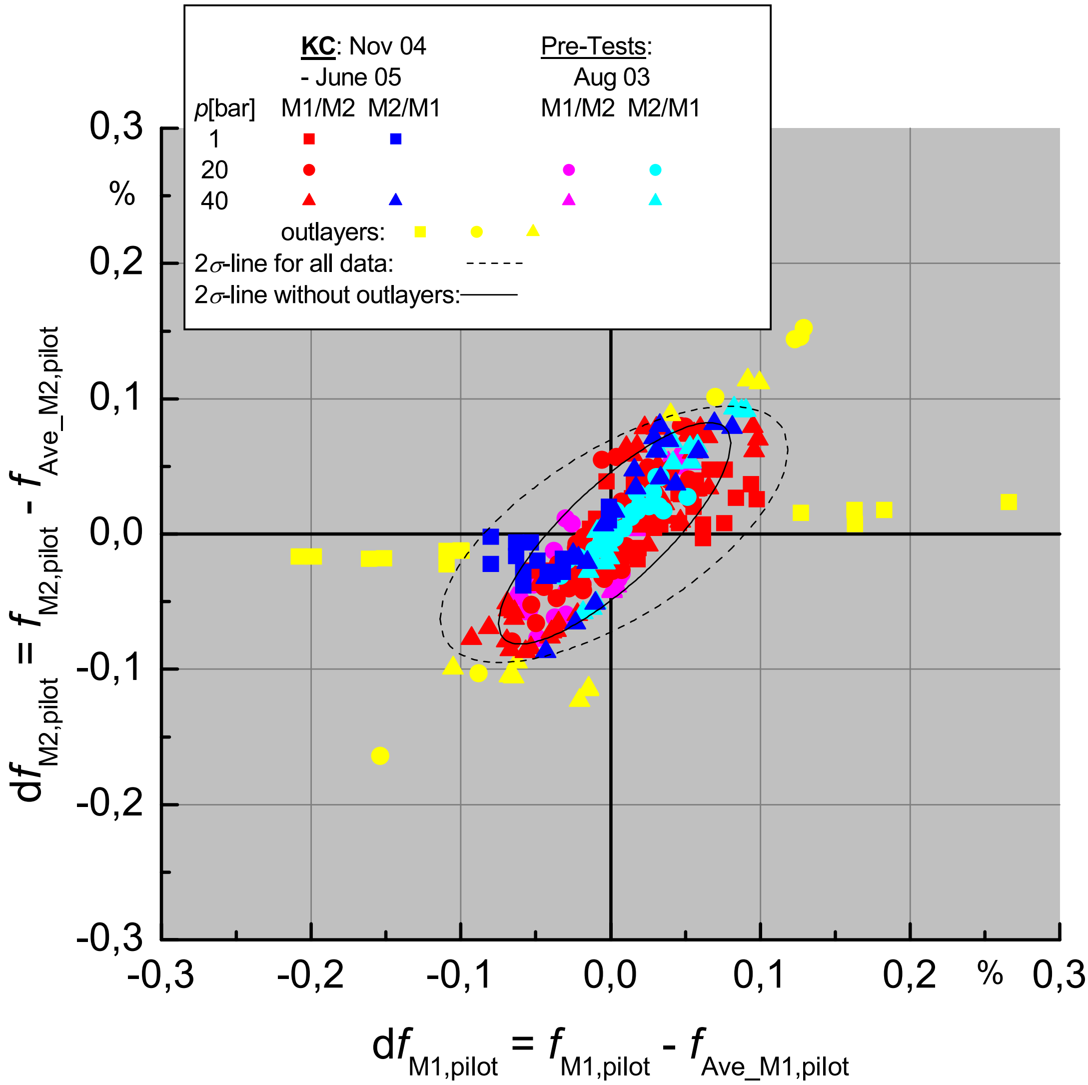

Fig. 7: Correlation plot of the differences d*f* for both meters of the transfer **package #3** DN150 (Meter 1: Turbine; Meter 2: Turbine meter). Data have been obtained during pre-tests and KC at pilot lab. 16 results out of 316 are real statistical outliers (approx. 5%). 17 results determined at low Re-numbers with p = 1 bar (data points with squares) are influenced by a change of bearing friction in meter 1 which was caused due to a shock event. They appeared in a Re-range which is not relevant for the evaluation of this key comparison (see

The tabulated results as obtained from the meter investigation are given in Table 2 below.

	Meter 1 M1	Meter 2 M2	combined $U_{repro,M1,M2}$	Pilot Lab
Overall reproduciblity	$0{,}032^{+0{,}006}_{-0{,}004}$	$0{,}041^{+0{,}007}_{-0{,}005}$	$0{,}052^{+0{,}009}_{-0{,}007}$	$0{,}076^{+0{,}013}_{-0{,}010}$

Table 2: Tabulated results for repeatability, hysteresis and overall reproducibility of the transfer package #3 and pilot lab as obtained from correlation plot in Fig. 7. The numbers for reproducibility include confidence intervals.

The final outcome is that the sum of repeatability, hystersis and overall reproducibility of the transfer meters is in the order of 0,05 % and is therefore small enough to see and detect any quantitative differences between the participants.
The impact of these quantities on KCs will be discussed in chapter 3.4

3.3 Investigation of installation effects

One of the outcomes of the overall reproducibility is that the indication of the transfer meters was not affected significantly by any installation effect *at the pilot lab*. In the following one uses the phrases “installation effects are affecting the meter indication in a negligible level” and “no installation effect” synonymously.

From these investigations we get a quiet comfortable possibility to check the results of the different participants using the base line results at the pilot lab. Mainly the difference of the meter indication $\Delta f = f_1 - f_2$ is helpful for this purpose, as it is explained below.

As it has been shown in chapter on reproducibility, both transfer meters 1 and meter 2 of package #3 produce an excellent reproducibility of 0,04 % and better during the complete duration of the pre-tests and the entire duration of the KC (from August 2003 until June 2005). This is the main prerequisite for an intercomparison which has the aim to quantify the differences between facilities in the order of 0,1 %

It can be shown, that the difference $\Delta f = f_1 - f_2$ of the meter readings, as obtained from the individual calibrations of meter 1 and meter 2 is a measure, which is nearly independent of the method used for the realization of the unit itself.

Therefore, one obtains two calibrations, f_1 and f_2 (13)

$$f_1 = \left(\frac{Q_{MuT,1}}{Q_{fac}} - 1 \right) \cdot 100\% \qquad f_2 = \left(\frac{Q_{MuT,2}}{Q_{fac}} - 1 \right) \cdot 100\% \qquad (14)$$

Q_{fac} is the flow rate as generated by the facility, $Q_{MuT,\,1(2)}$ means for the flow rate measured by the meter under test (MuT).

=>

$$f = \left(\frac{Q_{\mathrm{MuT}}}{Q_{\mathrm{fac}}} - 1 \right) \cdot 100\% \qquad (15)$$

As the meters show meter readings f very close to zero, one can replace in first good approximation Q_{fac} by $Q_{\mathrm{MUT,2}}$.

=>

$$\Delta f \approx \left(\frac{Q_{\mathrm{MuT,1}}}{Q_{\mathrm{MuT,2}}} - 1 \right) \cdot 100\% \qquad (16)$$

Therefore, the measure □*f* is actually the same quantity /value as the calibration value of meter 1 referred to the meter reading of meter 2. It can be concluded that the difference Δf is independent of the technique of realization of the unit itself. The reproducibility of □*f* itself is closely connected with the reproducibility of the meters themselves.

The considerations can mainly be applied, if no installation effects have influence on the calibration. An installation effect can be described as a meter deviation of the meter under test, which affects the meter reading f_i due to slightly modified calibration boundary conditions of the experiment, which are mostly disturbed flow profiles.

The installation effect depends on the installation of the meter and the piping conditions. In the following we note by P1 and P2 the first and second position in a package with two meters in series. The meters #1 and #2 shall have the same construction and my be identical in order to allow the assumption, that the installation effects may be the same for both meters #1 and #2.

$$f_{1,inst,P1} = f_1 + I_{P1} \qquad f_{1,inst,P2} = f_1 + I_{P2} \qquad f_{2,inst,P1} = f_2 + I_{P1} \qquad f_{2,inst,P2} = f_2 + I_{P2} \qquad (17)$$

I_{P1} und I_{P2} describe the installation effects I for both positions P1 and P2 in the transfer package configuration.

If one calculates the differences of the meter readings Δf for both positions P1 and P2,
one gets for position 1 and meter 1 the quantity $\Delta f_{\mathrm{M1/M2}}$ and for position 2 and meter 2 the quantity $\Delta f_{\mathrm{M2/M1}}$ after meter swapping.

For position P1 with meter 1 first, one gets:

$$\Delta f_{M1/M2} = f_1 + I_{P1} - f_2 - I_{P2} = \Delta f + I_{P1} - I_{P2} = \Delta f + \Delta I \qquad (18)$$

For position P2 with meter 2 first:

$$\Delta f_{M2/M1} = f_1 + I_{P2} - f_2 - I_{P1} = \Delta f + I_{P2} - I_{P1} = \Delta f - \Delta I \qquad (19)$$

In the transfer package which has been used in this KC, the meter at Position 2 (the second meter) is three times isolated against installation effects of the facility:
Flow straightener + inlet pipe section of meter of meter in first position, the first meter itself + flow straightener + inlet section of second meter.

Therefore, the installation effects I_{P2} at the second Position can be assumed to be zero. We obtain for $\Delta f_{M1/M2}$:

$$\Delta f_{M1/M2} = \Delta f + I_{P1}$$

and in the same way after meter swapping:

$$\Delta f_{M2/M1} = \Delta f - I_{P1}$$

The installation effect I can be calculated quantitatively by meter swapping and measuring the differences Δf of the meter readings.

These tests have been done during the reproducibility tests at the pilot lab and at the high-pressure facility ***pigsar*****TM**. The following diagram in Fig. 8 present again the results for all measured differences $\Delta f = f_1 - f_2$ in order to allow a more detailed discussion.

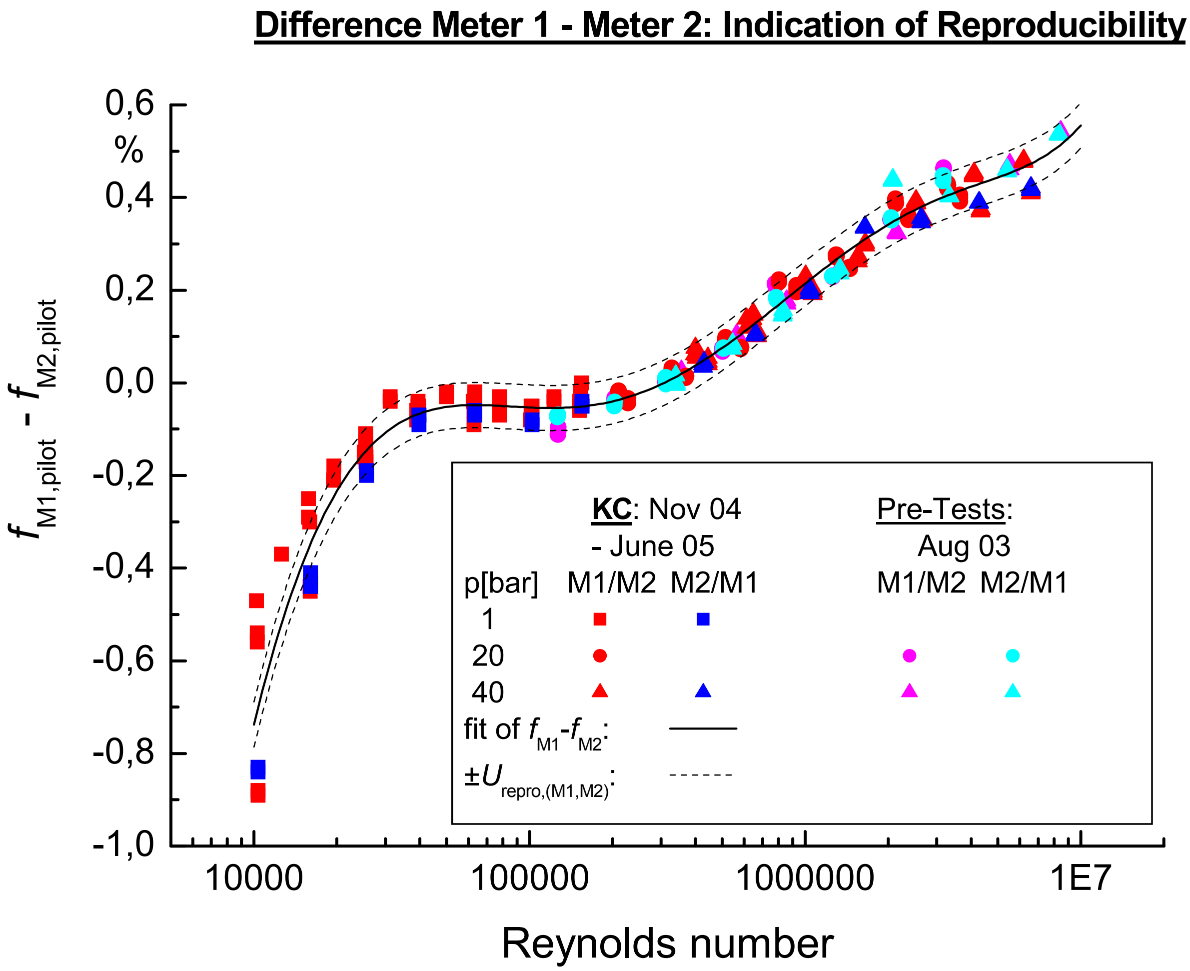

Fig. 8: Visualization of the measured differences of the meter readings $\Delta f = f_{M1} - f_{M2}$ as obtained at the pilot lab for meter M1 and M2 during pre-tests and KC as a function of Re number.

Fig. 8 visualizes all measured differences between M1 and M2 during all pre-tests as well as in the KC data. As the scatter of the differences remains very little, the meters have good reproducibility.
In Fig. 8 it can bee seen, that the values for $\Delta f_{M1/M2}$ for the sequence (M1/M2: red rsp. magenta) do not differ within the reproducibility from the differences obtained for he swapped meter configuration (M2/M1: blue rsp. cyan). These data point out the excellent reproducibility of the meters as well as the lack of any installation effects in the piping / facility itself. We will assume the quantity $\Delta f_{M1/M2}$ [$=f(Re)$] as obtained from the diagram as a time independent and installation free reference value.

Therefore, one obtains the chance to verify any possible amount of installation effect quantitatively by using the difference of the meter readings Δf .
Ass soon as the quantity Δf shows a deviation from the low base value, an installation effect can be assumed.

Such a situation shall be demonstrated for a laboratory in the following Fig. 9:

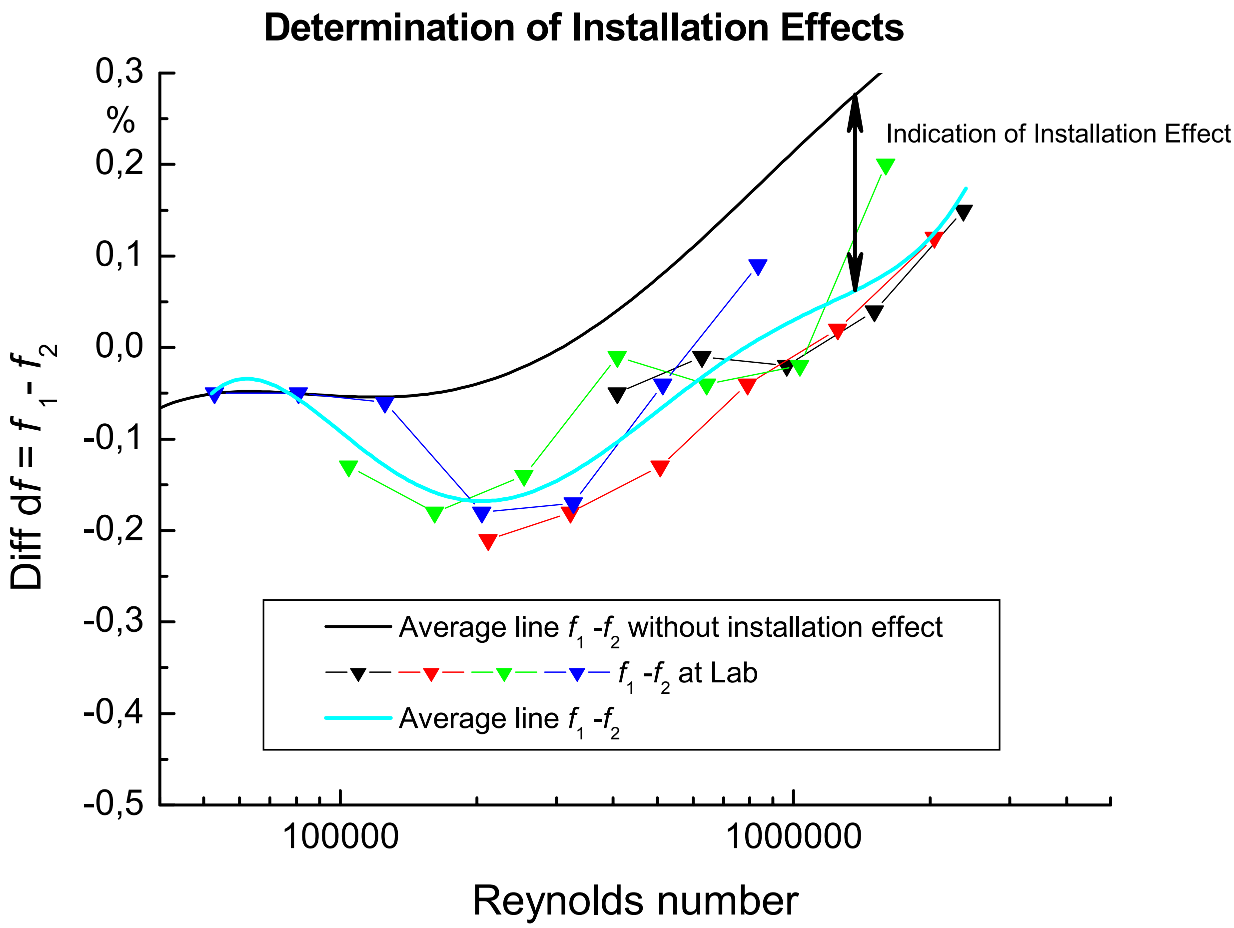

Fig. 9: Visualization of the measured differences of the meter readings $\Delta f = f_{M1} - f_{M2}$ as obtained at a certain lab for meter M1 and M2 during KC as a function of Re number (flow rate).

This diagram in Fig. 9 presents the measured differences between meter 1 and meter 2 for a limited flow rate range at ITRI/CMS and compares those with the average differences obtained at pilot lab (black line). These data have been discussed in Fig. 8 in detail. Please note that the horizontal scale in this Fig. 9 is different from Fig. 8.

The bias between the black average line from PTB and the light blue average of ITRI/CMS data, the installation effect can be estimated. An installation effect can be dependent on pressure, flow rate. For the shown effect in Fig. 9 we have quantified the installation effect as visualized by the differences of both averages for PTB and ITRI/CMS.

Accordingly to this method all installation effects for all labs, which have participated in the KC, have been quantified as they are presented in the following Fig. 10.

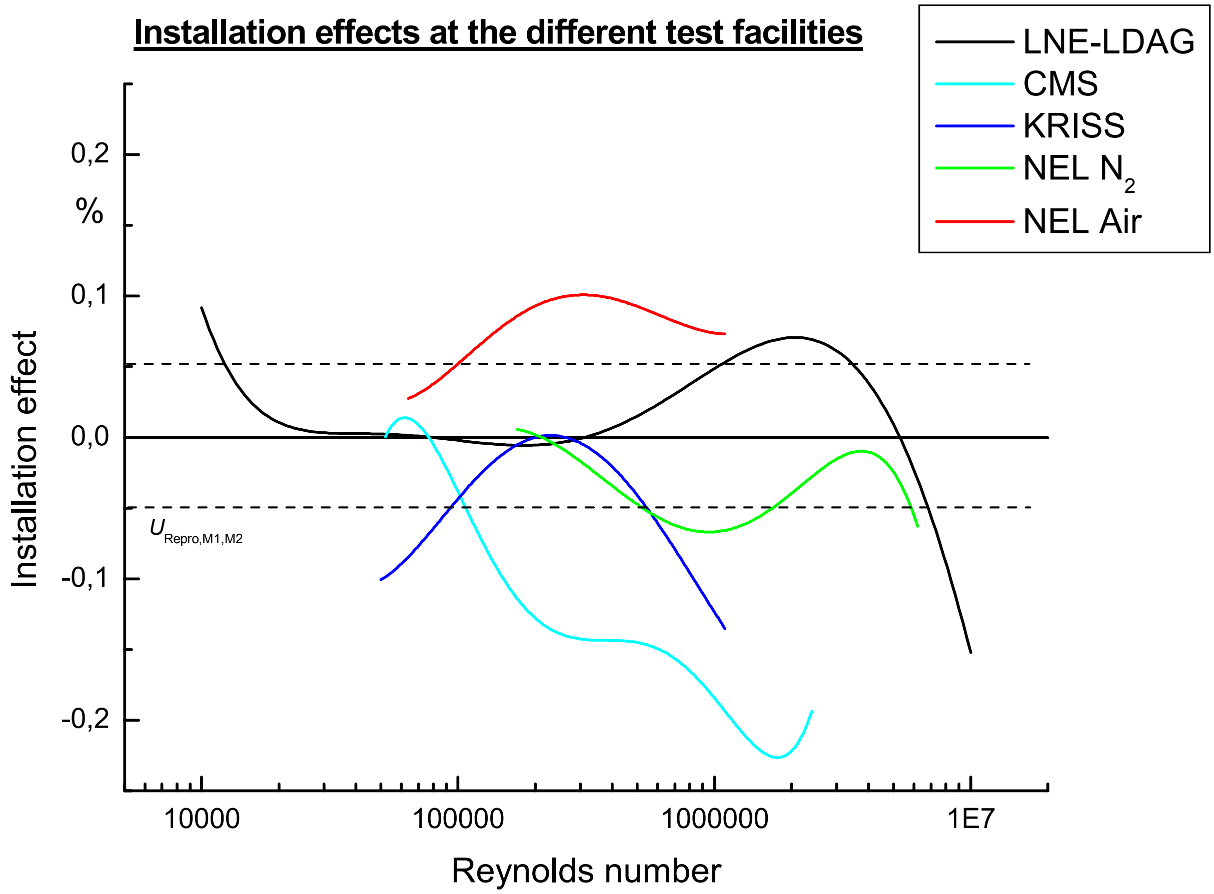

Fig. 10: Visualization of the measured differences of the meter readings $\Delta f = f_{M1} - f_{M2}$ as obtained at a certain lab for meter M1 and M2 during KC as a function of flow rate, for all participating labs. The zero line is the reference obtained at the pilot lab.

In Fig. 10 the averages differences of the meter readings as obtained at the pilot lab has been set to zero in order to show the deviations from the averages of the individual laboratories from this zero- reference.

It can be concluded, that the installation effects in most labs do not exceed the reproducibility of the transfer packages and will be covered in most cases by the total claimed uncertainty of the facilities quite well.
The quantifications of the installation effects have been used for the data evaluation of the KCRV procedure for meter 1.

A special problem which occurred at CMS due to problems with the temperature determination at the original temperature taps, which could not be used. As temperature measurement had to be done downstream, systematical effects happened, which have been interpreted here as installation effects at meter 1. Nevertheless, the final results for ITRI/CMS are not affecting the En-criterion and therefore, we have refrained from further investigations.

3.4 Impact of reproducibility on the quality of inter-comparison results

After determining the estimates for the parts of uncertainty propagated by the transfer meters to the measurement results, the question is, whether this level of quality of the transfer meters is sufficient to perform the intercomparison. To answer this, some simple calculations of virtual results of inter-comparison between two participants will be shown here. The calculation is done twice, once with the pure claimed CMC-uncertainties (i.e. with ideal transfer meters) and once with the combined uncertainties ($U_{\mathbf{CMC}}$ with additional uncertainties from the transfer meters).

The aim of the KC is to get a reference value x_{ref} and the degree of equivalence of each participant to this reference as well as the degree of equivalence between the partners. The analytical definitions and the formulas are given in the paper of Cox [4]. For our purpose following is necessary:

- Claimed uncertainty of participant number *i*: $U_{\mathrm{CMC},i}$
  We assume for our example two cases:
  A) both facilities have a $U_{\mathrm{CMC},1}$ = 0,15 % (0,15 % is the smallest value claimed in the CMC for high pressure gas) and
  B) one facility claims $U_{\mathrm{CMC},1}$ = 0,15 % and the other $U_{\mathrm{CMC},2}$ = 0,20 %
- Uncertainty propagated by the transfer meter U_{TM} =
  $\sqrt{U^2_{TM,repeat} + U^2_{TM,hyst} + U^2_{TM,repro}}$
  With the statements above we get U_{TM} = 0,060 %
- Uncertainty of the result x_i measured by participant *i*:
  $U_{x,i} = \sqrt{U^2_{CMC,i} + U^2_{TM}}$
- Uncertainty of reference value $U_{x,ref}$ (according to Cox [4]): $\frac{1}{U^2_{x,ref}} = \sum_{i=1}^{n} \frac{1}{U^2_{x,i}}$
  (*n* – number of participants, *n* = 2 for our example)
- Uncertainty of the difference d_i of participant *i* to reference value:
  $U_{d,i,ref} = \sqrt{U^2_{x,i} - U^2_{x,ref}}$
- Uncertainty of the difference $d_{i,j}$ of participant *i* to participant *j*:
  $U_{d,i,j} = \sqrt{U^2_{x,i} + U^2_{x,j}}$

The results of calculation using the equations above are given in the following table 3 to make it transparent what is happening with the uncertainties when an ideal or real transfer meter is used.

Type of uncertainty	Example 1		Example 2	
	Ideal transfer meter	Real transfer meter	Ideal transfer meter	Real transfer meter
$U_{CMC,1}$	0,15 %		0,15 %	
$U_{CMC,2}$	0,15 %		0,20 %	
U_{TM}	0 %	0,060%	0 %	0,060 %
$U_{x,1}$	0,150 %	0,161 %	0,150 %	0,161 %
$U_{x,2}$	0,150 %	0,161 %	0,200 %	0,209 %
$U_{x,ref}$	0,106 %	0,114 %	0,120 %	0,128 %
$U_{d,1,ref}$	0,106 %	0,114 %	0,090 %	0,099 %
$U_{d,2,ref}$	0,106 %	0,114 %	0,160 %	0,165 %
$U_{d,1,2}$	0,212	0,228	0,250 %	0,264 %

Table 3: Estimated uncertainties for two typical situations, example #1 and #2 in a high-pressure flow laboratory comparison.

From the results presented in table 3 the following conclusions can be drawn:

- The use of transfer meters with level of quality (reproducibility and repeatability) mentioned in this KC increases the uncertainties of inter-comparison results (reference value, differences of participants to reference value as well between participants) in the order of only 10 % or less. (as compared with an ideal meter)
- We can determine differences in flow rate in the order of 2/3 of the claimed uncertainties of the participants, even we use ideal or real transfer meters.

As shown in chapter 3.2 the actually used transfer meters can fulfill all these requirements as they have overall reproducibilities etc. in the order of 0,04 – 0,06 %.

4 MEASUREMENT PROGRAM in KC5b

4.1 Flow rate ranges in KC5b

The calibration points have been selected in order to cover a wide range of flow rates and pressures according to the calibration capabilities of each participant.

The following pressures and flow ranges are intended to be used in K5.b for high-press natural gas (using transfer packages #3):

Flow range = From 65 to 1000 m^3/hr, Pressures: (1), 5, 10, 20, 40 bar

The following table 4 presents the agreed test- and measurement points (loads) as well as pressures, at which the transfer standards will be calibrated.

Institute	LNE-LADG				CMS-ITRI				KRISS				NEL N2				NEL Air			
at pressure (bar)	5	10	20	40	5	10	20	40	5	10	20	40	5	10	20	40	5	10	20	40
Flow rate																				
65	X	X	X	X	X	X	X	X	X	X							X	X		
100	X	X	X	X	X	X	X	X	X	X				X	X	X	X	X		
160	X	X	X	X	X	X	X	X	X	X				X	X	X	X	X		
250	X	X	X	X	X	X	X	X	X	X				X	X	X	X	X		
400	X	X	X	X	X	X	X	X	X	X				X	X	X	X	X		
650	X	X	X	X	X	X	X		X	X				X	X	X	X			
1000	X	X	X	X	X	X			X					X	X	X	X			

Table 4. Compressed Air and Nitrogen Test Loop: Package No#3: G650/ DN 150 (6"); pressure stages and selected flow rates

The following Figure 11 visualizes the applied flow rates and pressures during K5.b at PTB-**pigsar**^{TM}, LNE-LADG(BNM), NEL, KRISS and CMS-ITRI

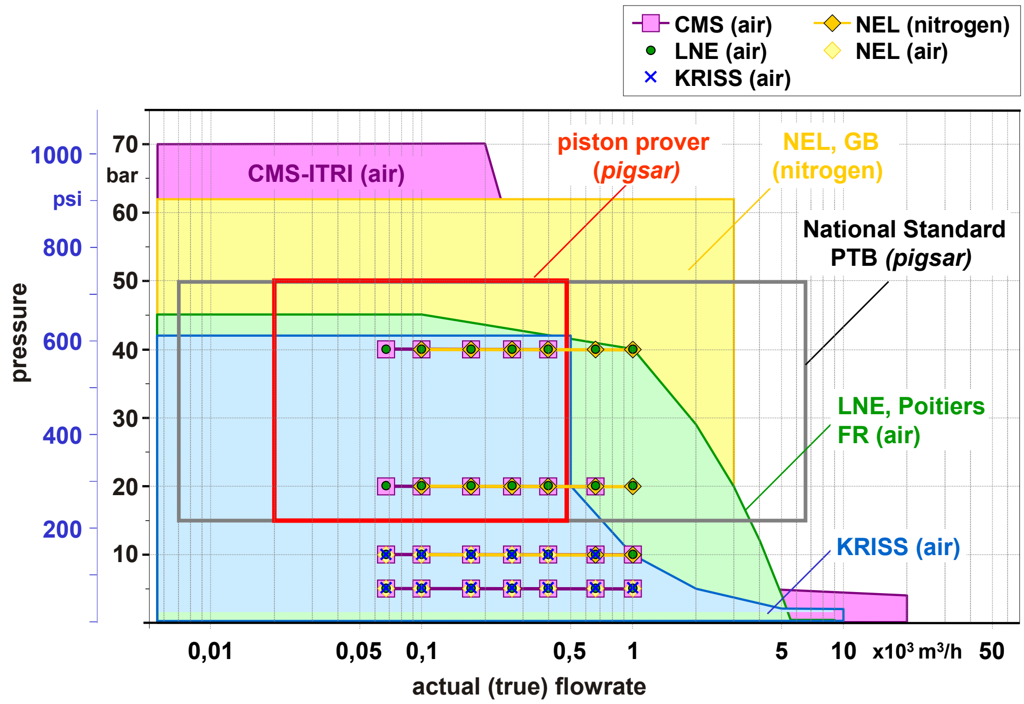

Fig.11: Visualization of selected flow rates as well as pressures during K5.b at PTB-***pigsar***^{TM}, LNE-LADG (BNM), NEL, KRISS and CMS-ITRI.

In contrast to the previous Fig. 1 the visualization of the calibration and measuring capabilities have been restricted here to the laboratories actually participating in the KC.

The transfer package #3 has been calibrated at 7 loads per pressure stage if the facility allows to do that.

4.2 Degree of equivalence of the laboratories

This chapter shall explain how to get the degree of equivalence between all participants and the degree of equivalence of laboratories with respect to the KCRV.

In Fig. 12 one recognizes “measured” data at 5 fictive laboratories for a single meter and the calculated KCRV function. Using the nomenclature there, the following quantities can be obtained:

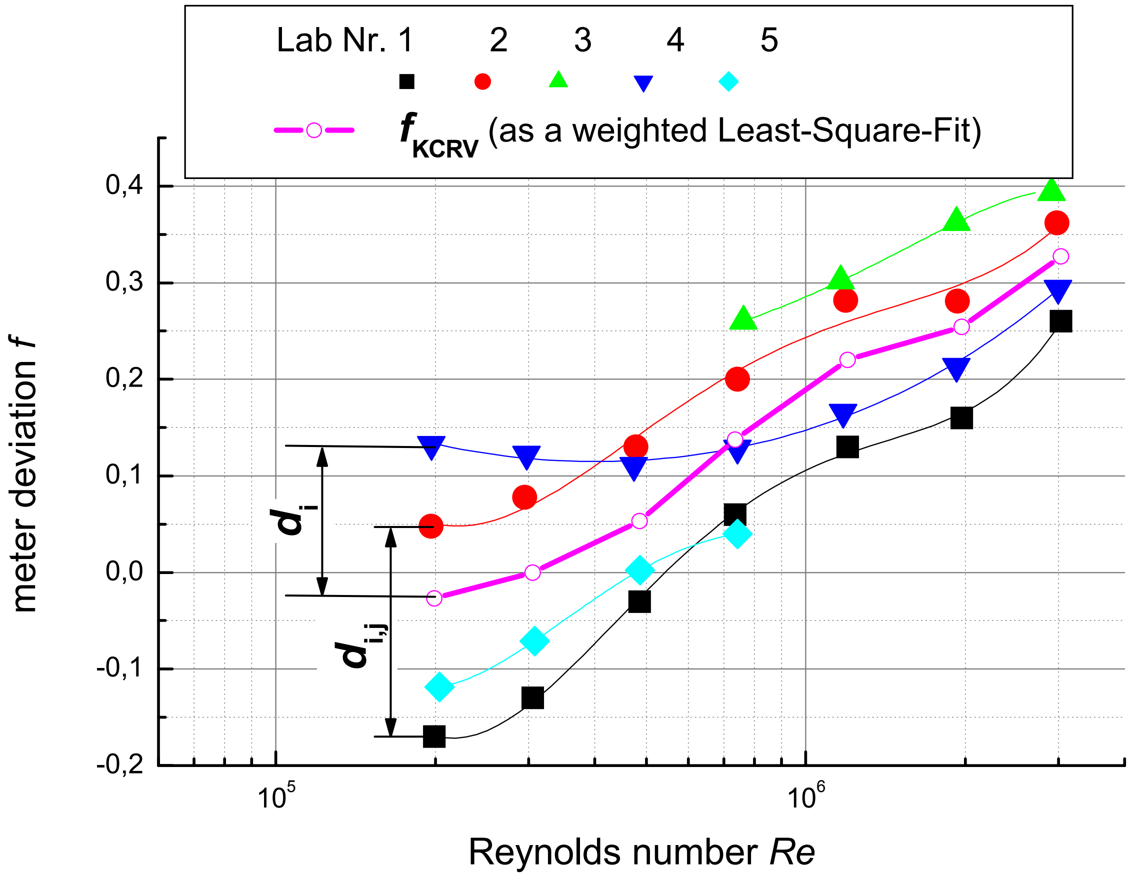

Fig. 12: Illustration of differences d_i between laboratories and KCRV and $d_{i,j}$ between the laboratories itself.

Using the results in Fig. 12, one can calculate the following quantities:

$$d_i = f_i - f_{KCRV}; \quad d_{i,j} = f_i - f_j \tag{20}$$

A so-called En-criterion can be calculated, which describes the degree of equivalence, see [4-6]. This En-criterion is widely used for accredited laboratories and which describes the degree of equivalence nicely.

$$En_i = \frac{|d_i|}{U(d_i)}; \quad U(d_i) = \sqrt{U_{MuT}^2 - U_{KCRV}^2} \tag{21}$$

with

$$U_{MuT}^2 = U_{CMC,i}^2 + U_{TM}^2$$

d_i means the bias between the KCRV and the measured value and $U(d_i)$ is the corresponding uncertainty of this bias between the KCRV and the measured value, which will be calculated according to Cox, see [4], chapter 5, section 4 equations (3) and (5).

Such a non-dimensional number describes very well the degree of equivalence between the laboratories and the KCRV. Such a number E_n is in use in EAL Interlaboratory Comparisons, see e. g. [5, 6]. The meaning of “En numbers” or “normalized error” has been pointed out e.g. in [5].

Following this international accepted way, it will be possible to describe the degree of equivalence of a laboratory to the KCRV using a dimensionless number. E_n should be between 0 and 1 and may go up to 1, 2.

$En_i = \frac{|d_i|}{U(d_i)}$ will be the degree of equivalence which we suggest to use here for the high-press KCs.

The idea behind the E_n definition has been described e. g. by Wöger in [5].
This technique has been realized in pre-test by the pilot laboratories very successfully and will be used in K5.b.

The meaning will be explained in the following chapter using measured data of all KC participants.

5 KCRV K5.b results using transfer package #3

5.1 Verification of the longtime stability of transfer package

The transfer package #3 has been investigated in detail before the KCs have been started and it has been re-calibrated at the pilot lab after all comparisons have been completed. This allows to identify and shift or instability of the meter during calibrations, shipping and handling procedures. The results are shown in Fig. 13 and 14.

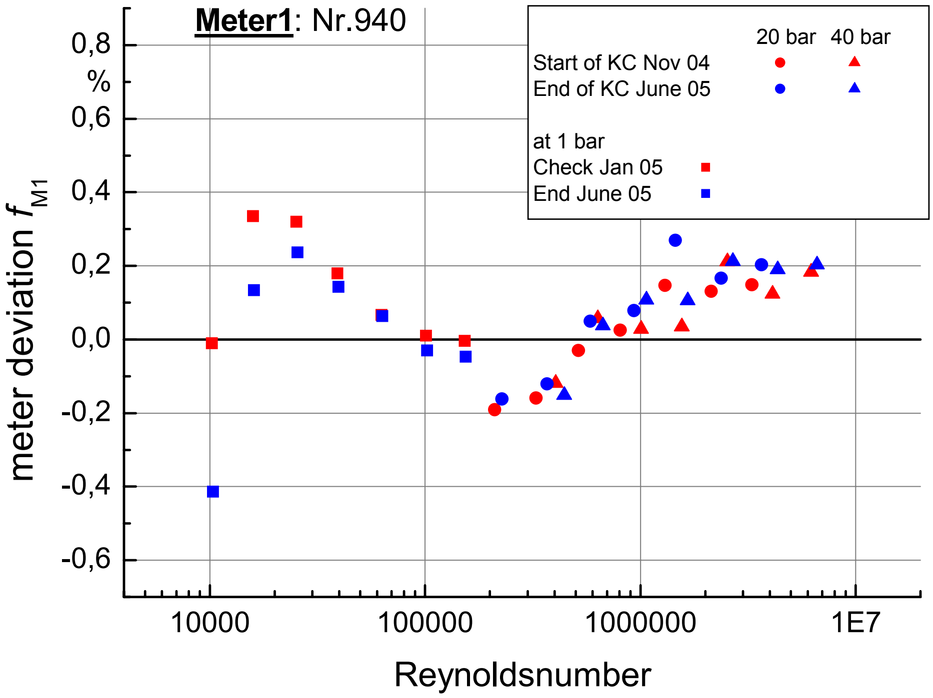

Fig. 13: Calibration of meter 1 of the transfer package at the beginning and at the end of the KC-5b. The results visualize the excellent stability of the meter during the entire procedure. Tests have been done with high-press natural gas at pigsar and with ambient air at PTB

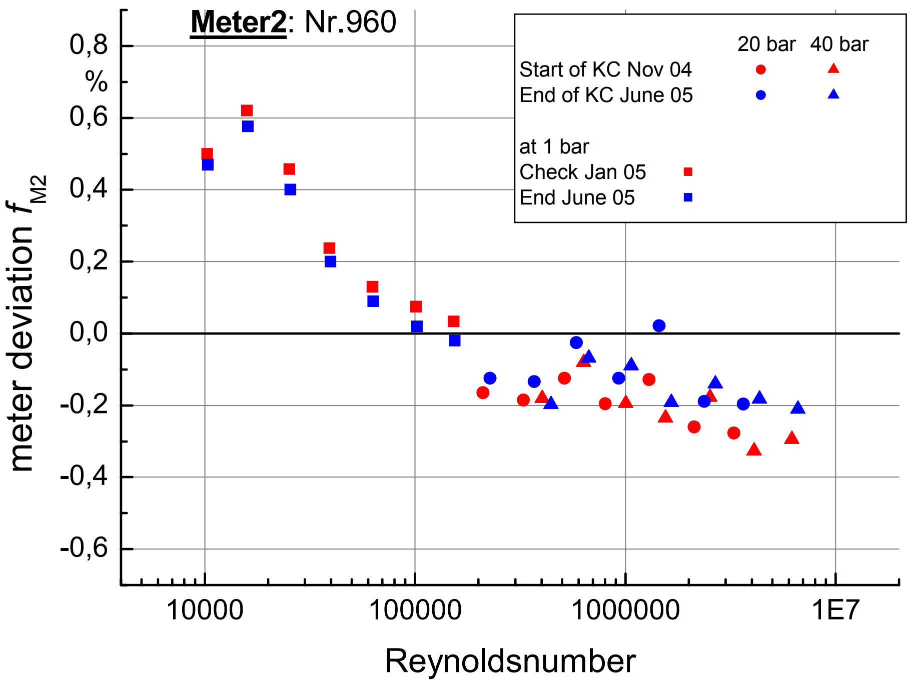

Fig. 14: Calibration of meter 2 of the transfer package at the beginning and at the end of the KC-5b. The results visualize the excellent stability of the meter during the entire procedure. Test have been done with high-press natural gas at pigsar and with ambient air at PTB

All calibrations have been done at pigsar using high-press natural gas and with ambient air at PTB. There was no quantitative shift detectable, all results are well within the reproducibility and claimed uncertainties.

5.2 Presentation of all data at all labs

In order to give an overview and an impression about the total KC, at first all calibration data for meter 1 of the transfer package #3, compare Figs. 2a,b and Fig. 3 are presented at first in Fig. 15.

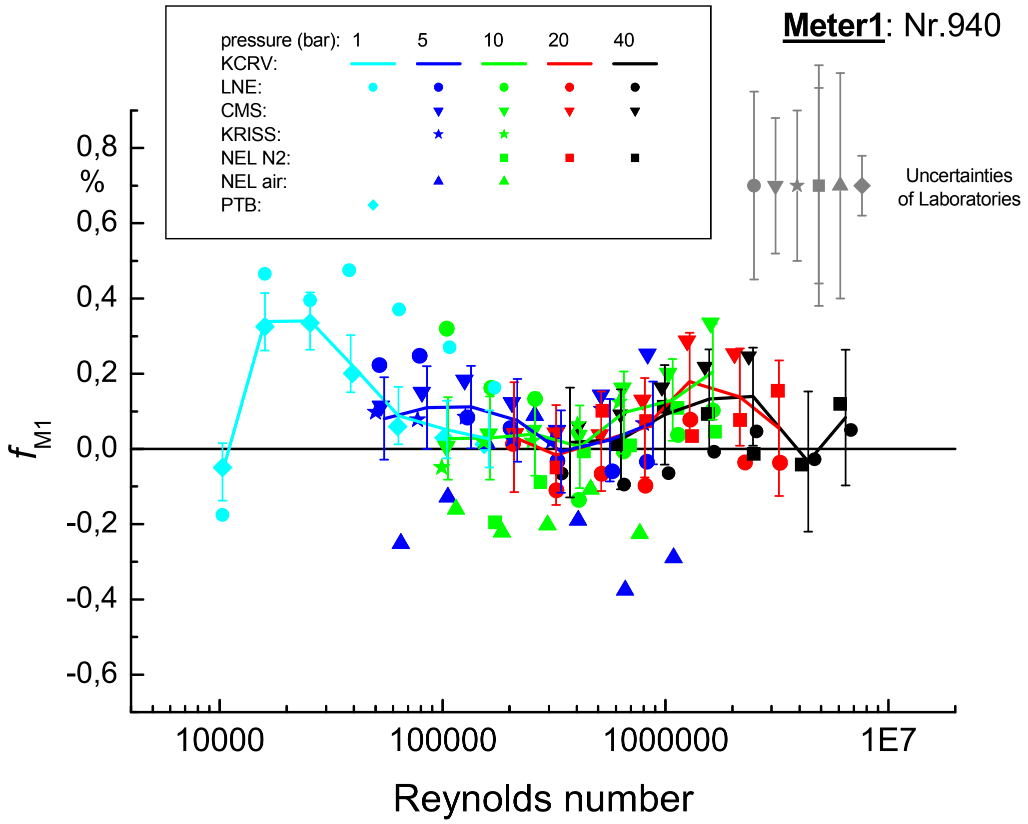

Fig. 15: Calibration results of meter 1 of the transfer package at all participants and all pressures between 1 bar and 40 bars. The claimed uncertainty bars for all labs are indicated in grey. The resulting KCRV at the different pressure stages and its uncertainty is presented throughout the entire flow range. The results at p = 1 bar are added for information purpose only. They are not part of the KC5b ($p \geq 5$ bar) and do not influencing the KCRVs of the KC5b.

The following uncertainties have been claimed by the participants:

LNE-LADG:	Uclaimed = ***0,25*** %;
ITRI/CMS:	Uclaimed = ***0,18*** %;
KRISS:	Uclaimed = ***0,20*** %
NEL N2:	Uclaimed = ***0,26 – 0,32*** %
NEL Air:	Uclaimed = ***0,30*** %
PTB air	Uclaimed = ***0,08*** % (not a participant, pilot lab only)

The KCRV function has been calculated using the weighted average of all participants; see the colored lines in Fig. 15. The corresponding error bars indicates the uncertainty of the KCRV. Calculations have been done using the weighed mean accordingly to Cox [4], chapter 5, equation (2).

One recognizes a quite good overlap of all institutes with the KCRV function and among each other.

Figure 16 shows all measured calibration data for meter 2 of the transfer package #3 for all participants in the same way as for meter 1. Meter readings are plotted as a function of Reynolds number Re.

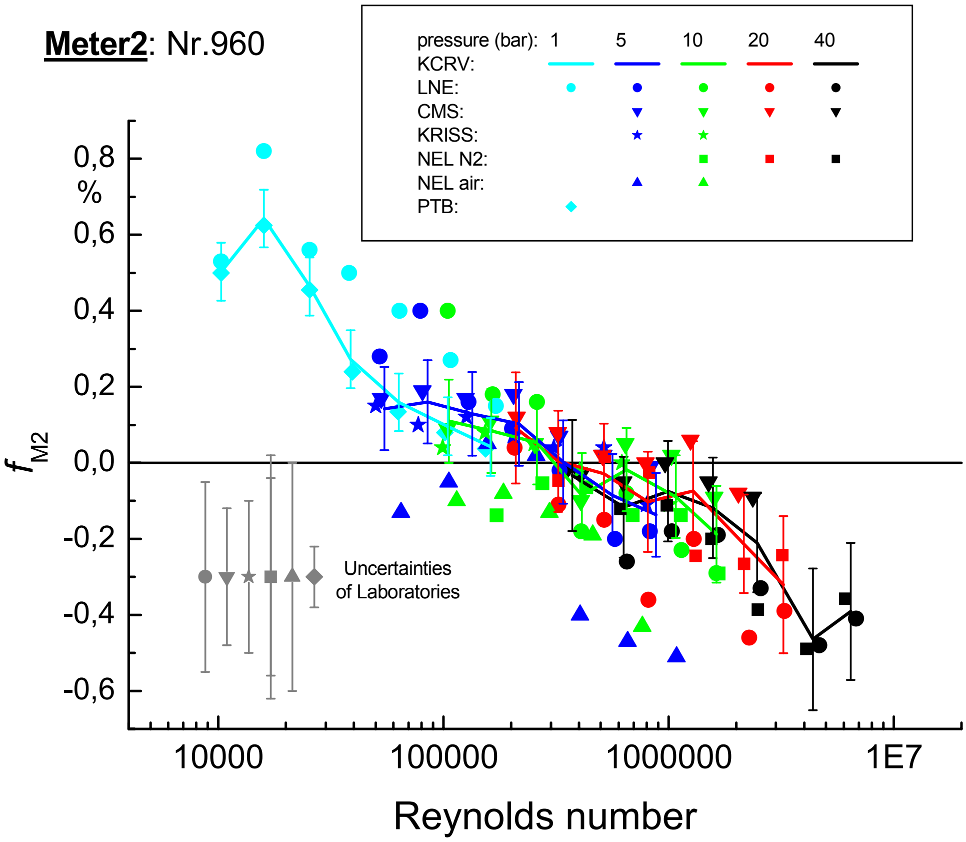

Fig. 16: Calibration results of meter 2 of the transfer package at all participants and all pressures between 1 bar and 40 bars. The claimed uncertainty bars for all labs are indicated in grey. The resulting KCRV at the different pressure stages and its uncertainty is presented throughout the entire flow range. The results at p = 1 bar are added for information purpose only. They are not part of the KC5b ($p \geq 5$ bar) and do not influencing the KCRVs of the KC5b.

One recognizes a quite good overlap of all institutes with the KCRV function and among each other from Fig. 16. The conclusions from Fig. 16 are actually the same as for meter 2: The data are very fine and acceptable. It shall be mentioned here, that the test at ambient air have been used in order to test the quality of the meter and in order to get al link between air at 1 bar and compressed air. Without this link, the results are less useful.

In the following, the detailed calibrations shall be discussed for both meters at all pressures:

5.3 Calibration data for meter 1and 2 at different pressure stages

Extract for 1 bar

At first the data for calibration of both meters at 1 bar will be shown:

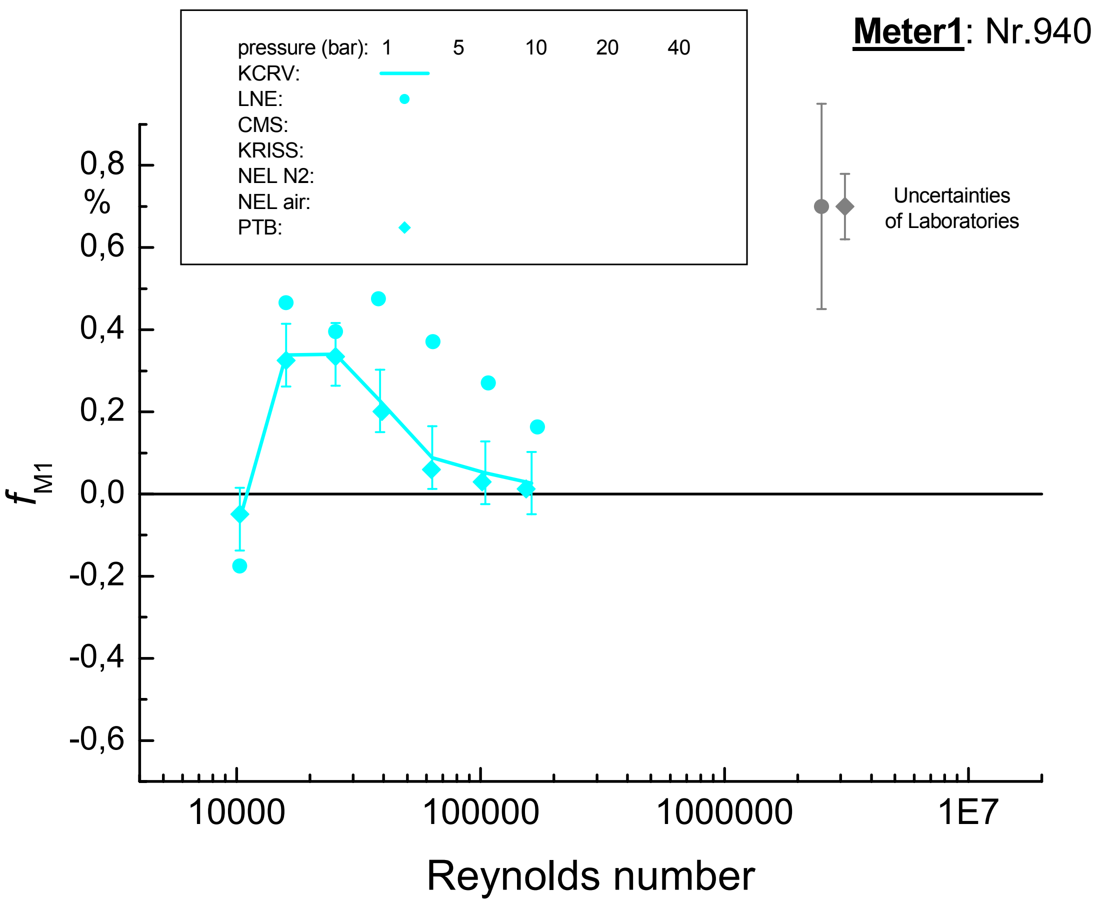

Fig. 17: Calibration results of meter 1 of the transfer package at PTB and LNE-LADG (BNM) at 1 bar. The claimed uncertainty bars for all labs are indicated in grey. The resulting KCRV at the different pressure stages and its uncertainty is presented throughout the entire flow range. The results at p = 1 bar are added for information purpose only. They are not part of the KC5b ($p \geq 5$ bar) and do not influencing the KCRVs of the KC5b.

The KCRV is the weighted means of all single results. All uncertainty bars do overlap very well. One recognizes a quite good overlap of all institutes with the KCRV function and among each other.

The following Fig. 18 presents the data for calibration of meters 2 at 1 bar for air.

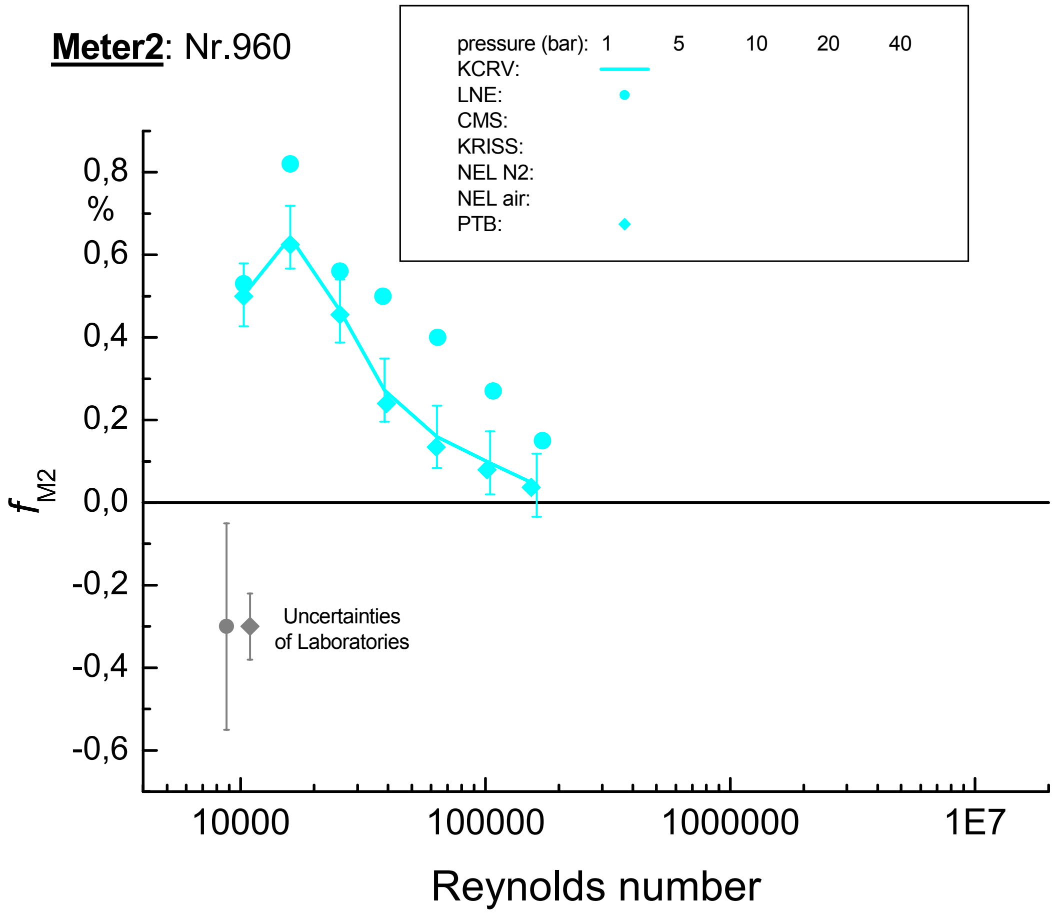

Fig. 18: Calibration results of meter 2 of the transfer package at PTB and LNE-LADG (BNM) at 1 bar. The claimed uncertainty bars for all labs are indicated in grey. The resulting KCRV at the different pressure stages and its uncertainty is presented throughout the entire flow range. The results at p = 1 bar are added for information purpose only. They are not part of the KC5b ($p \geq 5$ bar) and do not influencing the KCRVs of the KC5b.

The KCRV is the weighted means of all single results.
All uncertainty bars do overlap very well for meter 2.

One recognizes a quite good overlap of all institutes with the KCRV function and among each other.

Extract for 5bar

The following Fig. 19 and Fig. 20 show the extract to all calibrations for meter 1 and meter 2 at 5 bar.

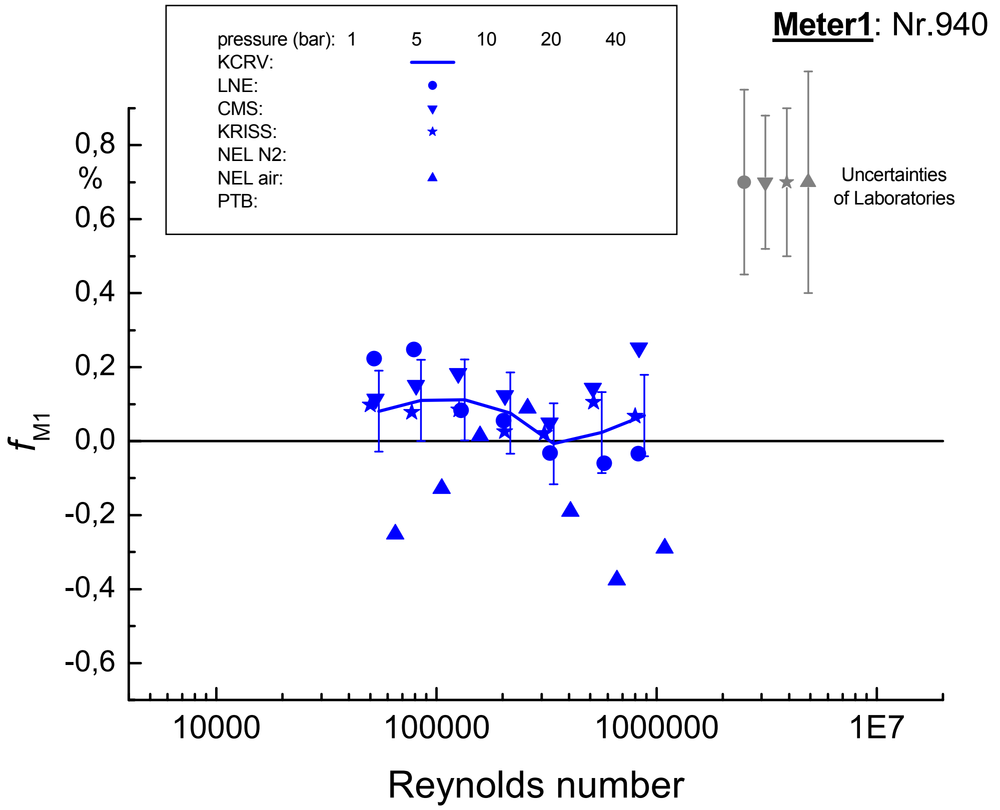

Fig. 19: Calibration results of meter 1 of the transfer package at NEL (air), KRISS, CMS and LNE-LADG (BNM) at 5 bars for all air data. The claimed uncertainty bars for all labs are indicated in grey. The resulting KCRV at the different pressure stages and its uncertainty is presented throughout the entire overlapping flow range.

The KCRV is the weighted means of all single results.
All uncertainty bars do overlap very well for meter 1.

One recognizes a quite good overlap of all institutes with the KCRV function and among each other.

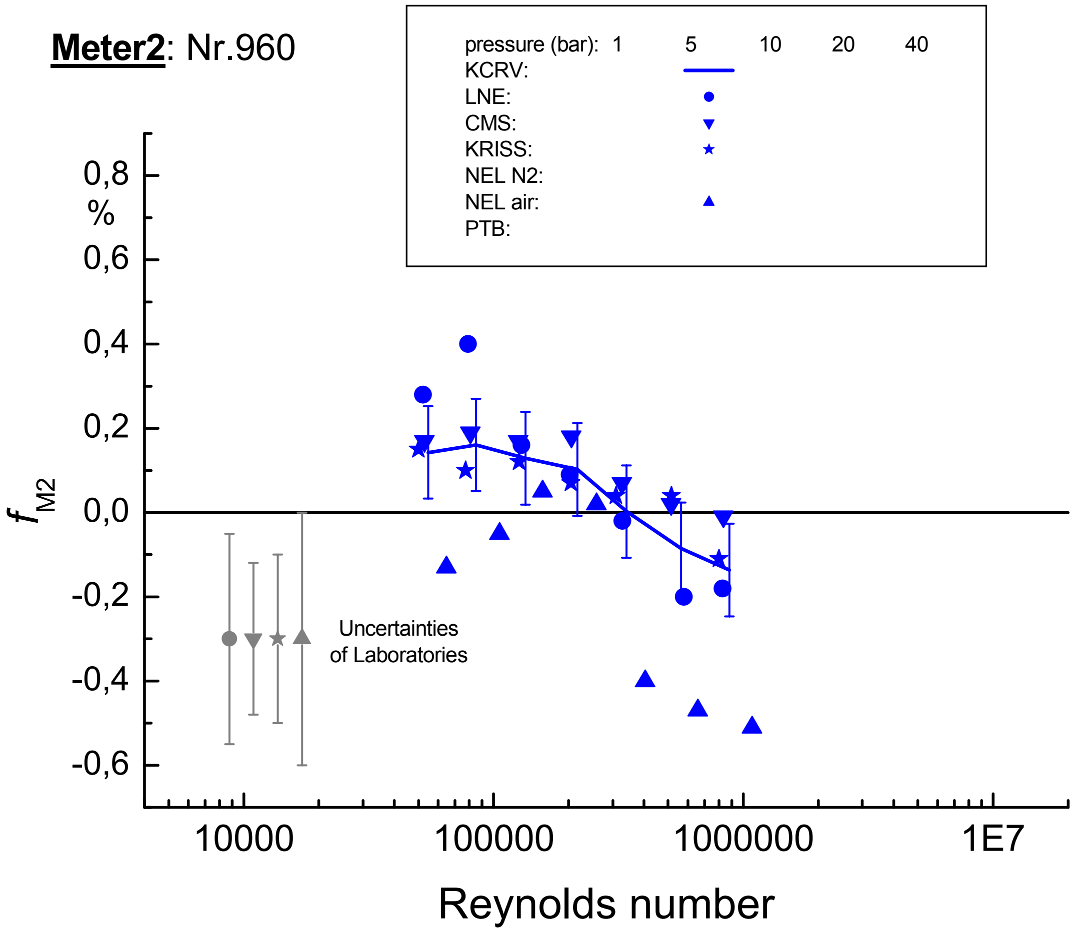

Fig. 20: Calibration results of meter 2 of the transfer package at NEL, KRISS, CMS and LNE-LADG (BNM) at 5 bars for all air data. The claimed uncertainty bars for all labs are indicated in grey. The resulting KCRV at the different pressure stages and its uncertainty is presented throughout the entire overlapping flow range.

The KCRV is the weighted means of all single results.
All uncertainty bars do overlap very well for meter 2.

One recognizes a quite good overlap of all institutes with the KCRV function and among each other.

Extract for 10 bars

The following Fig. 21 and Fig. 22 show the extract to all calibrations for meter 1 and meter 2 at 10 bar.

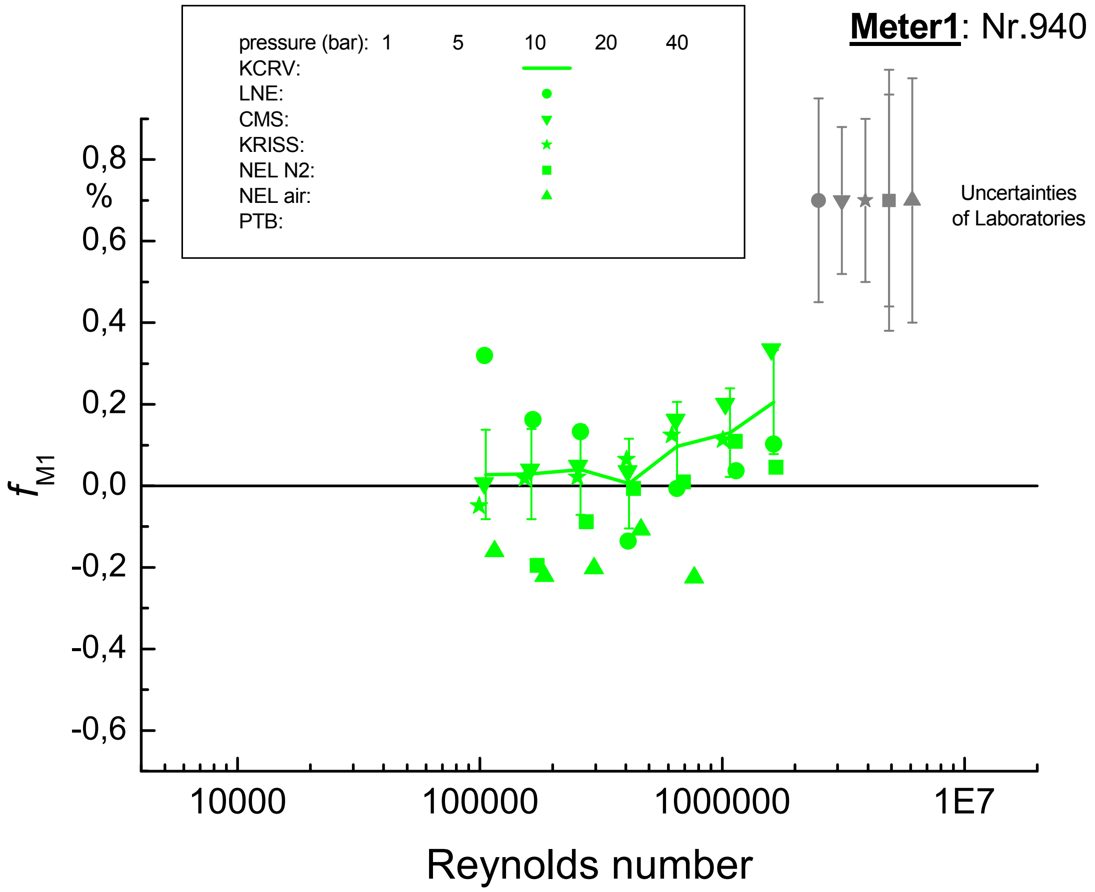

Fig. 21: Calibration results of meter 1 of the transfer package at NEL, KRISS, CMS and LNE-LADG (BNM) at 10 bars for air and Nitrogen data. The claimed uncertainty bars for all labs are indicated in grey. The resulting KCRV at the different pressure stages and its uncertainty is presented throughout the entire overlapping flow range.

The KCRV is the weighted means of all single results.
All uncertainty bars do overlap very well for meter 1.

One recognizes a quite good overlap of all institutes with the KCRV function and among each other.

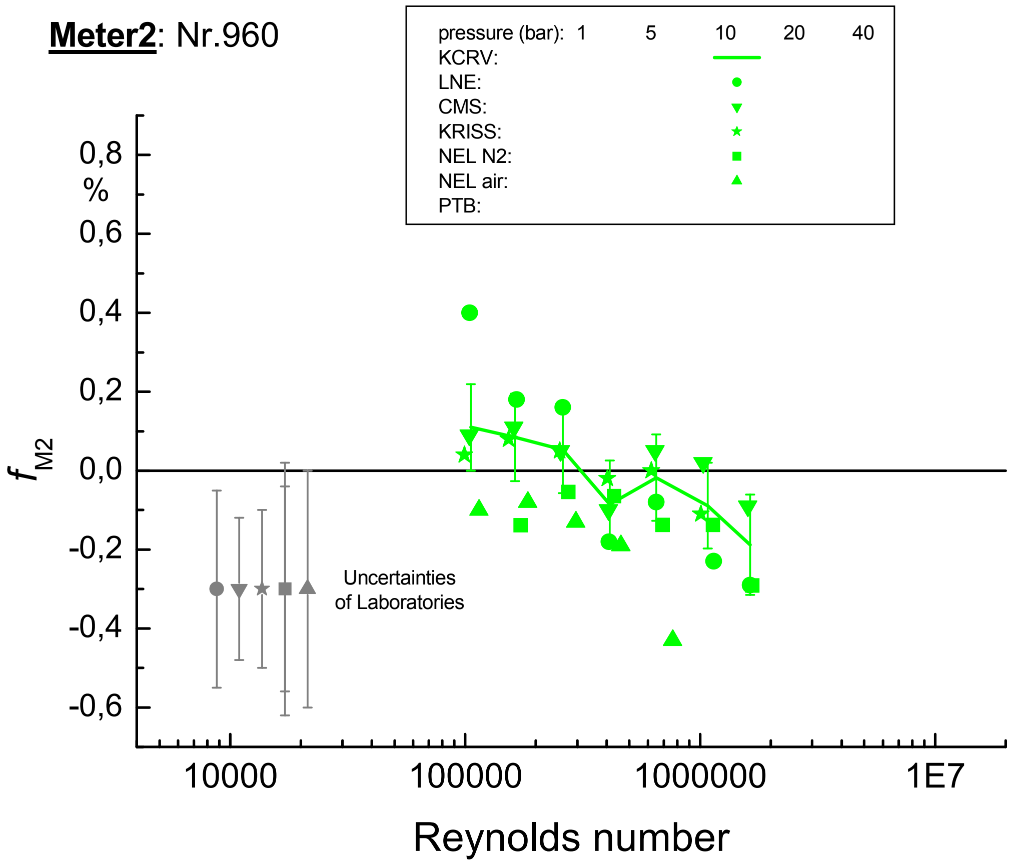

Fig. 22: Calibration results of meter 2 of the transfer package at NEL, KRISS, CMS and LNE-LADG (BNM) at 10 bars for air and Nitrogen data. The claimed uncertainty bars for all labs are indicated in grey. The resulting KCRV at the different pressure stages and its uncertainty is presented throughout the entire overlapping flow range.

The KCRV is the weighted means of all single results.
All uncertainty bars do overlap very well for meter 2 as for meter 1.

One recognizes a quite good overlap of all institutes with the KCRV function and among each other.

Extract for 20 bar

The following Fig. 23 and Fig. 24 show the extract to all calibrations for meter 1 and meter 2 at 20 bar.

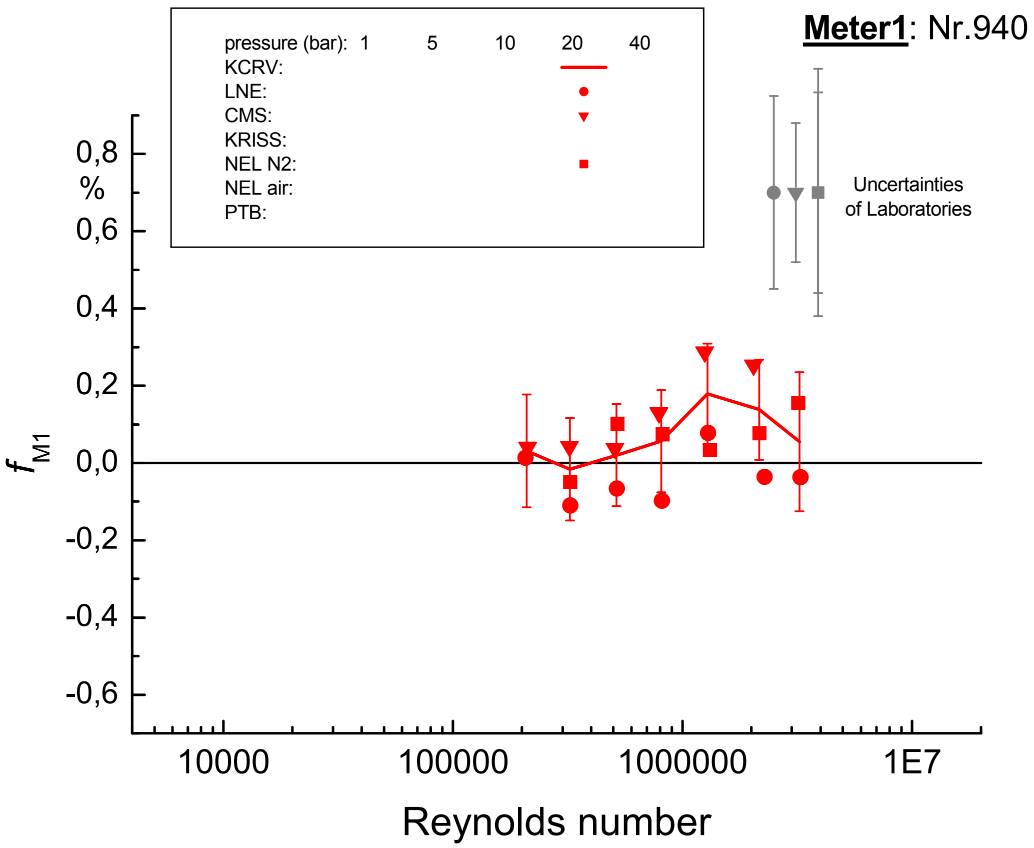

Fig. 23: Calibration results of meter 1 of the transfer package at NEL(N2), CMS and LNE-LADG (BNM) at 20 bar for air and Nitrogen for NEL. The claimed uncertainty bars for all labs are indicated in grey. The resulting KCRV at the different pressure stages and its uncertainty is presented throughout the entire overlapping flow range.

The KCRV is the weighted means of all single results.
All uncertainty bars do overlap very well for meter 1.

One recognizes a quite good overlap of all institutes with the KCRV function and among each other.

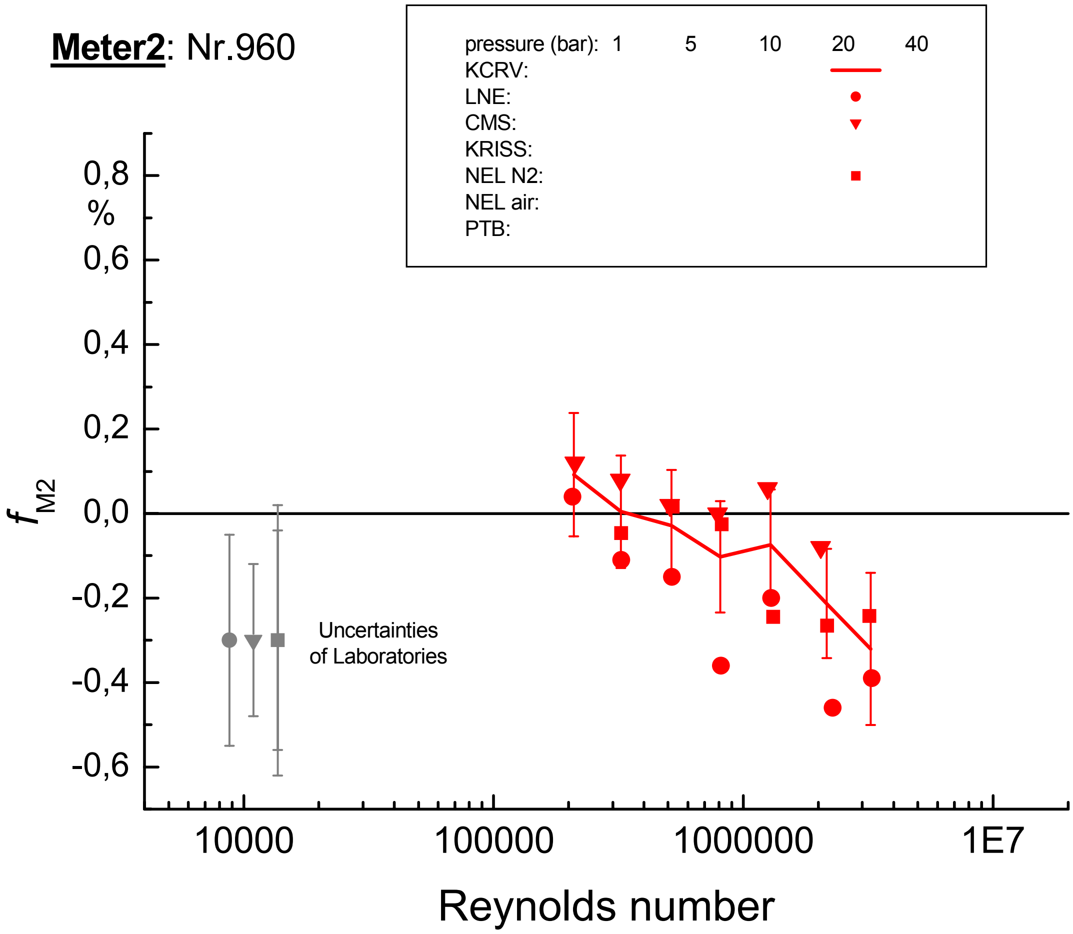

Fig. 24: Calibration results of meter 2 of the transfer package at NEL, CMS and LNE-LADG (BNM) at 20 bars for air and Nitrogen (NEL). The claimed uncertainty bars for all labs are indicated in grey. The resulting KCRV at the different pressure stages and its uncertainty is presented throughout the entire overlapping flow range.

The KCRV is the weighted means of all single results.
All uncertainty bars do overlap very well for meter 2 as for meter 1.

One recognizes a quite good overlap of all institutes with the KCRV function and among each other.

Extract for 40 bar

The following Fig. 25 and Fig. 26 show the extract to all calibrations for meter 1 and meter 2 at 40 bar.

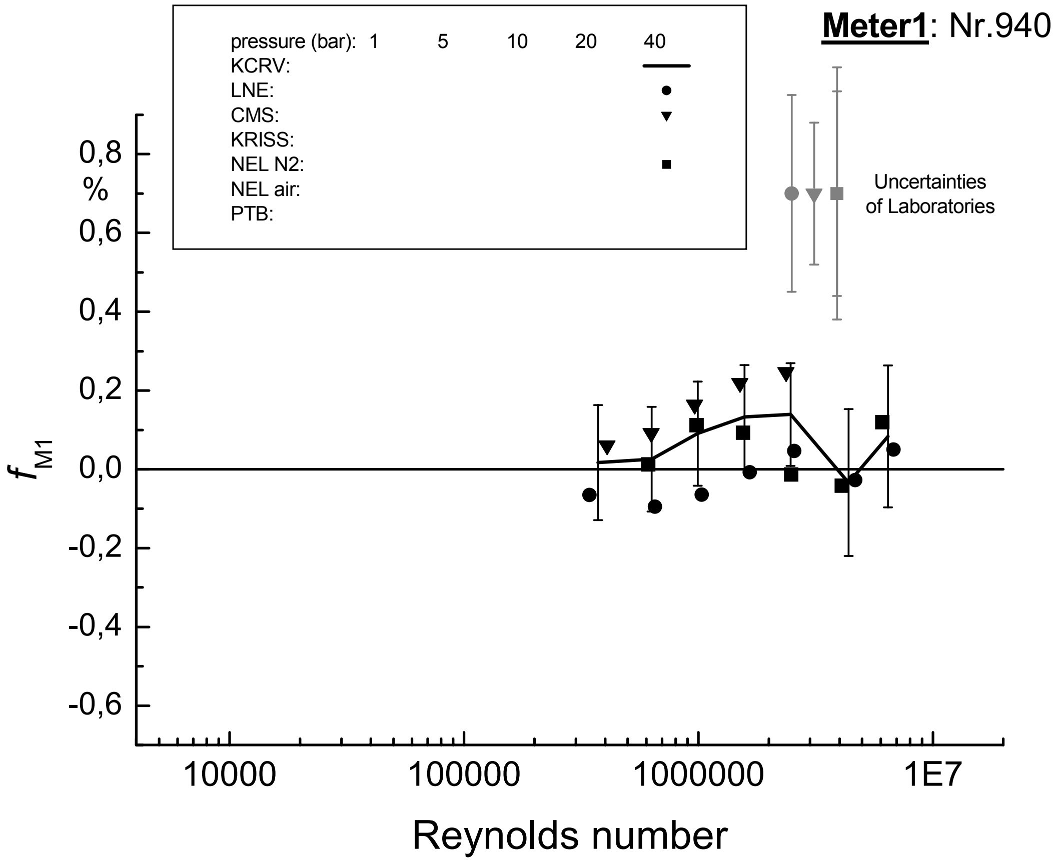

Fig. 25: Calibration results of meter 1 of the transfer package at NEL(N2), CMS and LNE-LADG (BNM) at 40 bar for air and Nitrogen (NEL). The claimed uncertainty bars for all labs are indicated in grey. The resulting KCRV at the different pressure stages and its uncertainty is presented throughout the entire overlapping flow range.

The KCRV is the weighted means of all single results.
All uncertainty bars do overlap very well for meter 1.

One recognizes a quite good overlap of all institutes with the KCRV function and among each other.

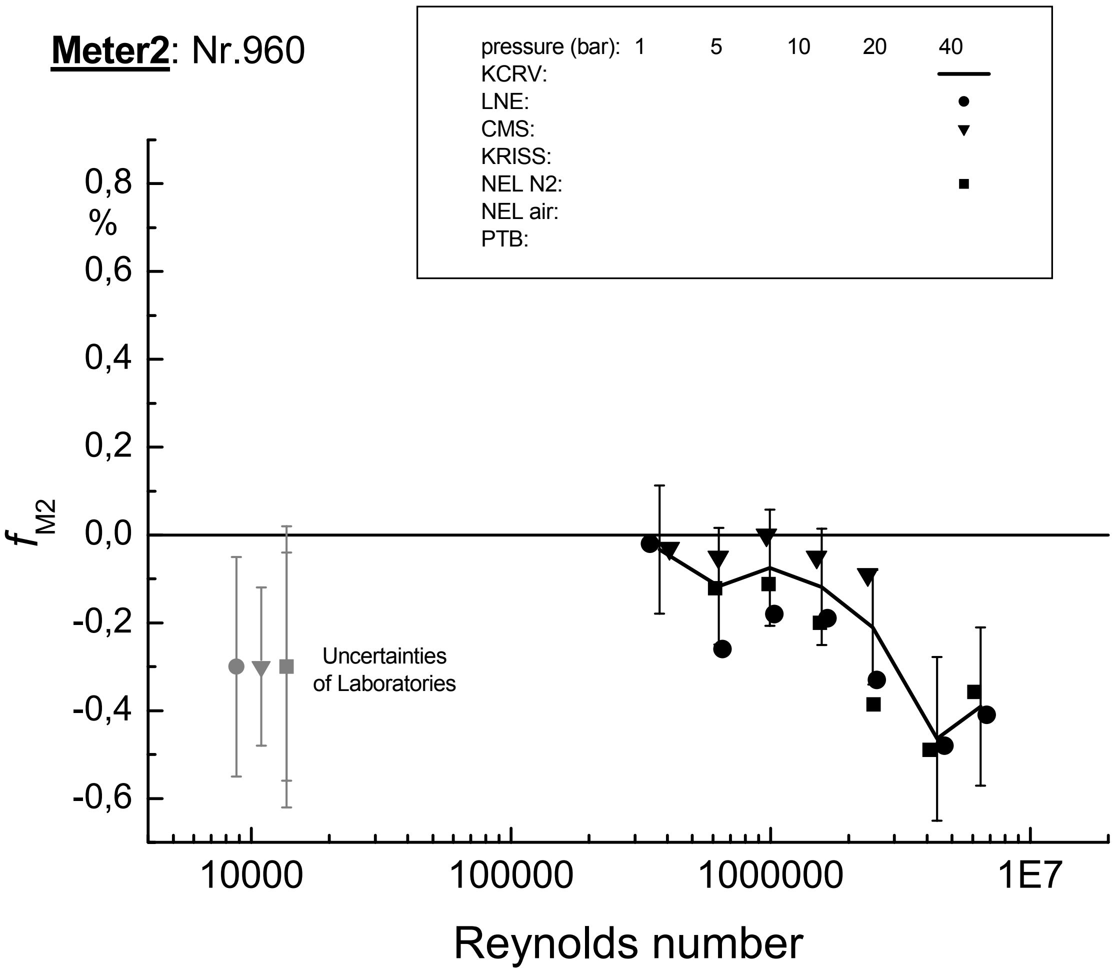

Fig. 26: Calibration results of meter 2 of the transfer package at NEL, CMS and LNE-LADG (BNM) at 40 bar for air and Nitrogen (NEL). The claimed uncertainty bars for all labs are indicated in grey. The resulting KCRV at the different pressure stages and its uncertainty is presented throughout the entire overlapping flow range.

The KCRV is the weighted means of all single results.
All uncertainty bars do overlap very well for meter 2 as for meter 1.

One recognizes a quite good overlap of all institutes with the KCRV function and among each other.

The final conclusion for the entire intercomparisons is finally an excellent agreement among each other and the KCRVs. The following chapters refer to this in more detail.

In the following chapter the degree of equivalence En between all laboratories and the KCRV will be presented, as this is the most important result of the KC.

5.4 Degree of Equivalence En of the labs with the KCRV

In order to quantify the degree of equivalence between the KVRV function and the participants as well as the degree of equivalence among the participants, we have used the relationship in equation (21) for E_n.

As we get a lot of single values of En for each measured result, it is helpful to define an overall value as characteristic criteria for each laboratory taking part in the KC. Based on the fact that the degree of equivalence is a random variable with a log-normal probability density, it is the simplest approach to use the geometric mean as the characteristic value En_{total}:

$$\mathrm{En}_{\mathrm{total}} = \left(\Pi_{i=1}^{n} \mathrm{En}_i\right)^{\frac{1}{n}} = \mathbf{exp}\left\{\frac{\mathbf{1}}{\boldsymbol{n}}\sum_{i=1}^{n} \mathbf{ln}\left(\mathrm{En}_i\right)\right\} \qquad (22)$$

Using the data obtained from Figures 15 – 26, one gets the following En-numbers, which characterize the degree of equivalence of PTB, LNE-LADG, NEL, KRISS and CMS with respect to the KCRV. In order to calculate this degree, all measured data for both turbine meters calibrated at all pressures (1 bar, 5 bar, 10 bar, 20 bars and 40 bars) have been used.

The calculation leads to the following result for the overall degree of equivalence for the participating NMIs:

LNE-LADG:	En_{total} = ***0,37***;
CMS:	En_{total} = ***0,38***;
KRISS:	En_{total} = ***0,13***;
NEL N2:	En_{total} = ***0,19***;
NEL Air:	En_{total} = ***0,67***;

The visualization of the overall En numbers is given in Fig. 27 and then we show the detailed results as a function of flow rate for the different degrees of equivalence among the partners and the KCRVs.

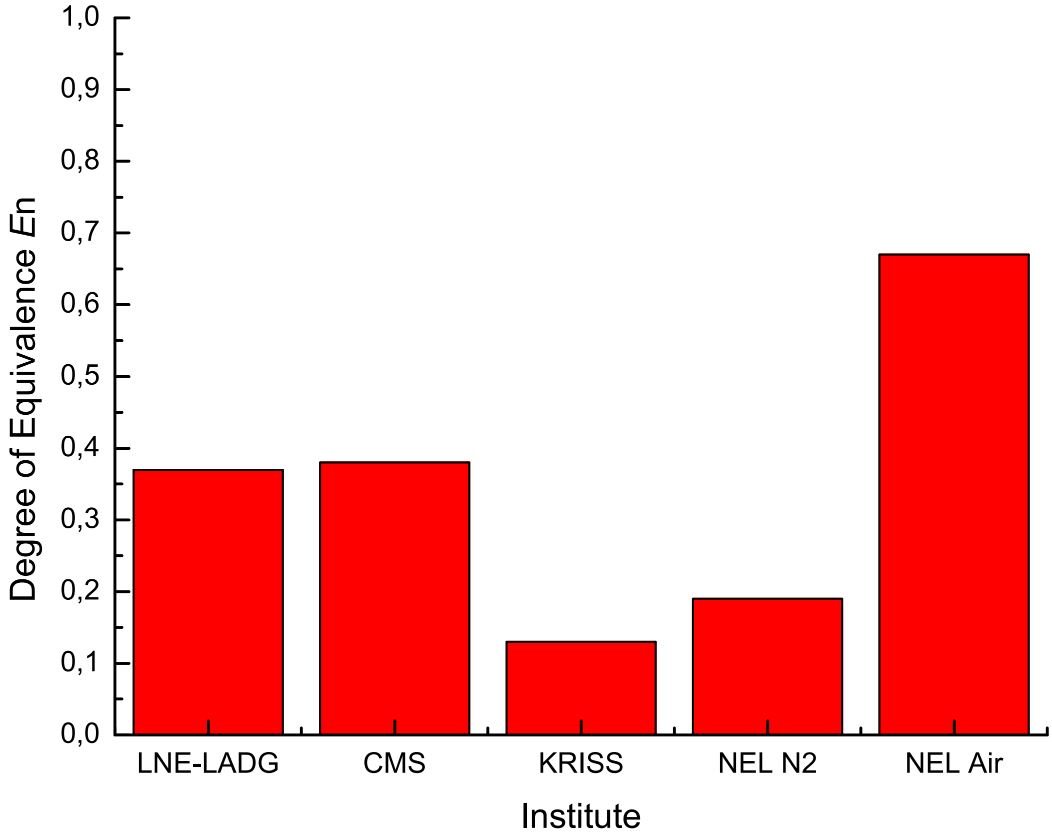

Fig. 27: Characteristic overall degree of equivalence En for all institutes PTB, LNE-LADG, CMS (invited guest of pilot lab), KRISS and NEL for compressed air at high pressure. En has been calculated based on the geometric mean (eq. 22) using all results as shown in Fig. 17 - 26

E_n should be as close as possible to "0". E_n=0 means no deviation between the KCRV and the laboratory.
En=0 means complete agreement. En=1 means, that the error bars do overlap nicely.

Obviously the Korean Metrology Institute KRISS seems to agree best with the KCRV for all measurements.

The following Figures 28 to 33 present the degrees of equivalence of PTB, LNE-LADG, NEL, KRISS and CMS referred to the KCRV as a function of flow rate and pressure. This gives a deeper insight into the functionality of the individual facilities.

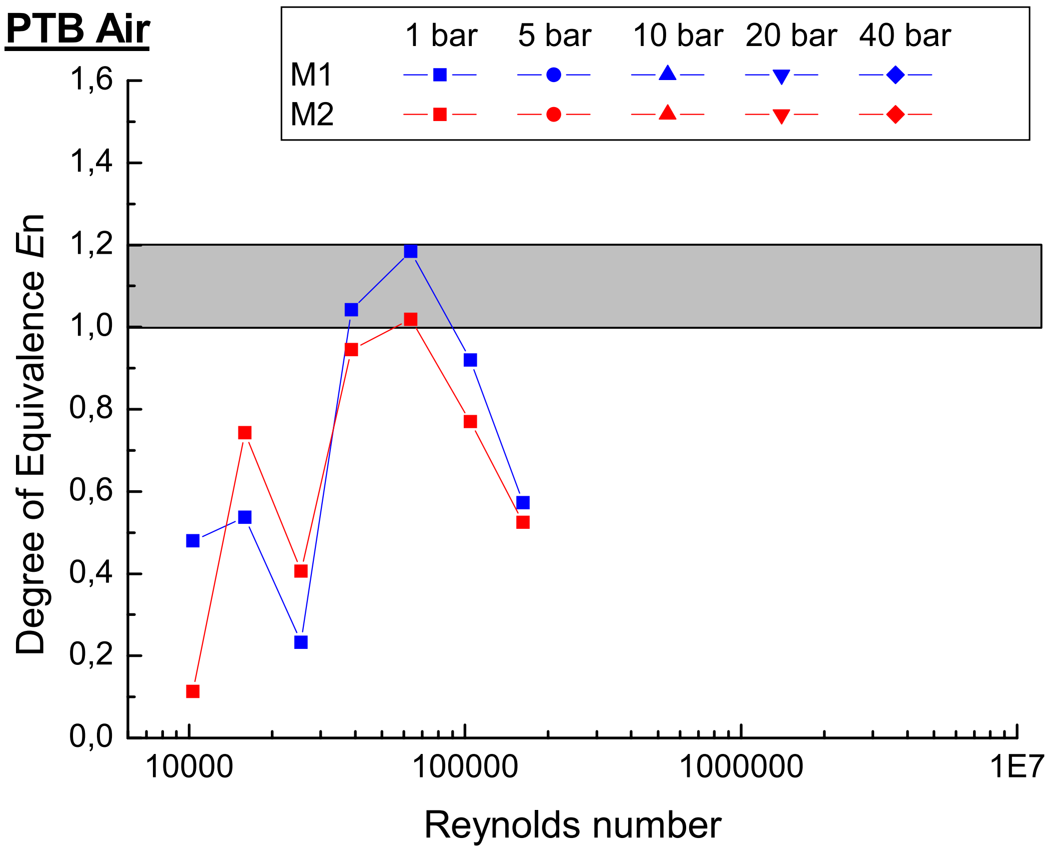

Fig. 28: Calculated degree of equivalence E_n of PTB with respect to the KCRV as determined from all calibration results for meter M1 an M2, according to Fig. 17 to Fig. 18. The results at p = 1 bar are added for information purpose only. They are not part of the KC5b ($p \geq 5$ bar) and do not influencing the KCRVs of the KC5b.

E_n should be as close as possible to “0”. E_n=0 means no deviation between the KCRV and the laboratory.
En=0 means complete agreement. En=1 means, that the error bars do overlap nicely.

The degree of equivalence of the air measurements with the KCRV for air is acceptable.
Only a very few data points exceed the desired limit of En=1.
These additional data allow a later link to ambient air results for high-press calibrations.

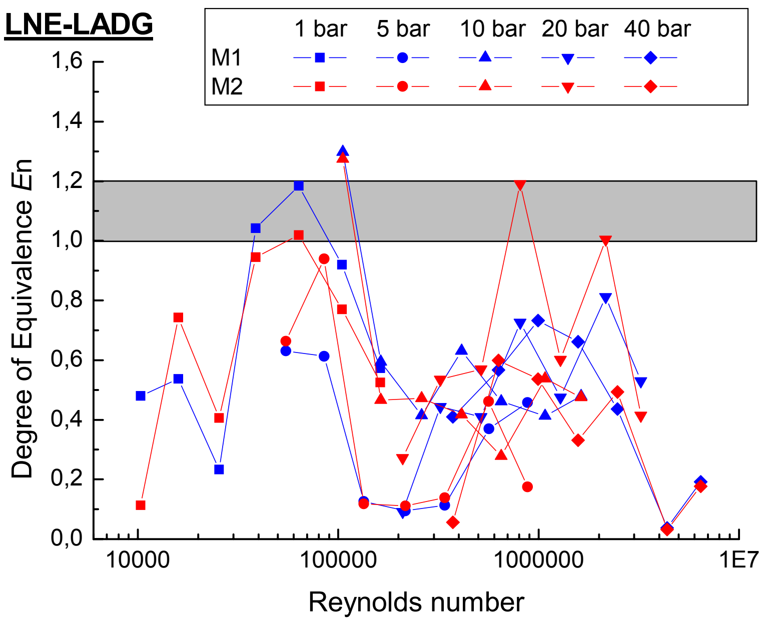

Fig. 29: Calculated degree of equivalence E_n of LNE-LADG with respect to the KCRV as determined from all calibration results for meter M1 an M2 as visualized in the previous Figs. 17 to 26. The results at *p* = 1 bar are added for information purpose only. They are not part of the KC5b ($p \geq 5$ bar) and do not influencing the KCRVs of the KC5b.

E_n should be as close as possible to "0". E_n=0 means no deviation between the KCRV and the laboratory. En=0 means complete agreement. En=1 means, that the error bars do overlap nicely.
The degree of equivalence of the air measurements with the KCRV for air is good over the entire flow and pressure range. The majority of all data are below the upper limit of En=1,0 – 1,2. These additional data at 1 bar allow a later link to ambient air results for high-press calibrations.

$En_{LNE-LADG,KCRV} = abs(d_{LNE-LADG,KCRV})/U(d_{LNE-LADG,KCRV})$									
Flow rate m³/h	*p* = 5 bar		*p* = 10 bar		*p* = 20 bar		*p* = 40 bar		En Flow
	M1	M2	M1	M2	M1	M2	M1	M2	
65	0,63	0,66	1,3	1,27	0,09	0,27	0,41	0,06	**0,38**
100	0,61	0,94	0,59	0,47	0,44	0,54	0,57	0,6	**0,58**
160	0,13	0,12	0,41	0,47	0,41	0,57	0,73	0,54	**0,36**
250	0,09	0,11	0,63	0,42	0,73	1,19	0,66	0,33	**0,39**
400	0,11	0,14	0,46	0,28	0,47	0,6	0,44	0,49	**0,32**
650	0,37	0,46	0,41	0,54	0,81	1	0,04	0,03	**0,28**
1000	0,46	0,18	0,48	0,47	0,53	0,41	0,19	0,18	**0,33**
En(*p*)	**0,26**		**0,53**		**0,50**		**0,26**		***0,37***

Fig. 30: Tabulated results of En for LNE-LADG as visualized in Fig. 29

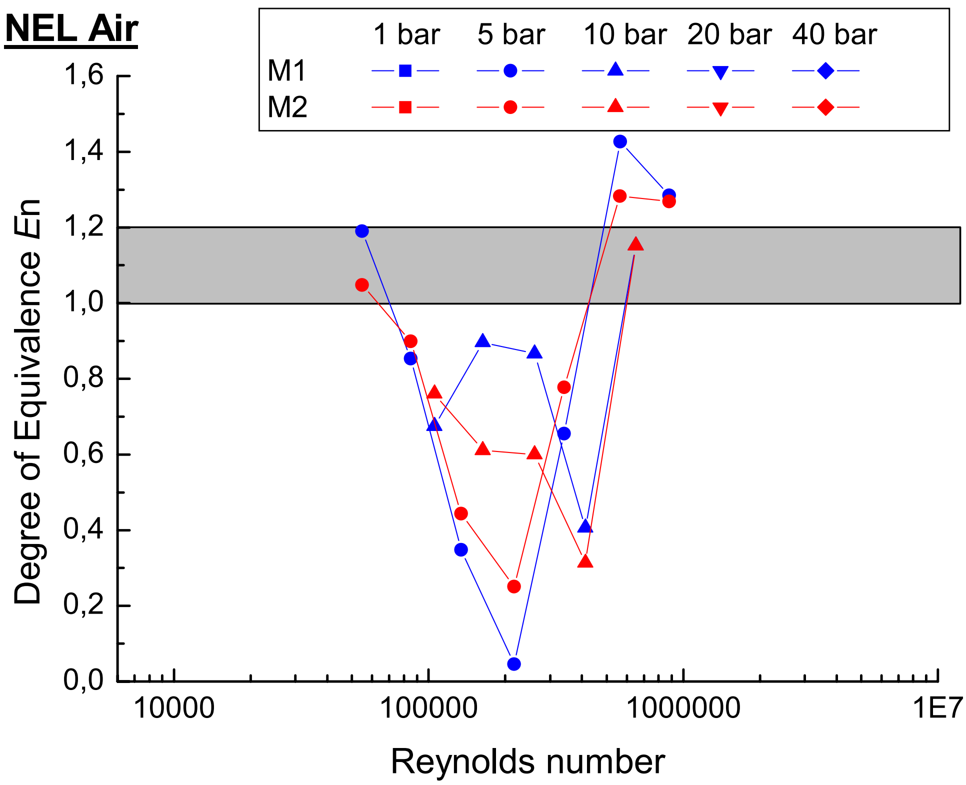

Fig. 31: Calculated degree of equivalence E_n of NEL for air with respect to the KCRV as **determined** from all calibration results for meter M1 an M2 as visualized in the previous Figs. 17 to 26.

E_n should be as close as possible to "0". E_n=0 means no deviation between the KCRV and the laboratory. En=0 means complete agreement. En=1 means, that the error bars do overlap nicely.
The degree of equivalence of the air measurements with the KCRV for air is good over the entire flow and pressure range. The majority of all data are below the upper limit range of En=1,0 – 1,2 Only 4 points are not acceptable at pressures of 5 bar and very large flow rates.

$En_{NEL\ air,KCRV} = \text{abs}(d_{NEL\ air,KCRV})/U(d_{NEL\ air,KCRV})$

Flow rate m³/h	*p* = 5 bar		*p* = 10 bar		*p* = 20 bar		*p* = 40 bar		En Flow
	M1	M2	M1	M2	M1	M2	M1	M2	
65	1,19	1,05	0,67	0,76					**0,89**
100	0,85	0,9	0,9	0,61					**0,81**
160	0,35	0,44	0,87	0,6					**0,53**
250	0,05	0,25	0,41	0,31					**0,20**
400	0,65	0,78	1,15	1,15					**0,90**
650	1,43	1,28							**1,35**
1000	1,29	1,27							**1,28**
En(*p*)	**0,66**		**0,69**						***0,67***

Fig. 32: Tabulated results of En for NEL air as visualized in Fig. 31

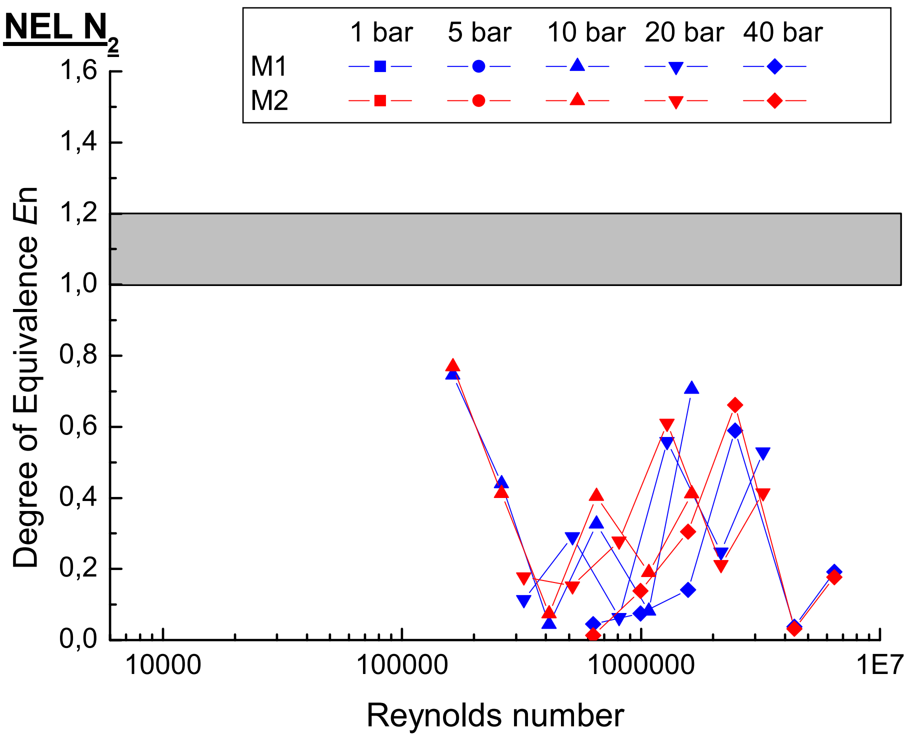

Fig. 33: Calculated degree of equivalence E_n of NEL for N2 with respect to the KCRV as **determined** from all calibration results for meter M1 an M2 as visualized in the previous Figs. 17 to 26.

E_n should be as close as possible to "0". E_n=0 means no deviation between the KCRV and the laboratory. En=0 means complete agreement. En=1 means, that the error bars do overlap nicely. The degree of equivalence of the air measurements with the KCRV for N2 is quite good over the entire flow and pressure range. The majority of all data are much below the upper limit range of En=1,0 – 1,2. NEL's data for N2 were taken in a recirculating loop, in which the temperature varies little; the data taken in air were taken in a blow-down system, in which the temperature can be as low as 0 °C especially at high flow rates.

$En_{NEL\_N2,KCRV} = abs(d_{NEL\_N2,KCRV})/U(d_{NEL\_N2,KCRV})$										
Flow rate m³/h	*p* = 5 bar		*p* = 10 bar		*p* = 20 bar		*p* = 40 bar		En Flow
	M1	M2	M1	M2	M1	M2	M1	M2	
65									**####**
100			0,75	0,77	0,11	0,18	0,04	0,01	**0,13**
160			0,44	0,41	0,29	0,15	0,07	0,14	**0,21**
250			0,04	0,07	0,06	0,28	0,14	0,3	**0,11**
400			0,33	0,4	0,56	0,61	0,59	0,66	**0,51**
650			0,08	0,19	0,25	0,21	0,04	0,03	**0,10**
1000			0,71	0,41	0,53	0,41	0,19	0,18	**0,36**
En(*p*)			**0,27**		**0,25**		**0,11**		***0,19***

Fig. 34: Tabulated results of En for NEL N2 as visualized in Fig. 33

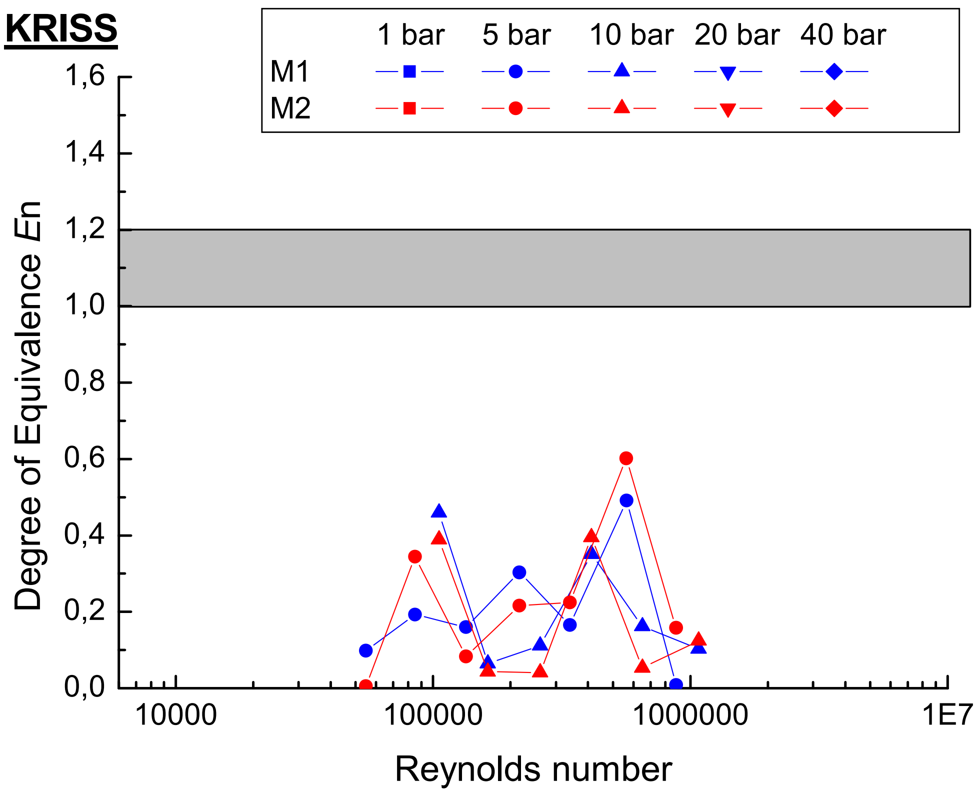

Fig. 35: Calculated degree of equivalence E_n of NEL for air with respect to the KCRV as **determined** from all calibration results for meter M1 an M2 as visualized in the previous Figs. 17 to 26.

E_n should be as close as possible to "0". E_n=0 means no deviation between the KCRV and the laboratory. En=0 means complete agreement. En=1 means, that the error bars do overlap nicely. The degree of equivalence of the air measurements with the KCRV for air is excellent over the entire flow and pressure range. The majority of all data are much below the upper limit range of En=1,0 – 1,2. Obviously, the gravimetric system at KRISS has been carefully designed.

$En_{KRISS,KCRV}$ = abs($d_{KRISS,KCRV}$)/U($d_{KRISS,KCRV}$)									
Flow rate m³/h	*p* = 5 bar		*p* = 10 bar		*p* = 20 bar		*p* = 40 bar		En Flow
	M1	M2	M1	M2	M1	M2	M1	M2	
65	0,1	0,01	0,46	0,39					**0,12**
100	0,19	0,34	0,06	0,04					**0,11**
160	0,16	0,08	0,11	0,04					**0,09**
250	0,3	0,22	0,35	0,39					**0,31**
400	0,17	0,22	0,16	0,05					**0,13**
650	0,49	0,6	0,1	0,12					**0,24**
1000	0,01	0,16							**0,04**
En(*p*)	**0,14**		**0,13**						***0,13***

Fig. 36: Tabulated results of En for KRISS air as visualized in Fig. 35

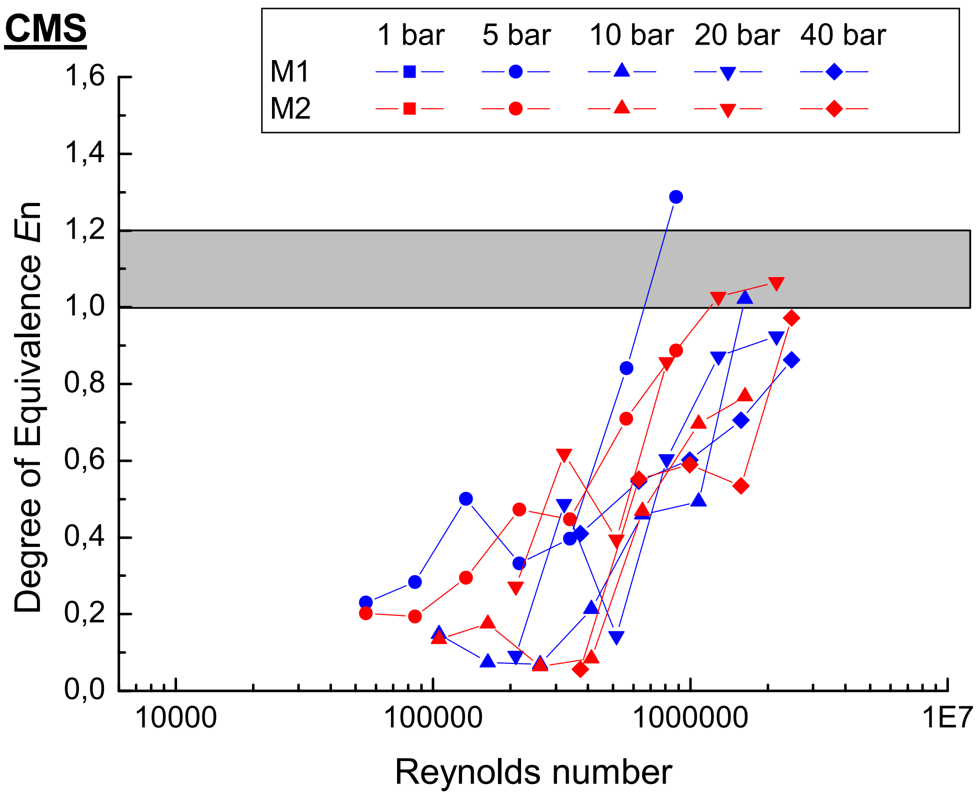

Fig. 37: Calculated degree of equivalence E_n of CMS for air with respect to the KCRV as determined from all calibration results for meter M1 an M2 as visualized in the previous Figs. 17 to 26.

E_n should be as close as possible to “0”. E_n=0 means no deviation between the KCRV and the laboratory. En=0 means complete agreement. En=1 means, that the error bars do overlap nicely. The degree of equivalence of the air measurements with the KCRV for air is excellent over the entire flow and pressure range. The majority of all data are below the upper limit range of En=1,0 – 1,2. Only a single data points has to be discussed probably.

$En_{CMS,KCRV}$ = abs($d_{CMS,KCRV}$)/U($d_{CMS,KCRV}$)									
Flow rate m³/h	*p* = 5 bar		*p* = 10 bar		*p* = 20 bar		*p* = 40 bar		En Flow
	M1	M2	M1	M2	M1	M2	M1	M2	
65	0,23	0,2	0,15	0,14	0,09	0,27	0,41	0,06	**0,17**
100	0,28	0,19	0,07	0,17	0,49	0,62	0,55	0,55	**0,30**
160	0,5	0,3	0,07	0,06	0,14	0,39	0,6	0,59	**0,24**
250	0,33	0,47	0,21	0,08	0,6	0,86	0,71	0,53	**0,39**
400	0,4	0,45	0,46	0,47	0,87	1,03	0,86	0,97	**0,64**
650	0,84	0,71	0,49	0,7	0,92	1,07			**0,77**
1000	1,29	0,89	1,02	0,77					**0,97**
En(*p*)	**0,43**		**0,23**		**0,49**		**0,49**		***0,38***

Fig. 38: Tabulated results of En for CMS air as visualized in Fig. 37

5.5 Visualization and tabulation of differences of labs-to-KCRV.

In this chapter, the tabulation of all deviations between the KCRV and the participating labs $d_{lab,\ KCRV}$ as well as associated uncertainty $U(d_{BNM,KCRV})$ and the degree of equivalence $En_{lab,KCRV}$ of the individual labs with the KCRV have to be presented.

At first we present the individual participants' differences of calibration in respect to the Key Comparison Reference Value (KVRV). The notation $d_{ref} = f_{lab} - f_{KCRV}$ has been chosen in the following figures for the quantity $d_{lab,\ KCRV}$. The results have been visualized and tabulated for all labs, but PTB. The uncertainty of the differences are indicated by error bars, for example $U(d_{LNE-LADG,KCRV})$ (k = 2) for $d_{lab,,KCRV}$ is for LNE-LADG.

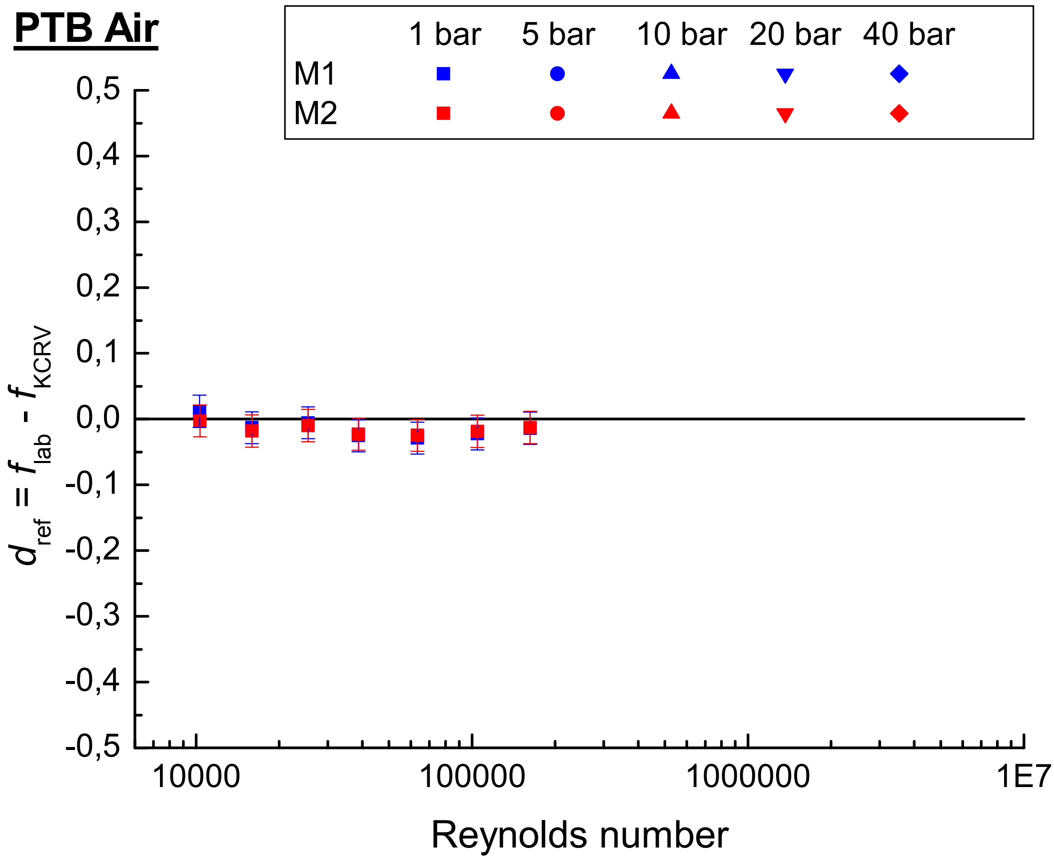

Fig. 39: Calculated differences of PTB calibration to the KCRV of the KC and the corresponding uncertainty of the difference. Data are presented for meter 1 and meter 2 and for all flow loads as well as pressure stages. The data have been extracted from Figs.: 17 to 26. The results at p = 1 bar are added for information purpose only. They are not part of the KC5b ($p \geq 5$ bar) and do not influencing the KCRVs of the KC5b.

The PTB data at 1 bar are not included into the KCRV calculation for compressed air.

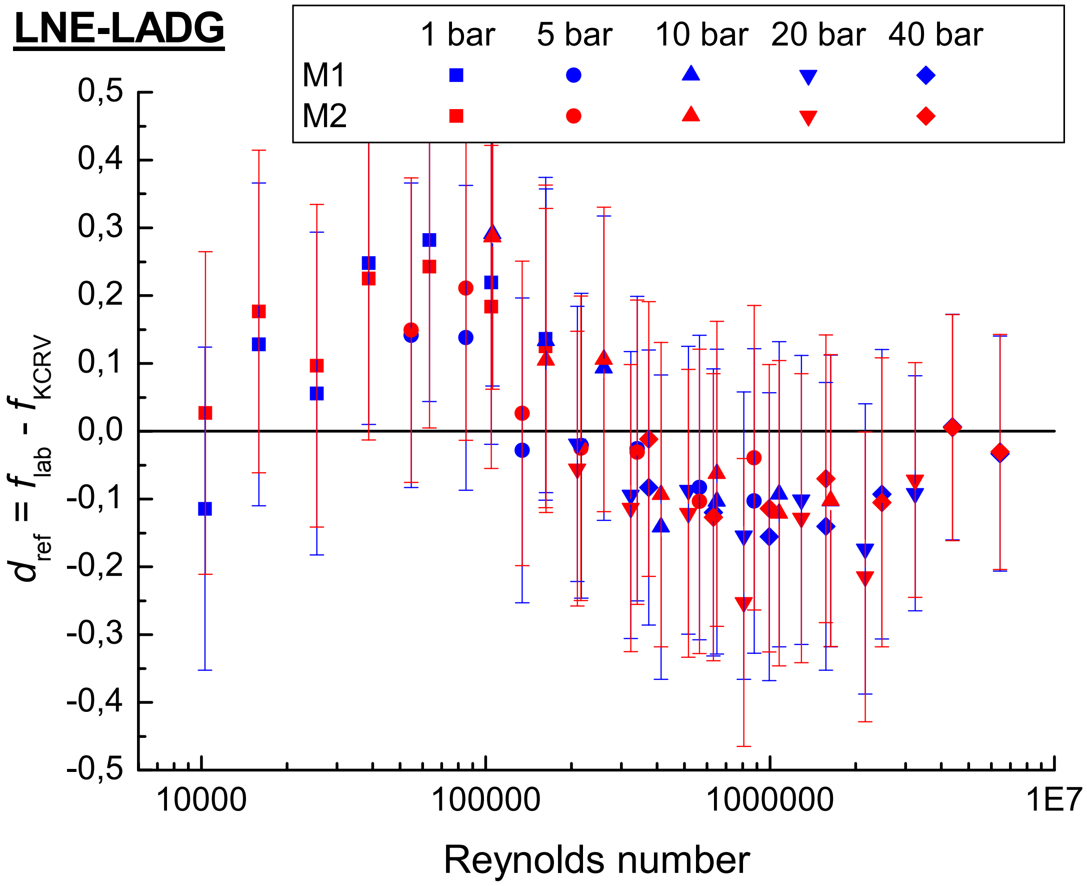

Fig. 40: Calculated differences LNE-LAGD calibration to the KCRV of the KC. Data are presented for meter 1 and meter 2 and for all flow loads as well as pressure stages. The data have been extracted from Figs.: 17 to 26. The results at p = 1 bar are added for information purpose only. They are not part of the KC5b ($p \geq 5$ bar) and do not influencing the KCRVs of the KC5b.

$d_{LNE\text{-}LADG,KCRV} = f_{LNE\text{-}LADG} - f_{KCRV}$								
Flow rate m^3/h	p = 5 bar		p = 10 bar		p = 20 bar		p = 40 bar	
	M1	M2	M1	M2	M1	M2	M1	M2
65	0,14	0,15	0,29	0,29	-0,02	-0,06	-0,08	-0,01
100	0,14	0,21	0,13	0,1	-0,09	-0,11	-0,12	-0,13
160	-0,03	0,03	0,09	0,11	-0,09	-0,12	-0,16	-0,11
250	-0,02	-0,03	-0,14	-0,09	-0,15	-0,25	-0,14	-0,07
400	-0,03	-0,03	-0,1	-0,06	-0,1	-0,13	-0,09	-0,11
650	-0,08	-0,1	-0,09	-0,12	-0,17	-0,21	0,01	0,01
1000	-0,1	-0,04	-0,1	-0,1	-0,09	-0,07	-0,03	-0,03

$U(d_{LNE\text{-}LADG,KCRV})$ (k = 2)								
Flow rate m^3/h	p = 5 bar		p = 10 bar		p = 20 bar		p = 40 bar	
	M1	M2	M1	M2	M1	M2	M1	M2
65	0,22	0,22	0,22	0,22	0,2	0,2	0,2	0,2
100	0,22	0,22	0,22	0,22	0,21	0,21	0,21	0,21
160	0,22	0,22	0,22	0,22	0,21	0,21	0,21	0,21
250	0,22	0,22	0,22	0,22	0,21	0,21	0,21	0,21
400	0,22	0,22	0,22	0,22	0,21	0,21	0,21	0,21
650	0,22	0,22	0,23	0,23	0,21	0,21	0,17	0,17
1000	0,22	0,22	0,22	0,22	0,17	0,17	0,17	0,17

Fig. 41: Tabulated differences of LNE-LADG calibration to the KCRV of the KC and the corresponding uncertainty of the difference. Data are presented for meter 1 and meter 2 and for all flow loads as well as pressure stages. The visualization of this table is presented in Fig. 40

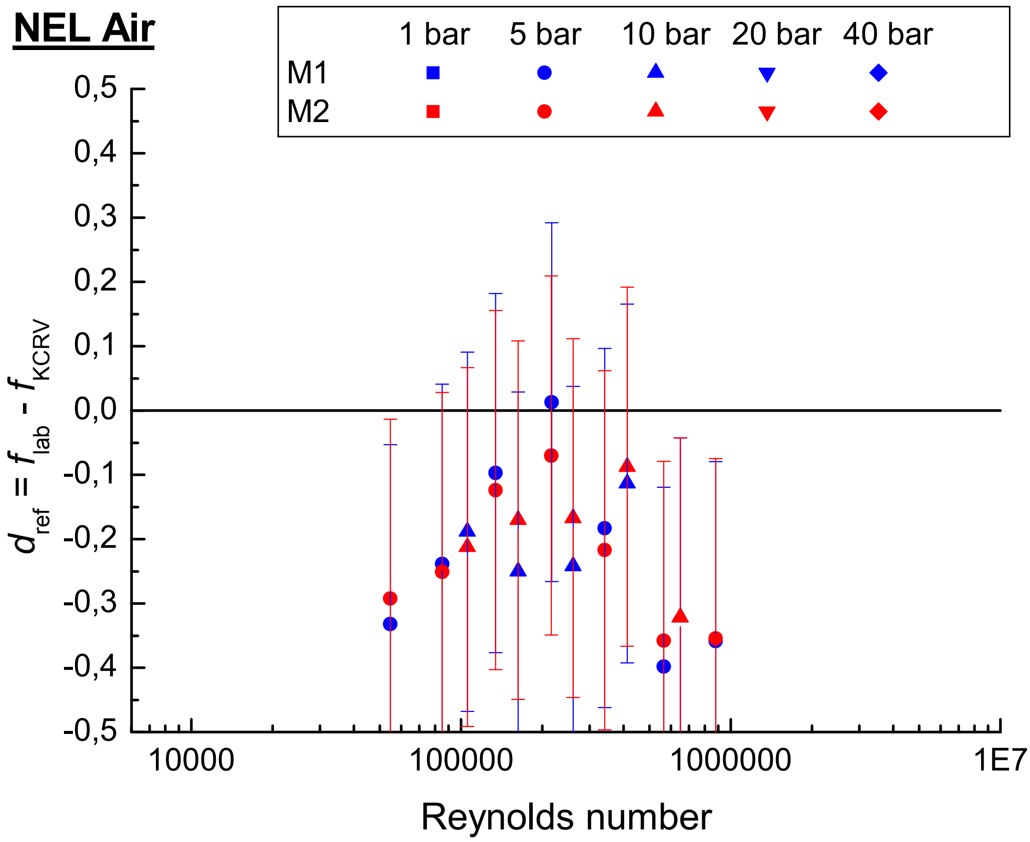

Fig. 42: Calculated differences of NEL calibration (air) to the KCRV of the KC. Data are presented for meter 1 and meter 2 and for all flow loads as well as pressure stages. The data have been extracted from Figs.: 17 to 26.

$d_{\text{NEL air,KCRV}} = f_{\text{NEL air}} - f_{\text{KCRV}}$

Flow rate m³/h	p = 5 bar		p = 10 bar		p = 20 bar		p = 40 bar	
	M1	M2	M1	M2	M1	M2	M1	M2
65	-0,33	-0,29	-0,19	-0,21				
100	-0,24	-0,25	-0,25	-0,17				
160	-0,1	-0,12	-0,24	-0,17				
250	0,01	-0,07	-0,11	-0,09				
400	-0,18	-0,22	-0,32	-0,32				
650	-0,4	-0,36						
1000	-0,36	-0,35						

$U(d_{\text{NEL air,KCRV}})$ ($k = 2$)

Flow rate m³/h	p = 5 bar		p = 10 bar		p = 20 bar		p = 40 bar	
	M1	M2	M1	M2	M1	M2	M1	M2
65	0,28	0,28	0,28	0,28				
100	0,28	0,28	0,28	0,28				
160	0,28	0,28	0,28	0,28				
250	0,28	0,28	0,28	0,28				
400	0,28	0,28	0,28	0,28				
650	0,28	0,28						
1000	0,28	0,28						

Fig. 43: Tabulated differences of NEL air calibration to the KCRV of the KC and the corresponding uncertainty of the difference. Data are presented for meter 1 and meter 2 and for all flow loads as well as pressure stages. The visualization of this table is presented in Fig. 42

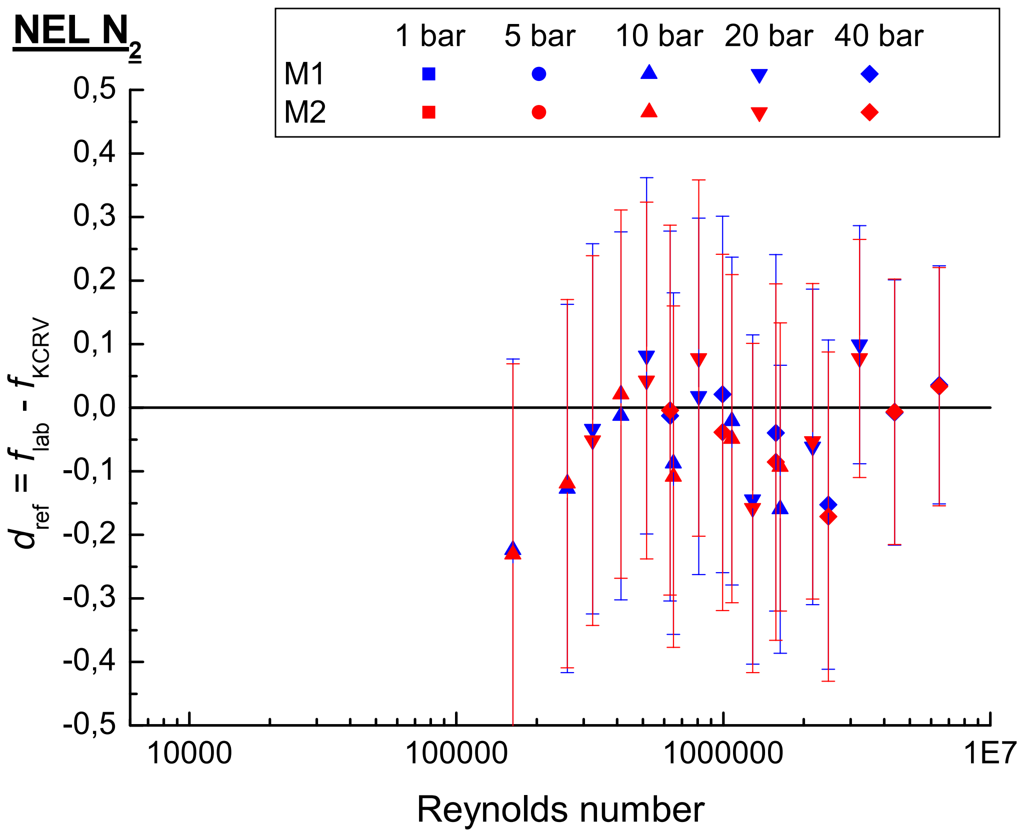

Fig. 44: Calculated differences of NEL calibration (N2) to the KCRV of the KC and the corresponding uncertainty of the difference. Data are presented for meter 1 and meter 2 and for all flow loads as well as pressure stages. The data have been extracted from Figs.: 17 to 26.

$d_{NEL\_N2,KCRV} = f_{NEL\_N2} - f_{KCRV}$									
Flow rate m³/h	*p* = 5 bar		*p* = 10 bar		*p* = 20 bar		*p* = 40 bar		
	M1	M2	M1	M2	M1	M2	M1	M2	
65									
100			-0,22	-0,23	-0,03	-0,05	-0,01	0	
160			-0,13	-0,12	0,08	0,04	0,02	-0,04	
250			-0,01	0,02	0,02	0,08	-0,04	-0,09	
400			-0,09	-0,11	-0,14	-0,16	-0,15	-0,17	
650			-0,02	-0,05	-0,06	-0,05	-0,01	-0,01	
1000			-0,16	-0,09	0,1	0,08	0,04	0,03	

$U(d_{NEL\_N2,KCRV})$ (k = 2)								
Flow rate m³/h	*p* = 5 bar		*p* = 10 bar		*p* = 20 bar		*p* = 40 bar	
	M1	M2	M1	M2	M1	M2	M1	M2
65								
100			0,3	0,3	0,29	0,29	0,29	0,29
160			0,29	0,29	0,28	0,28	0,28	0,28
250			0,29	0,29	0,28	0,28	0,28	0,28
400			0,27	0,27	0,26	0,26	0,26	0,26
650			0,26	0,26	0,25	0,25	0,21	0,21
1000			0,23	0,23	0,19	0,19	0,19	0,19

Fig. 45: Tabulated differences of NEL N2 calibration to the KCRV of the KC and the corresponding uncertainty of the difference. Data are presented for meter 1 and meter 2 and for all flow loads as well as pressure stages. The visualization of this table is presented in Fig. 44

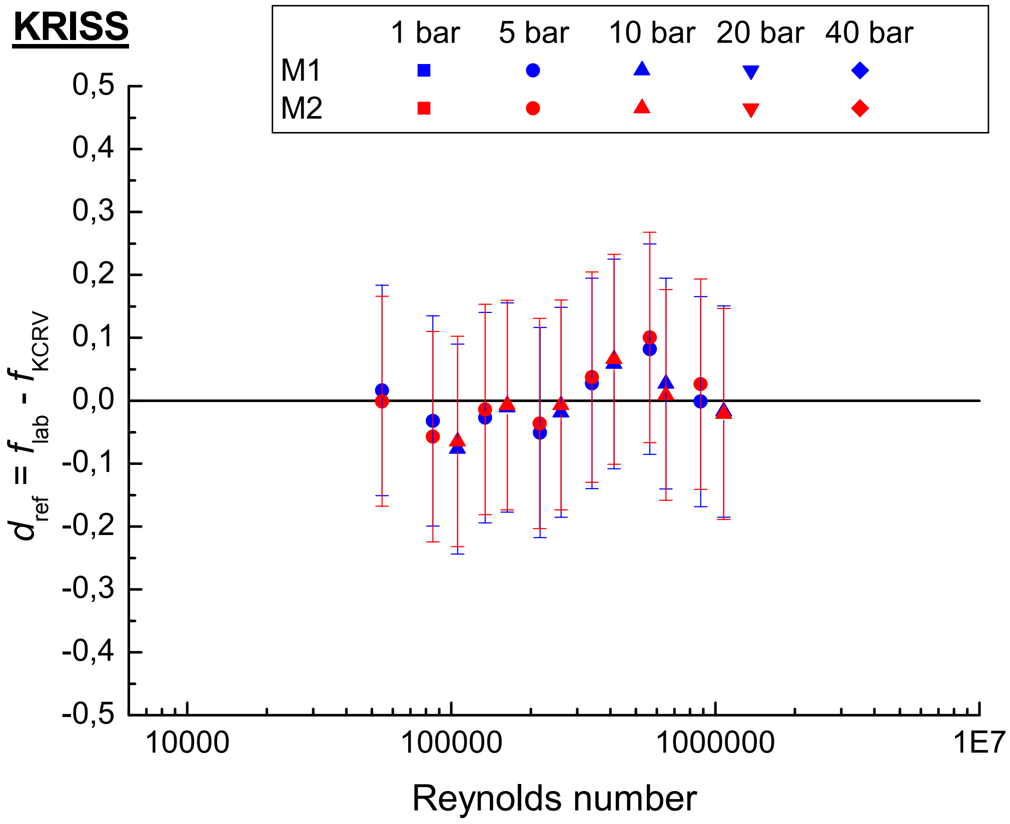

Fig. 46: Calculated differences of KRISS calibration (air) to the KCRV of the KC. Data are presented for meter 1 and meter 2 and for all flow loads as well as pressure stages. The data have been extracted from Figs.: 17 to 26.

$d_{KRISS,KCRV} = f_{KRISS} - f_{KCRV}$								
Flow rate m³/h	*p* = 5 bar		*p* = 10 bar		*p* = 20 bar		*p* = 40 bar	
	M1	M2	M1	M2	M1	M2	M1	M2
65	0,02	0	-0,08	-0,07				
100	-0,03	-0,06	-0,01	-0,01				
160	-0,03	-0,01	-0,02	-0,01				
250	-0,05	-0,04	0,06	0,07				
400	0,03	0,04	0,03	0,01				
650	0,08	0,1	-0,02	-0,02				
1000	0	0,03						

$U(d_{KRISS,KCRV})$ (k = 2)								
Flow rate m³/h	*p* = 5 bar		*p* = 10 bar		*p* = 20 bar		*p* = 40 bar	
	M1	M2	M1	M2	M1	M2	M1	M2
65	0,17	0,17	0,17	0,17				
100	0,17	0,17	0,17	0,17				
160	0,17	0,17	0,17	0,17				
250	0,17	0,17	0,17	0,17				
400	0,17	0,17	0,17	0,17				
650	0,17	0,17	0,17	0,17				
1000	0,17	0,17						

Fig. 47: Tabulated differences of KRISS air calibration to the KCRV of the KC and the corresponding uncertainty of the difference. Data are presented for meter 1 and meter 2 and for all flow loads as well as pressure stages. The visualization of this table is presented in Fig. 46

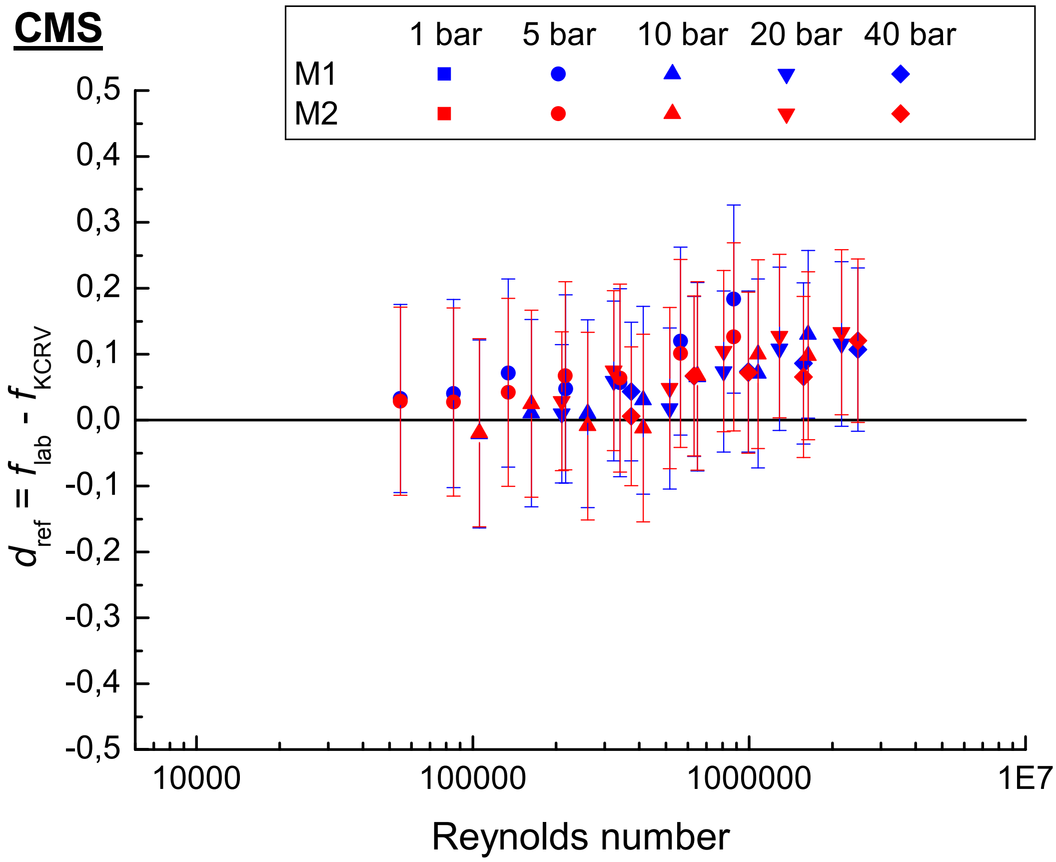

Fig. 48: Calculated differences of CMS calibration (air) to the KCRV of the KC. Data are presented for meter 1 and meter 2 and for all flow loads as well as pressure stages. The data have been extracted from Figs.: 17 to 26.

$d_{CMS,KCRV} = f_{CMS} - f_{KCRV}$								
Flow rate m^3/h	p = 5 bar		p = 10 bar		p = 20 bar		p = 40 bar	
	M1	M2	M1	M2	M1	M2	M1	M2
65	0,03	0,03	-0,02	-0,02	0,01	0,03	0,04	0,01
100	0,04	0,03	0,01	0,02	0,06	0,08	0,07	0,07
160	0,07	0,04	0,01	-0,01	0,02	0,05	0,07	0,07
250	0,05	0,07	0,03	-0,01	0,07	0,1	0,09	0,07
400	0,06	0,06	0,07	0,07	0,11	0,13	0,11	0,12
650	0,12	0,1	0,07	0,1	0,12	0,13		
1000	0,18	0,13	0,13	0,1				

$U(d_{CMS,KCRV})$ (k = 2)								
Flow rate m^3/h	p = 5 bar		p = 10 bar		p = 20 bar		p = 40 bar	
	M1	M2	M1	M2	M1	M2	M1	M2
65	0,14	0,14	0,14	0,14	0,11	0,11	0,11	0,11
100	0,14	0,14	0,14	0,14	0,12	0,12	0,12	0,12
160	0,14	0,14	0,14	0,14	0,12	0,12	0,12	0,12
250	0,14	0,14	0,14	0,14	0,12	0,12	0,12	0,12
400	0,14	0,14	0,14	0,14	0,12	0,12	0,12	0,12
650	0,14	0,14	0,14	0,14	0,13	0,13		
1000	0,14	0,14	0,13	0,13				

Fig. 49: Tabulated differences of CMS air calibration to the KCRV of the KC and the corresponding uncertainty of the difference. Data are presented for meter 1 and meter 2 and for all flow loads as well as pressure stages. The visualization of this table is presented in Fig. 48

5.6 Visualization and tabulation of lab-to-lab differences and its En

In this chapter, we present the lab-to-lab differences $d_{lab1,\ lab2} = f_{lab1} – f_{lab2}$ (in %) among all participants as well as the degree of equivalence En among all partners. The uncertainties of the measured differences among the partners have been calculated and indicated by error bars.
All results have been visualized in order to allow a fast overview.

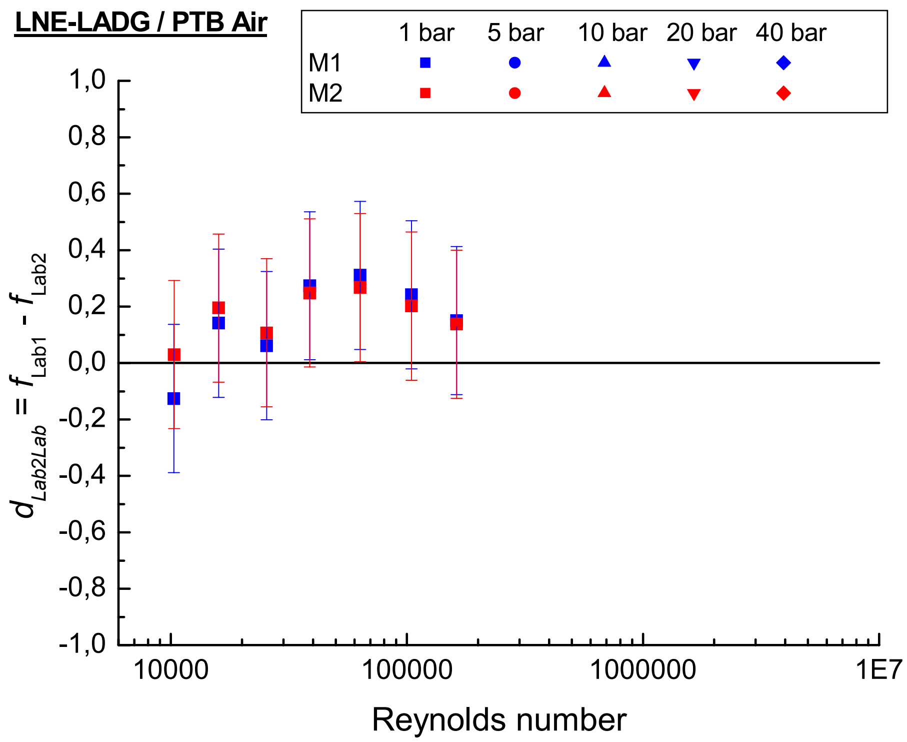

Fig. 50: Visualized differences of meter readings between LND-LADG and PTB air (in %) for both meters 1 and 2. Data are shown for all pressure stages and flow rates. Compare Figs. 15 – 26. The results at p = 1 bar are added for information purpose only. They are not part of the KC5b ($p \geq 5$ bar) and do not influencing the KCRVs of the KC5b.

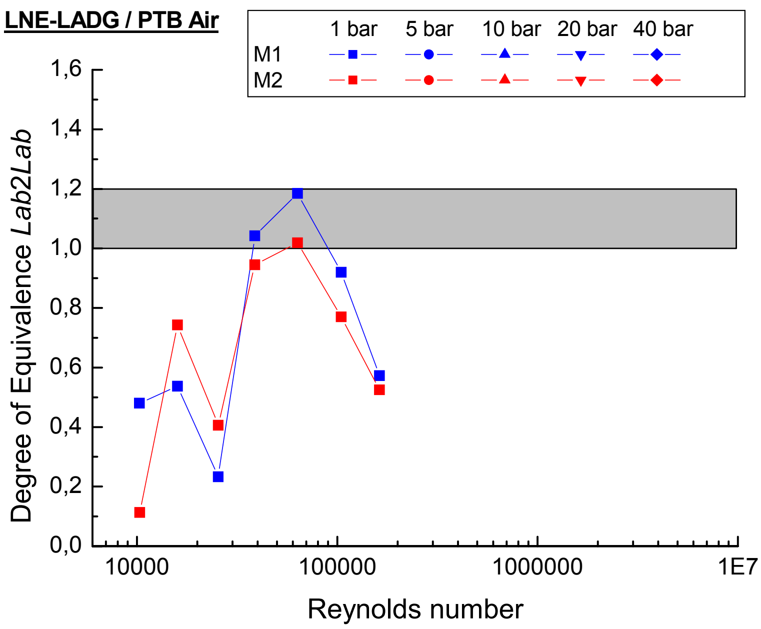

Fig. 51: Visualized degree of equivalence En of meter readings between LNE-LADG and PTB air for both meters 1 and 2. Data are shown for all pressure stages and flow rates according to Fig. 50. The results at p = 1 bar are added for information purpose only. They are not part of the KC5b ($p \geq 5$ bar) and do not influencing the KCRVs of the KC5b.

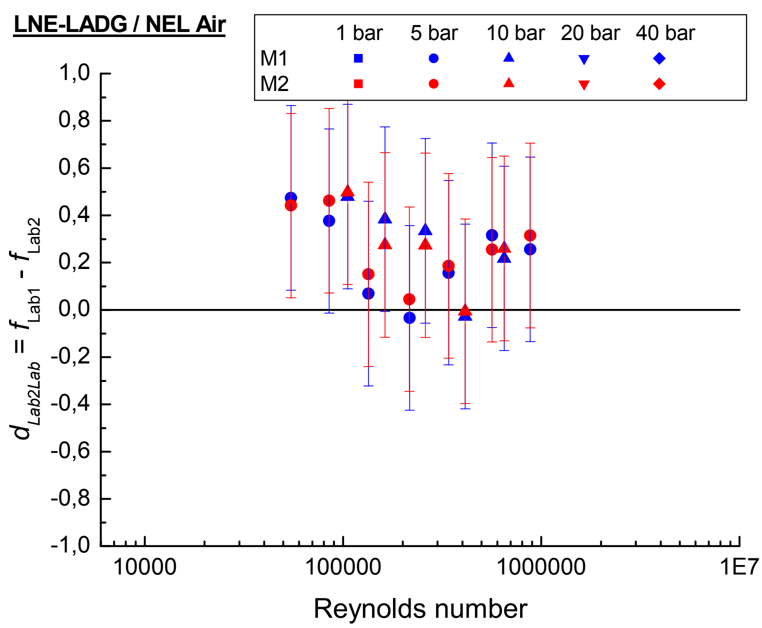

Fig. 52: Visualized differences of meter readings between LNE-LADG and NEL air (in %) for both meters 1 and 2. Data are shown for all pressure stages and flow rates. Compare Figs. 15 - 26

$d_{LNE-LADG,NELAir} = f_{LNE-LADG} - f_{NELAir}$								
Flow rate m³/h	*p* = 5 bar		*p* = 10 bar		*p* = 20 bar		*p* = 40 bar	
	M1	M2	M1	M2	M1	M2	M1	M2
65	0,47	0,44	0,48	0,5				
100	0,38	0,46	0,38	0,28				
160	0,07	0,15	0,34	0,27				
250	-0,03	0,05	-0,03	-0,01				
400	0,16	0,19	0,22	0,26				
650	0,32	0,25						
1000	0,26	0,32						

$U(d_{LNE-LADG,NELAir})$ $(k = 2)$								
Flow rate m³/h	*p* = 5 bar		*p* = 10 bar		*p* = 20 bar		*p* = 40 bar	
	M1	M2	M1	M2	M1	M2	M1	M2
65	0,39	0,39	0,39	0,39				
100	0,39	0,39	0,39	0,39				
160	0,39	0,39	0,39	0,39				
250	0,39	0,39	0,39	0,39				
400	0,39	0,39	0,39	0,39				
650	0,39	0,39						
1000	0,39	0,39						

Fig. 53: Tabulated differences of measurements between LNE-LADG and NEL for air and the associated uncertainty of this difference, compare visualized data in Fig. 52. Data are for both meters 1 and 2 at all measured pressures and flow rates.

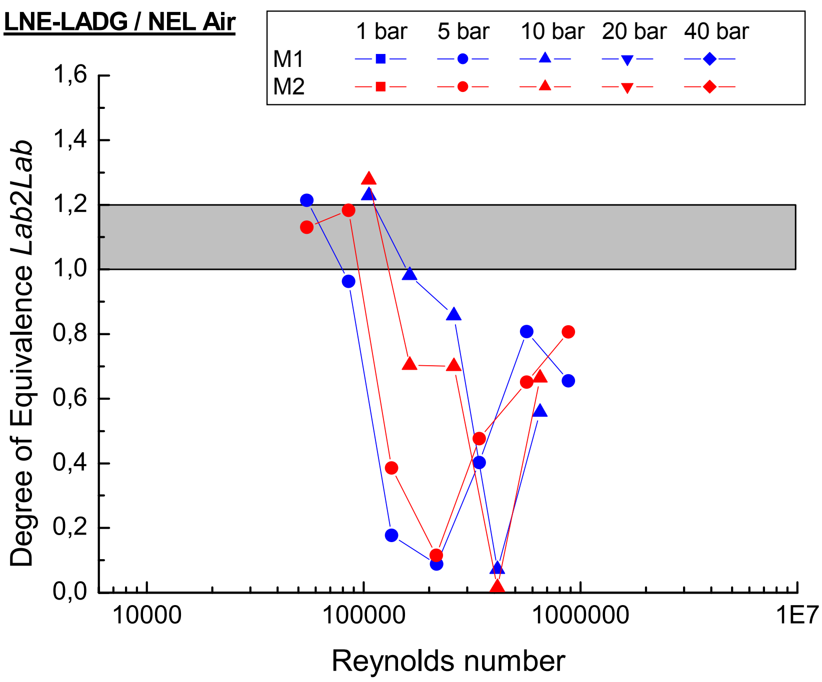

Fig. 54: Visualized degree of equivalence En of meter readings between LNE-LADG and NEL (air) for both meters 1 and 2. Data are shown for all pressure stages and flow rates according to Fig. 52.

$En_{LNE-LADG,NELAir} = abs(d_{LNE-LADG,NELAir})/U(d_{LNE-LADG,NELAir})$

Flow rate m³/h	*p* = 5 bar		*p* = 10 bar		*p* = 20 bar		*p* = 40 bar		En Flow
	M1	M2	M1	M2	M1	M2	M1	M2	
65	1,21	1,13	1,23	1,28					**1,21**
100	0,96	1,18	0,98	0,7					**0,94**
160	0,18	0,39	0,86	0,7					**0,45**
250	0,09	0,12	0,07	0,02					**0,06**
400	0,4	0,48	0,56	0,66					**0,52**
650	0,81	0,65							**0,73**
1000	0,66	0,81							**0,73**
En(*p*)	**0,50**		**0,44**						***0,47***

Fig. 55: Tabulated results for the degree of equivalence between LNE-LADG and NEL for air for both meters 1 and 2 and for all pressures and flow rates, compare the visualized data in Fig. 54.

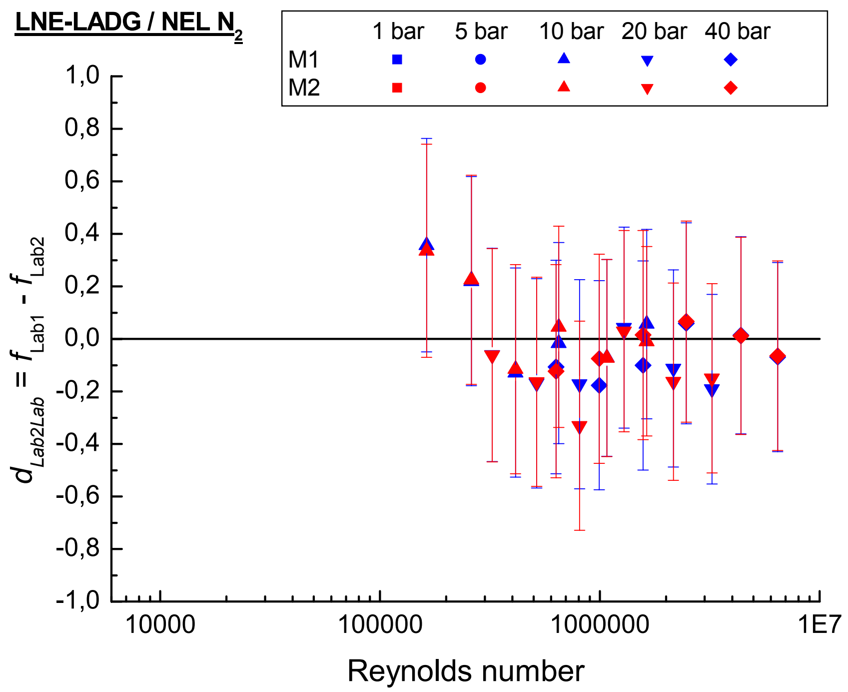

Fig. 56: Visualized differences of meter readings between LNE-LADG and NEL for (N2) (in %) for both meters 1 and 2. Data are shown for all pressure stages and flow rates. Compare Figs. 15 - 26

$d_{LNE-LADG,NELN2} = f_{LNE-LADG} - f_{NELN2}$

Flow rate m³/h	*p* = 5 bar		*p* = 10 bar		*p* = 20 bar		*p* = 40 bar	
	M1	M2	M1	M2	M1	M2	M1	M2
65								
100			0,36	0,34	-0,06	-0,06	-0,11	-0,12
160			0,22	0,23	-0,17	-0,16	-0,18	-0,08
250			-0,13	-0,12	-0,17	-0,33	-0,1	0,02
400			-0,02	0,05	0,04	0,03	0,06	0,07
650			-0,07	-0,07	-0,11	-0,16	0,01	0,01
1000			0,06	-0,01	-0,19	-0,15	-0,07	-0,06

$U(d_{LNE-LADG,NELN2})$ $(k = 2)$

Flow rate m³/h	*p* = 5 bar		*p* = 10 bar		*p* = 20 bar		*p* = 40 bar	
	M1	M2	M1	M2	M1	M2	M1	M2
65								
100			0,41	0,41	0,41	0,41	0,41	0,41
160			0,4	0,4	0,4	0,4	0,4	0,4
250			0,4	0,4	0,4	0,4	0,4	0,4
400			0,38	0,38	0,38	0,38	0,38	0,38
650			0,38	0,38	0,38	0,38	0,38	0,38
1000			0,36	0,36	0,36	0,36	0,36	0,36

Fig. 57: Tabulated differences of measurements between LNE-LADG and NEL for N2 and the associated uncertainty of this difference, compare visualized data in Fig. 56. Data are for both meters 1 and 2 at all measured pressures and flow rates.

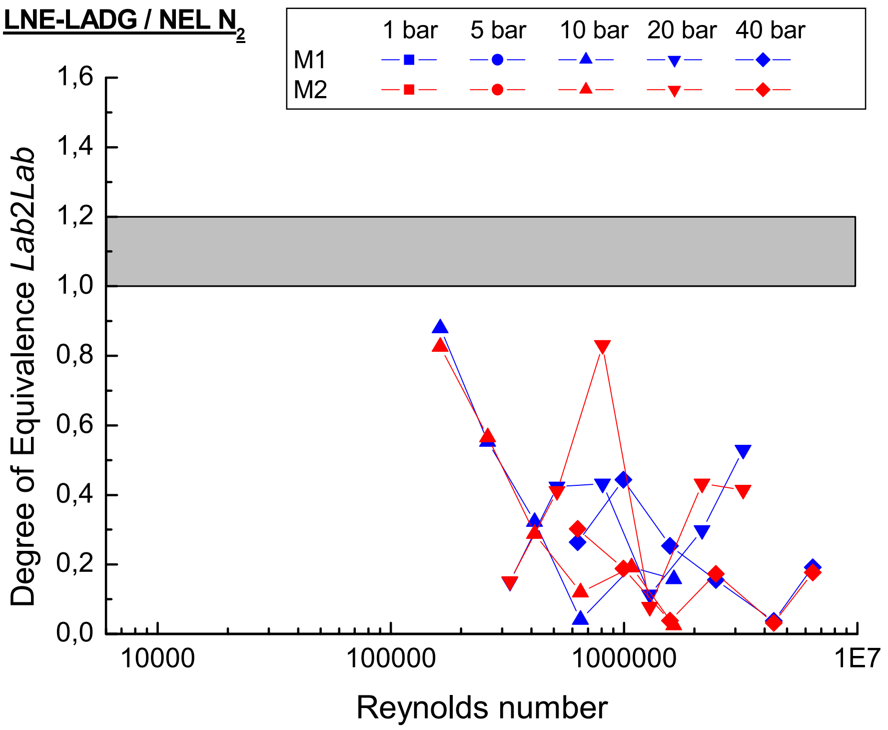

Fig. 58: Visualized degree of equivalence En of meter readings between LNE-LADG and NEL (N2) for both meters 1 and 2. Data are shown for all pressure stages and flow rates according to Fig. 56.

$En_{LNE-LADG,NELN2} = abs(d_{LNE-LADG,NELN2})/U(d_{LNE-LADG,NELN2})$										
Flow rate m^3/h	p = 5 bar		p = 10 bar		p = 20 bar		p = 40 bar		En Flow
	M1	M2	M1	M2	M1	M2	M1	M2	
65									
100			0,88	0,83	0,15	0,15	0,26	0,3	**0,33**
160			0,55	0,57	0,42	0,41	0,44	0,19	**0,41**
250			0,32	0,29	0,43	0,83	0,25	0,04	**0,26**
400			0,04	0,12	0,11	0,08	0,16	0,17	**0,10**
650			0,19	0,19	0,3	0,43	0,04	0,03	**0,13**
1000			0,16	0,03	0,53	0,42	0,19	0,18	**0,18**
En(p)			**0,22**		**0,29**		**0,14**		***0,21***

Fig. 59: Tabulated results for the degree of equivalence between LNE-LADG and NEL for N2 for both meters 1 and 2 and for all pressures and flow rates, compare the visualized data in Fig. 58.

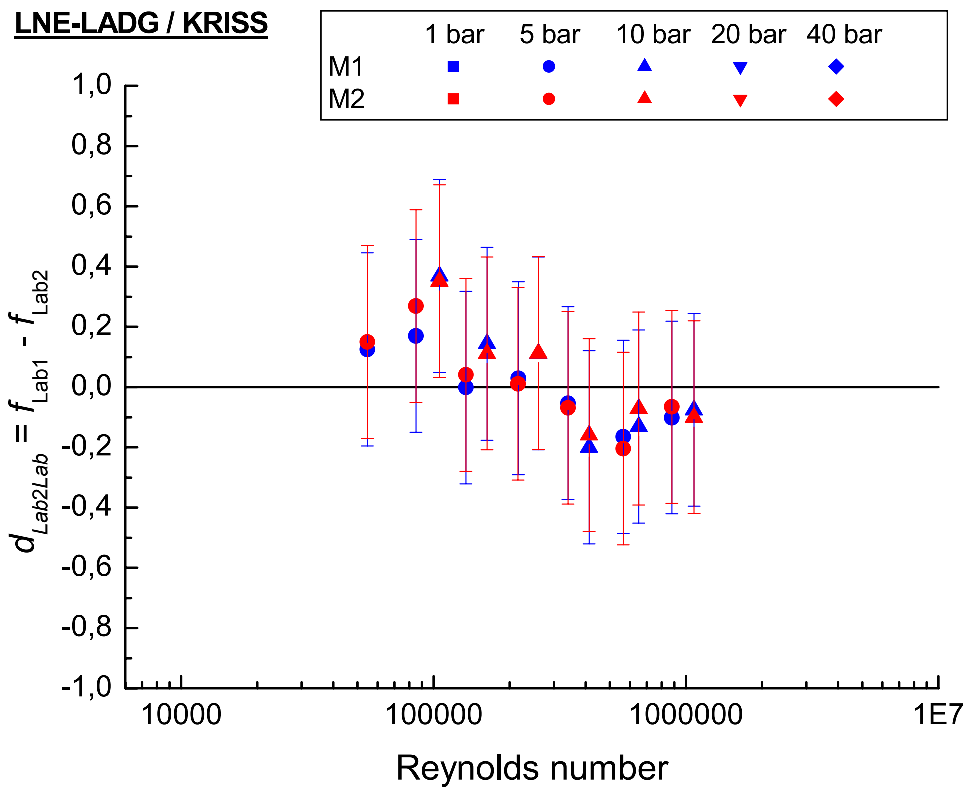

Fig. 60: Visualized differences of meter readings between LNE-LADG and KRISS air (in %) for both meters 1 and 2. Data are shown for all pressure stages and flow rates. Compare Figs. 15 - 26

$d_{LNE-LADG,KRISS} = f_{LNE-LADG} - f_{KRISS}$								
Flow rate m^3/h	p = 5 bar		p = 10 bar		p = 20 bar		p = 40 bar	
	M1	M2	M1	M2	M1	M2	M1	M2
65	0,13	0,15	0,37	0,35				
100	0,17	0,27	0,14	0,11				
160	-0	0,04	0,11	0,11				
250	0,03	0,01	-0,2	-0,16				
400	-0,05	-0,07	-0,13	-0,07				
650	-0,17	-0,2	-0,08	-0,1				
1000	-0,1	-0,07						

$U(d_{LNE-LADG,KRISS})$ (k = 2)								
Flow rate m^3/h	p = 5 bar		p = 10 bar		p = 20 bar		p = 40 bar	
	M1	M2	M1	M2	M1	M2	M1	M2
65	0,32	0,32	0,32	0,32				
100	0,32	0,32	0,32	0,32				
160	0,32	0,32	0,32	0,32				
250	0,32	0,32	0,32	0,32				
400	0,32	0,32	0,32	0,32				
650	0,32	0,32	0,32	0,32				
1000	0,32	0,32						

Fig. 61: Tabulated differences of measurements between LNE-LADG and KRISS for air and the associated uncertainty of this difference, compare visualized data in Fig. 60. Data are for both meters 1 and 2 at all measured pressures and flow rates.

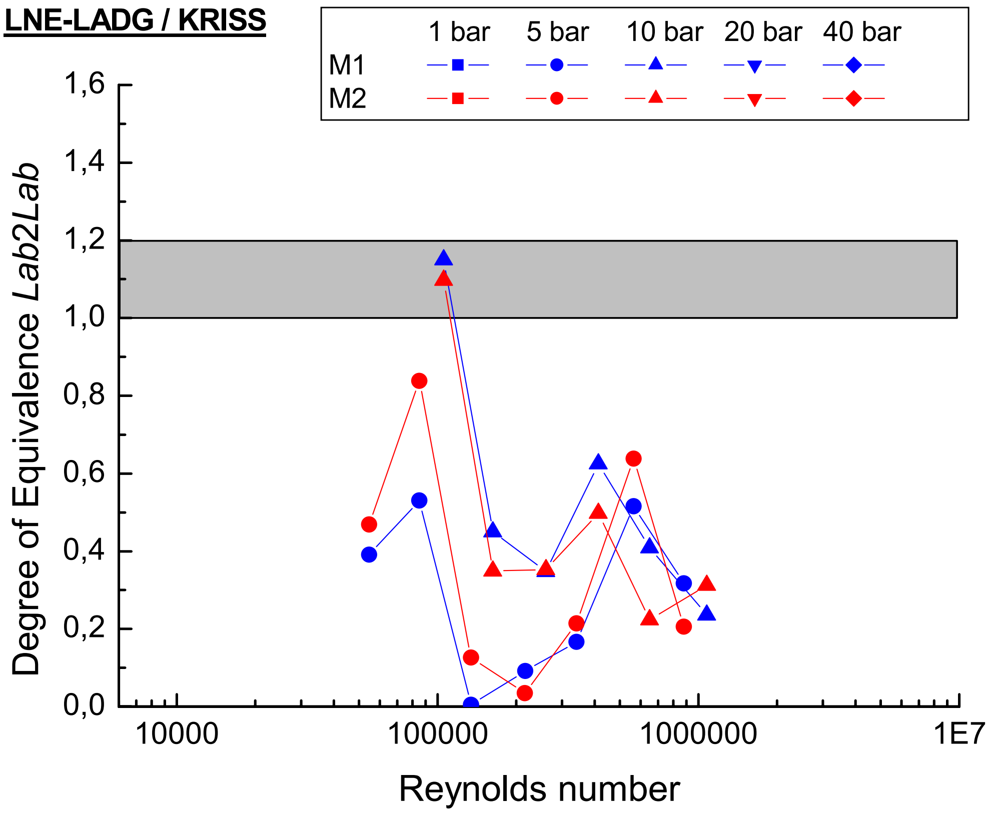

Fig. 62: Visualized degree of equivalence En of meter readings between LNE-LADG and KRISS for both meters 1 and 2. Data are shown for all pressure stages and flow rates according to Fig. 60.

$En_{LNE-LADG,KRISS} = abs(d_{LNE-LADG,KRISS})/U(d_{LNE-LADG,KRISS})$

Flow rate m³/h	*p* = 5 bar		*p* = 10 bar		*p* = 20 bar		*p* = 40 bar		En Flow
	M1	M2	M1	M2	M1	M2	M1	M2	
65	0,39	0,47	1,15	1,1					**0,69**
100	0,53	0,84	0,45	0,35					**0,51**
160	0,01	0,13	0,35	0,35					**0,09**
250	0,09	0,04	0,63	0,5					**0,18**
400	0,17	0,22	0,41	0,22					**0,24**
650	0,52	0,64	0,24	0,31					**0,39**
1000	0,32	0,21							**0,26**
En(*p*)	**0,20**		**0,44**						***0,28***

Fig. 63: Tabulated results for the degree of equivalence between LNE-LADG and NEL for air for both meters 1 and 2 and for all pressures and flow rates, compare the visualized data in Fig. 62.

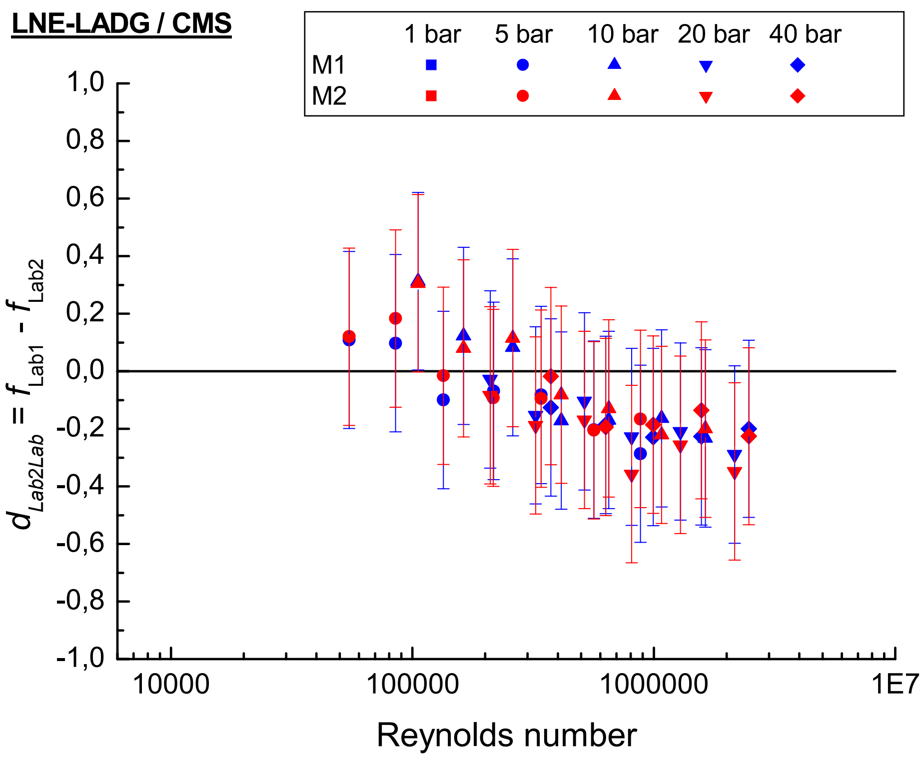

Fig. 64: Visualized differences of meter readings between LNE-LADG and CMS air (in %) for both meters 1 and 2. Data are shown for all pressure stages and flow rates. Compare Figs. 15 - 26

$d_{LNE\text{-}LADG,CMS} = f_{LNE\text{-}LADG} - f_{CMS}$								
Flow rate m³/h	*p* = 5 bar		*p* = 10 bar		*p* = 20 bar		*p* = 40 bar	
	M1	M2	M1	M2	M1	M2	M1	M2
65	0,11	0,12	0,31	0,31	-0,03	-0,08	-0,13	-0,02
100	0,1	0,18	0,12	0,08	-0,15	-0,19	-0,19	-0,19
160	-0,1	-0,02	0,08	0,12	-0,1	-0,17	-0,23	-0,19
250	-0,07	-0,09	-0,17	-0,08	-0,23	-0,36	-0,23	-0,14
400	-0,08	-0,1	-0,17	-0,13	-0,21	-0,26	-0,2	-0,23
650	-0,2	-0,21	-0,16	-0,22	-0,29	-0,35		
1000	-0,29	-0,17	-0,23	-0,2				

$U(d_{LNE\text{-}LADG,CMS})$ (k = 2)								
Flow rate m³/h	*p* = 5 bar		*p* = 10 bar		*p* = 20 bar		*p* = 40 bar	
	M1	M2	M1	M2	M1	M2	M1	M2
65	0,31	0,31	0,31	0,31	0,31	0,31	0,31	0,31
100	0,31	0,31	0,31	0,31	0,31	0,31	0,31	0,31
160	0,31	0,31	0,31	0,31	0,31	0,31	0,31	0,31
250	0,31	0,31	0,31	0,31	0,31	0,31	0,31	0,31
400	0,31	0,31	0,31	0,31	0,31	0,31	0,31	0,31
650	0,31	0,31	0,31	0,31	0,31	0,31		
1000	0,31	0,31	0,31	0,31				

Fig. 65: Tabulated differences of measurements between LNE-LADG and CMS for air and the associated uncertainty of this difference, compare visualized data in Fig. 64. Data are for both meters 1 and 2 at all measured pressures and flow rates.

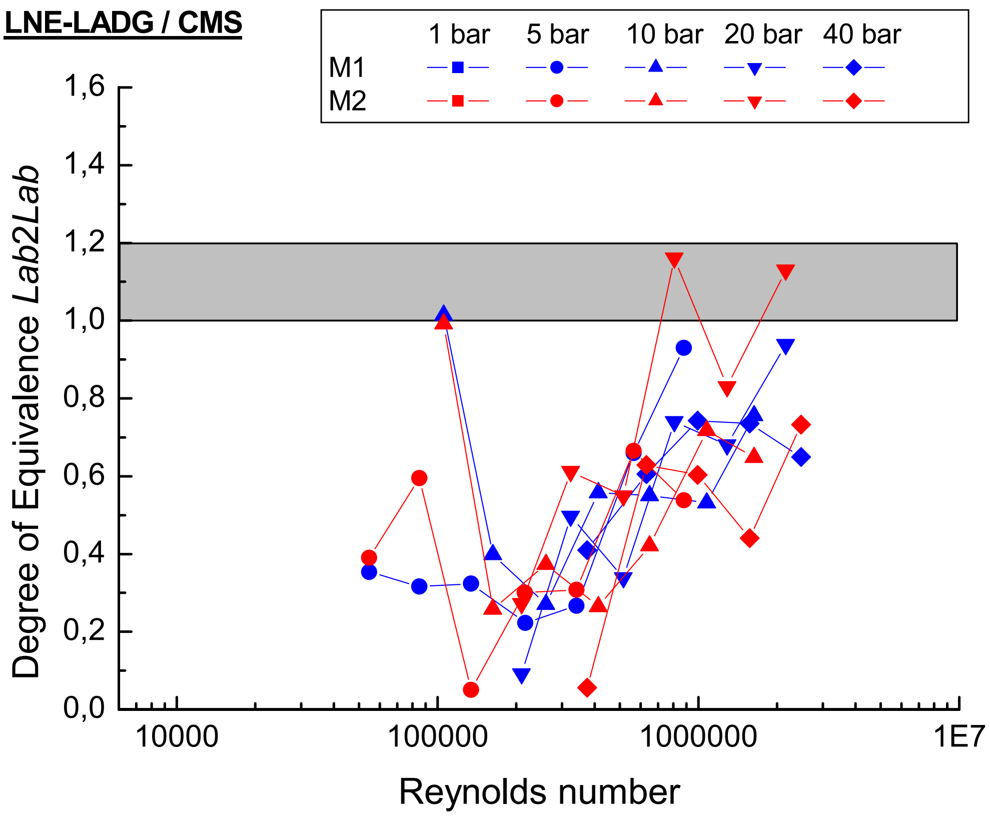

Fig. 66: Visualized degree of equivalence En of meter readings between LNE-LADG and KRISS for both meters 1 and 2. Data are shown for all pressure stages and flow rates according to Fig. 64.

$En_{LNE-LADG,CMS}$ = abs($d_{LNE-LADG,CMS}$)/U($d_{LNE-LADG,CMS}$)									
Flow rate m³/h	*p* = 5 bar		*p* = 10 bar		*p* = 20 bar		*p* = 40 bar		En Flow
	M1	M2	M1	M2	M1	M2	M1	M2	
65	0,35	0,39	1,01	0,99	0,09	0,27	0,41	0,06	**0,31**
100	0,32	0,6	0,4	0,26	0,5	0,61	0,61	0,63	**0,47**
160	0,32	0,05	0,27	0,37	0,34	0,55	0,74	0,6	**0,33**
250	0,22	0,3	0,56	0,27	0,74	1,16	0,74	0,44	**0,48**
400	0,27	0,31	0,55	0,42	0,68	0,83	0,65	0,73	**0,52**
650	0,66	0,67	0,53	0,72	0,94	1,13			**0,75**
1000	0,93	0,54	0,76	0,65					**0,70**
En(*p*)	**0,36**		**0,50**		**0,55**		**0,48**		***0,46***

Fig. 67: Tabulated results for the degree of equivalence between LNE-LADG and CMS for air for both meters 1 and 2 and for all pressures and flow rates, compare the visualized data in Fig. 66.

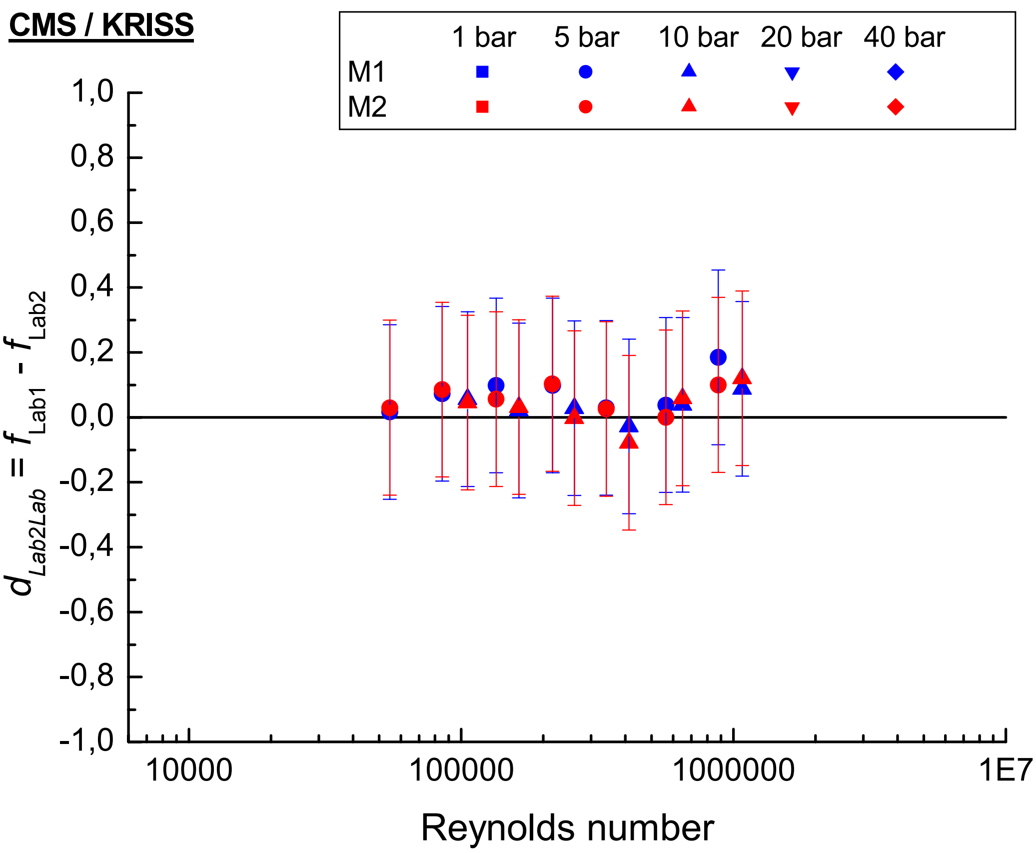

Fig. 68: Visualized differences of meter readings between CMS and KRISS (in %) for both meters 1 and 2. Data are shown for all pressure stages and flow rates. Compare Figs. 15 - 26

$d_{CMS,KRISS} = f_{CMS} - f_{KRISS}$								
Flow rate m³/h	p = 5 bar		p = 10 bar		p = 20 bar		p = 40 bar	
	M1	M2	M1	M2	M1	M2	M1	M2
65	0,02	0,03	0,06	0,05				
100	0,07	0,09	0,02	0,03				
160	0,1	0,06	0,03	-0				
250	0,1	0,1	-0,03	-0,08				
400	0,03	0,03	0,04	0,06				
650	0,04	0,00	0,09	0,12				
1000	0,19	0,1						

$U(d_{CMS,KRISS})$ (k = 2)								
Flow rate m³/h	p = 5 bar		p = 10 bar		p = 20 bar		p = 40 bar	
	M1	M2	M1	M2	M1	M2	M1	M2
65	0,27	0,27	0,27	0,27				
100	0,27	0,27	0,27	0,27				
160	0,27	0,27	0,27	0,27				
250	0,27	0,27	0,27	0,27				
400	0,27	0,27	0,27	0,27				
650	0,27	0,27	0,27	0,27				
1000	0,27	0,27						

Fig. 69: Tabulated differences of measurements between CMS and KRISS for air and the associated uncertainty of this difference, compare visualized data in Fig. 68. Data are for both meters 1 and 2 at all measured pressures and flow rates.

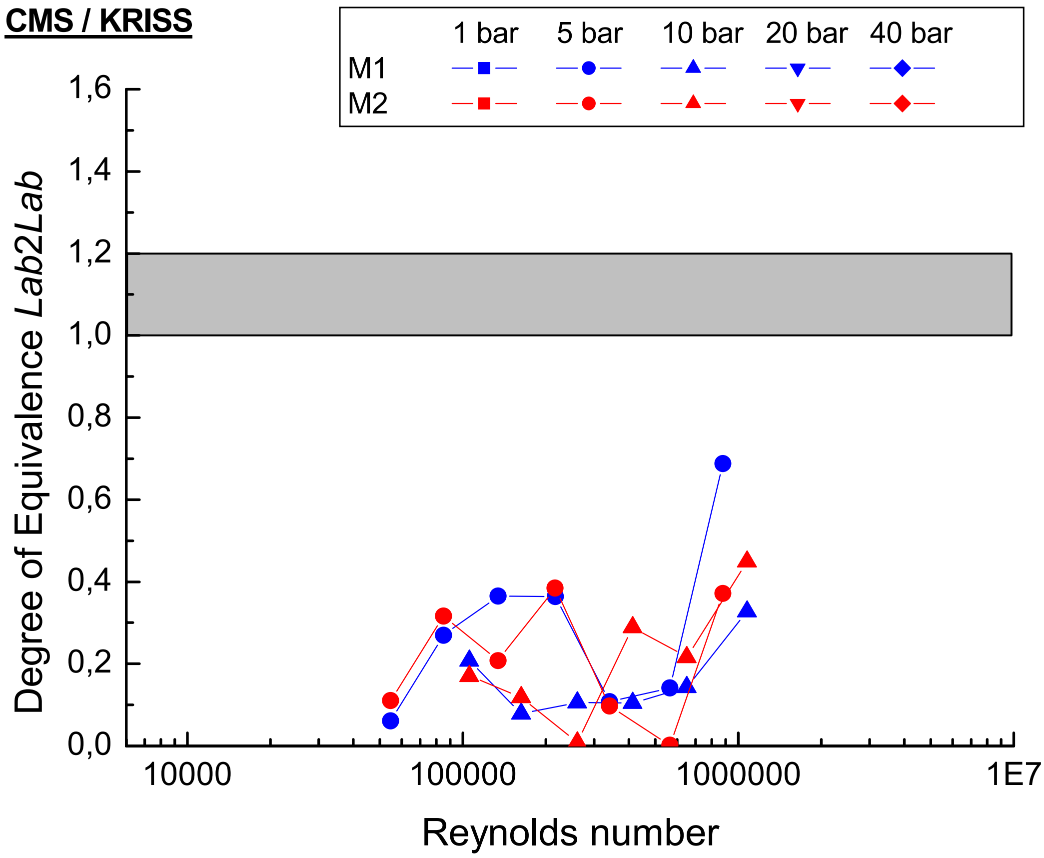

Fig. 70: Visualized degree of equivalence En of meter readings between CMS and KRISS for both meters 1 and 2. Data are shown for all pressure stages and flow rates according to Fig. 68.

$En_{CMS,KRISS} = abs(d_{CMS,KRISS})/U(d_{CMS,KRISS})$									
Flow rate m^3/h	*p* = 5 bar		*p* = 10 bar		*p* = 20 bar		*p* = 40 bar		En Flow
	M1	M2	M1	M2	M1	M2	M1	M2	
65	0,06	0,11	0,21	0,17					**0,12**
100	0,27	0,32	0,08	0,12					**0,17**
160	0,37	0,21	0,11	0,01					**0,09**
250	0,36	0,39	0,11	0,29					**0,26**
400	0,11	0,1	0,14	0,22					**0,13**
650	0,14	0	0,33	0,45					**0,08**
1000	0,69	0,37							**0,51**
En(*p*)	**0,16**		**0,14**						***0,15***

Fig. 71: Tabulated results for the degree of equivalence between CMS and KRISS for air for both meters 1 and 2 and for all pressures and flow rates, compare the visualized data in Fig. 70.

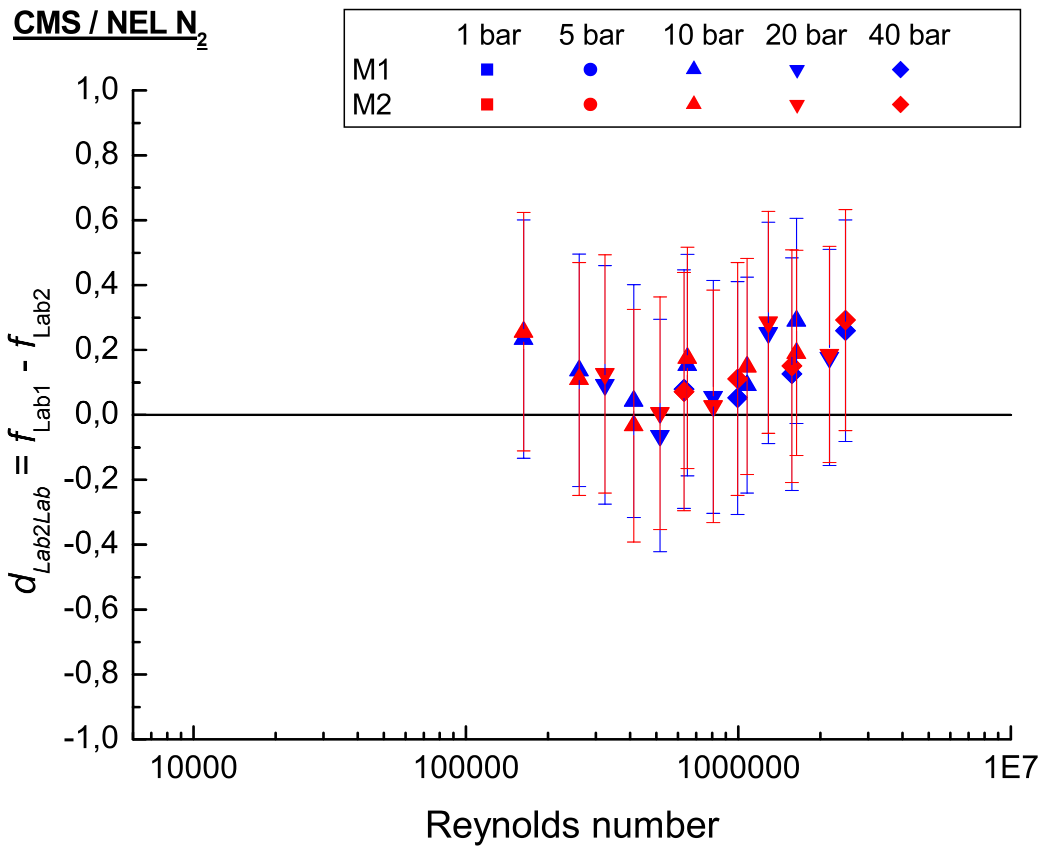

Fig. 72: Visualized differences of meter readings between CMS and NEL (N2) (in %) for both meters 1 and 2. Data are shown for all pressure stages and flow rates. Compare Figs. 15 - 26

$d_{CMS,NELN2} = f_{CMS} - f_{NELN2}$								
Flow rate m³/h	*p* = 5 bar		*p* = 10 bar		*p* = 20 bar		*p* = 40 bar	
	M1	M2	M1	M2	M1	M2	M1	M2
65								
100			0,23	0,26	0,09	0,13	0,08	0,07
160			0,14	0,11	-0,06	0,01	0,05	0,11
250			0,04	-0,03	0,06	0,03	0,13	0,15
400			0,15	0,18	0,25	0,29	0,26	0,29
650			0,09	0,15	0,18	0,19		
1000			0,29	0,19				

$U(d_{CMS,NELN2})$ (k = 2)								
Flow rate m³/h	*p* = 5 bar		*p* = 10 bar		*p* = 20 bar		*p* = 40 bar	
	M1	M2	M1	M2	M1	M2	M1	M2
65								
100			0,37	0,37	0,37	0,37	0,37	0,37
160			0,36	0,36	0,36	0,36	0,36	0,36
250			0,36	0,36	0,36	0,36	0,36	0,36
400			0,34	0,34	0,34	0,34	0,34	0,34
650			0,33	0,33	0,33	0,33		
1000			0,32	0,32				

Fig. 73: Tabulated differences of measurements between CMS and NEL for N2 and the associated uncertainty of this difference, compare visualized data in Fig. 72. Data are for both meters 1 and 2 at all measured pressures and flow rates.

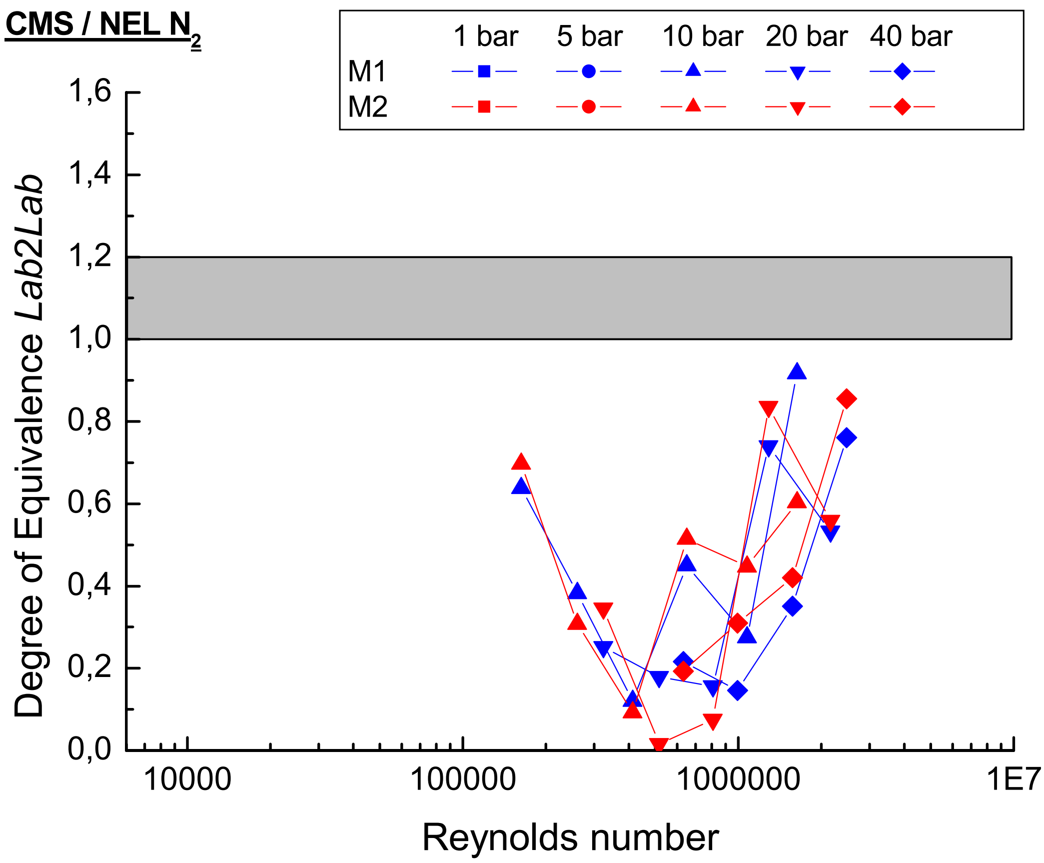

Fig. 74: Visualized degree of equivalence En of meter readings between CMS and NEL (N2) for both meters 1 and 2. Data are shown for all pressure stages and flow rates according to Fig. 72.

$En_{CMS,NELN2} = abs(d_{CMS,NELN2})/U(d_{CMS,NELN2})$

Flow rate m³/h	p = 5 bar		p = 10 bar		p = 20 bar		p = 40 bar		En Flow
	M1	M2	M1	M2	M1	M2	M1	M2	
65									
100			0,64	0,7	0,25	0,35	0,22	0,19	**0,34**
160			0,38	0,31	0,18	0,02	0,15	0,31	**0,16**
250			0,12	0,09	0,16	0,07	0,35	0,42	**0,16**
400			0,45	0,51	0,74	0,84	0,76	0,86	**0,67**
650			0,28	0,45	0,53	0,56			**0,44**
1000			0,92	0,6					**0,74**

Fig. 75: Tabulated results for the degree of equivalence between CMS and NEL for N2 for both meters 1 and 2 and for all pressures and flow rates, compare the visualized data in Fig. 74.

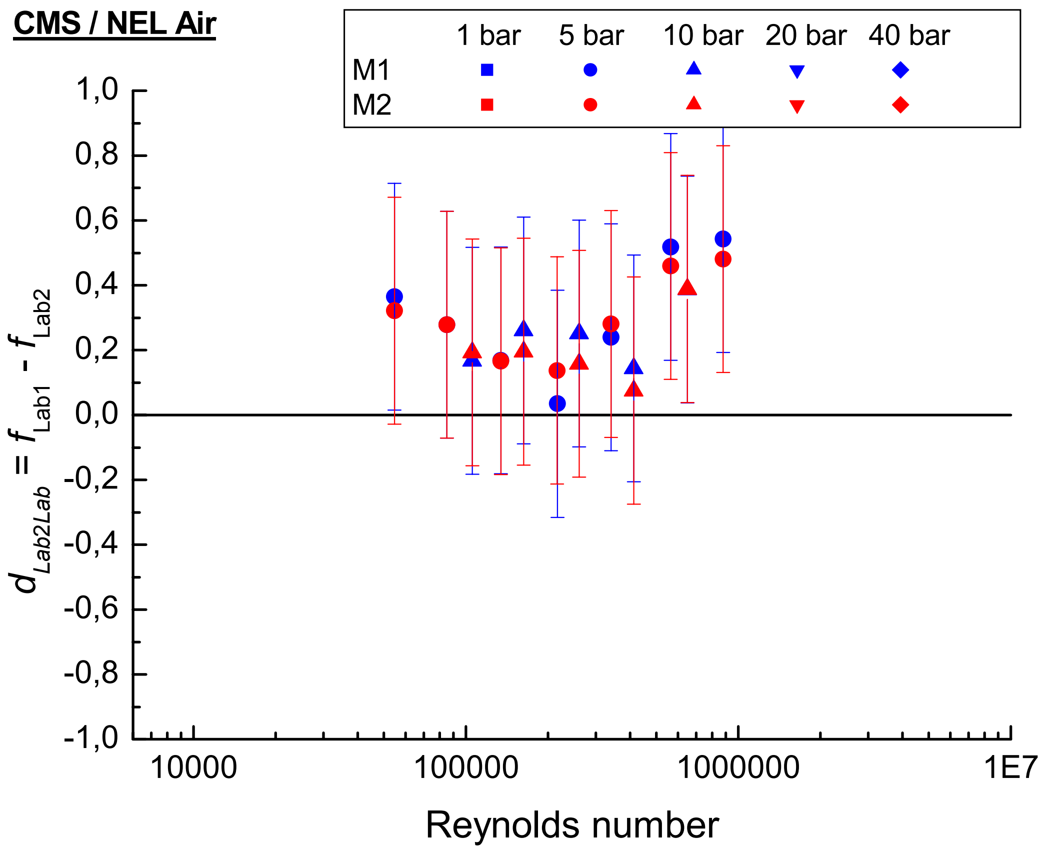

Fig. 76: Visualized differences of meter readings between CMS and NEL (air) (in %) for both meters 1 and 2. Data are shown for all pressure stages and flow rates. Compare Figs. 15 - 26

$d_{CMS,NELAir} = f_{CMS} - f_{NELAir}$								
Flow rate m³/h	p = 5 bar		p = 10 bar		p = 20 bar		p = 40 bar	
	M1	M2	M1	M2	M1	M2	M1	M2
65	0,37	0,32	0,17	0,19				
100	0,28	0,28	0,26	0,2				
160	0,17	0,17	0,25	0,16				
250	0,04	0,14	0,14	0,08				
400	0,24	0,28	0,39	0,39				
650	0,52	0,46						
1000	0,54	0,48						

$U(d_{CMS,NELAir})$ (k = 2)								
Flow rate m³/h	p = 5 bar		p = 10 bar		p = 20 bar		p = 40 bar	
	M1	M2	M1	M2	M1	M2	M1	M2
65	0,35	0,35	0,35	0,35				
100	0,35	0,35	0,35	0,35				
160	0,35	0,35	0,35	0,35				
250	0,35	0,35	0,35	0,35				
400	0,35	0,35	0,35	0,35				
650	0,35	0,35						
1000	0,35	0,35						

Fig. 77: Tabulated differences of measurements between CMS and NEL for air and the associated uncertainty of this difference, compare visualized data in Fig. 76. Data are for both meters 1 and 2 at all measured pressures and flow rates.

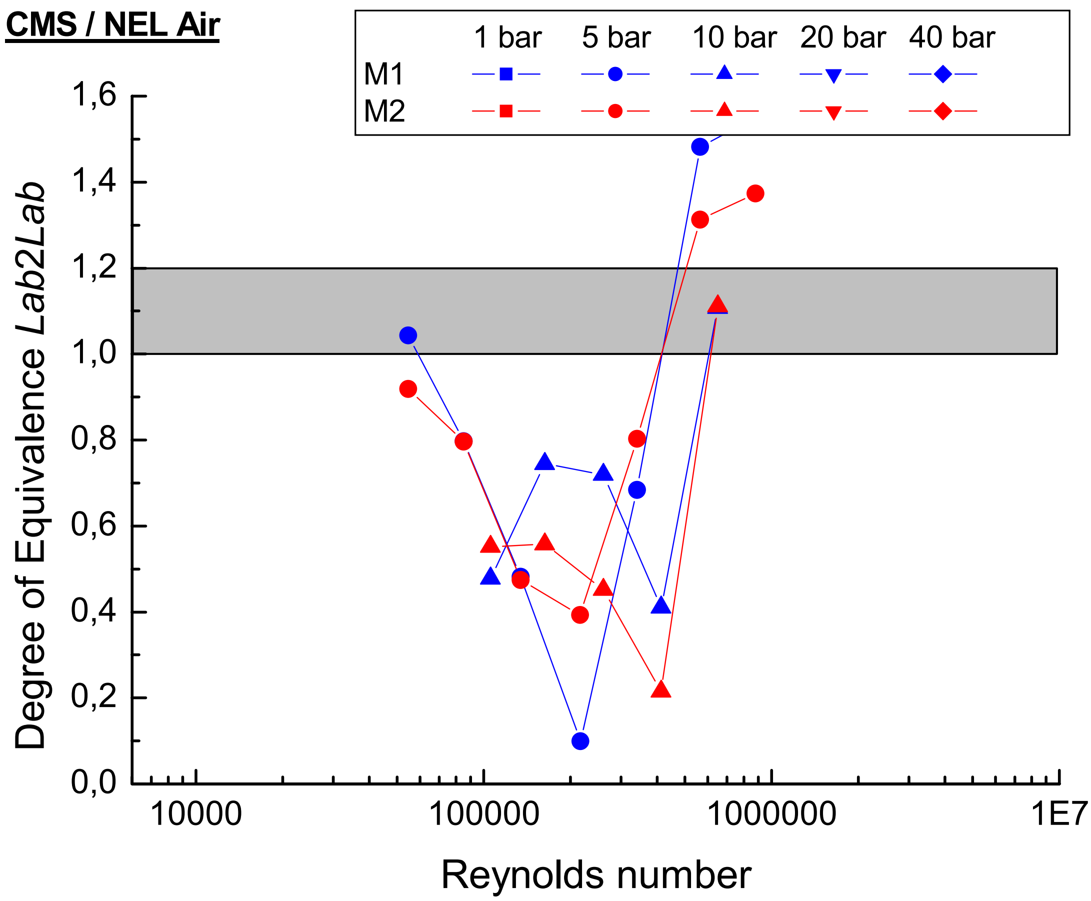

Fig. 78: Visualized degree of equivalence En of meter readings between CMS and NEL (air) for both meters 1 and 2. Data are shown for all pressure stages and flow rates according to Fig. 76.

$En_{CMS,NELAir} = abs(d_{CMS,NELAir})/U(d_{CMS,NELAir})$									
Flow rate m³/h	*p* = 5 bar		*p* = 10 bar		*p* = 20 bar		*p* = 40 bar		En Flow
	M1	M2	M1	M2	M1	M2	M1	M2	
65	1,04	0,92	0,48	0,55					**0,71**
100	0,8	0,8	0,75	0,56					**0,72**
160	0,48	0,47	0,72	0,45					**0,52**
250	0,1	0,39	0,41	0,22					**0,24**
400	0,68	0,8	1,11	1,11					**0,91**
650	1,48	1,31							**1,39**
1000	1,55	1,37							**1,46**

Fig. 79: Tabulated results for the degree of equivalence between CMS and NEL for air for both meters 1 and 2 and for all pressures and flow rates, compare the visualized data in Fig. 78.

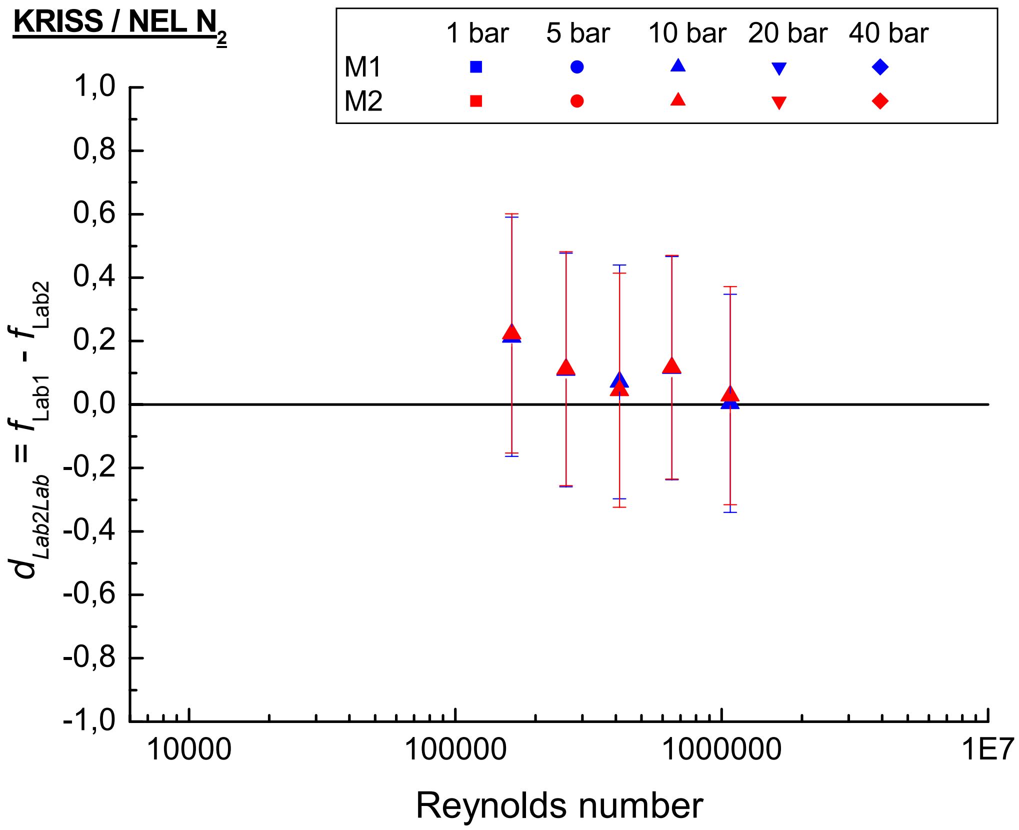

Fig. 80: Visualized differences of meter readings between KRISS and NEL (N2) (in %) for both meters 1 and 2. Data are shown for all pressure stages and flow rates. Compare Figs. 15 - 26

$d_{KRISS,NELN2} = f_{KRISS} - f_{NELN2}$

Flow rate m^3/h	p = 5 bar M1	p = 5 bar M2	p = 10 bar M1	p = 10 bar M2	p = 20 bar M1	p = 20 bar M2	p = 40 bar M1	p = 40 bar M2
65								
100			0,21	0,22				
160			0,11	0,11				
250			0,07	0,05				
400			0,12	0,12				
650			0	0,03				
1000								

$U(d_{KRISS,NELN2})$ (k = 2)

Flow rate m^3/h	p = 5 bar M1	p = 5 bar M2	p = 10 bar M1	p = 10 bar M2	p = 20 bar M1	p = 20 bar M2	p = 40 bar M1	p = 40 bar M2
65								
100			0,38	0,38				
160			0,37	0,37				
250			0,37	0,37				
400			0,35	0,35				
650			0,34	0,34				
1000								

Fig. 81: Tabulated differences of measurements between KRISS and NEL for N2 and the associated uncertainty of this difference, compare visualized data in Fig. 80. Data are for both meters 1 and 2 at all measured pressures and flow rates.

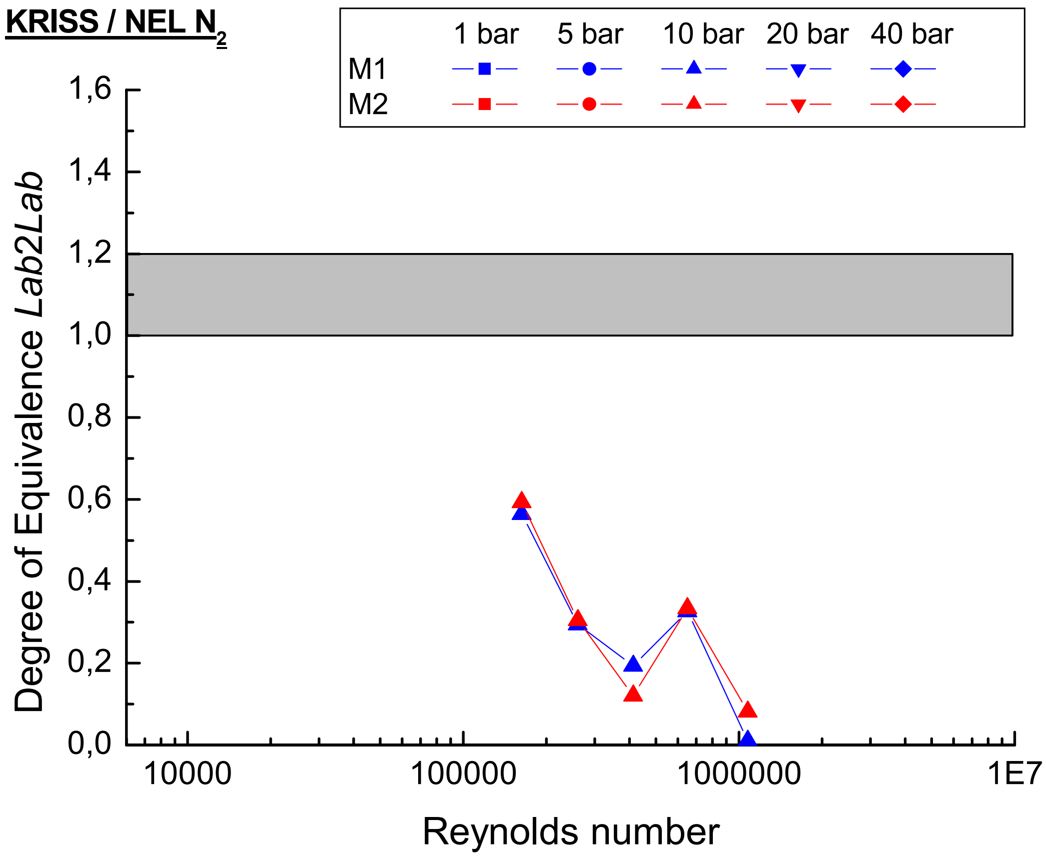

Fig. 82: Visualized degree of equivalence En of meter readings between KRISS and NEL (N2) for both meters 1 and 2. Data are shown for all pressure stages and flow rates according to Fig. 80.

$En_{KRISS,NELN2} = abs(d_{KRISS,NELN2})/U(d_{KRISS,NELN2})$

Flow rate m³/h	*p* = 5 bar M1	*p* = 5 bar M2	*p* = 10 bar M1	*p* = 10 bar M2	*p* = 20 bar M1	*p* = 20 bar M2	*p* = 40 bar M1	*p* = 40 bar M2	En Flow
65									
100			0,57	0,59					**0,58**
160			0,3	0,31					**0,30**
250			0,19	0,12					**0,15**
400			0,33	0,33					**0,33**
650			0,01	0,08					**0,03**
1000									
En(*p*)			**0,19**						***0,19***

Fig. 83: Tabulated results for the degree of equivalence between KRISS and NEL for N2 for both meters 1 and 2 and for all pressures and flow rates, compare the visualized data in Fig. 82.

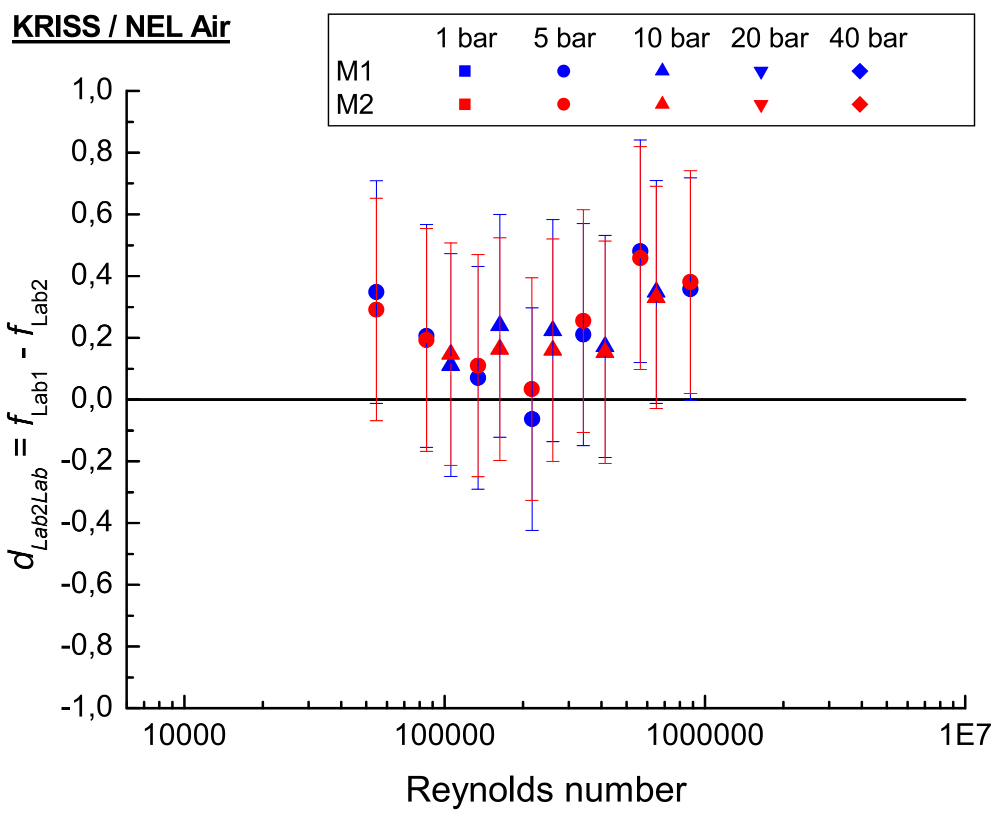

Fig. 84: Visualized differences of meter readings between KRISS and NEL (air) (in %) for both meters 1 and 2. Data are shown for all pressure stages and flow rates. Compare Figs. 15 - 26

$d_{KRISS,NELAir} = f_{KRISS} - f_{NELAir}$								
Flow rate m³/h	p = 5 bar		p = 10 bar		p = 20 bar		p = 40 bar	
	M1	M2	M1	M2	M1	M2	M1	M2
65	0,35	0,29	0,11	0,15				
100	0,21	0,19	0,24	0,16				
160	0,07	0,11	0,22	0,16				
250	-0,06	0,03	0,17	0,15				
400	0,21	0,26	0,35	0,33				
650	0,48	0,46						
1000	0,36	0,38						

$U(d_{KRISS,NELAir})$ (k = 2)								
Flow rate m³/h	p = 5 bar		p = 10 bar		p = 20 bar		p = 40 bar	
	M1	M2	M1	M2	M1	M2	M1	M2
65	0,36	0,36	0,36	0,36				
100	0,36	0,36	0,36	0,36				
160	0,36	0,36	0,36	0,36				
250	0,36	0,36	0,36	0,36				
400	0,36	0,36	0,36	0,36				
650	0,36	0,36						
1000	0,36	0,36						

Fig. 85: Tabulated differences of measurements between KRISS and NEL for air and the associated uncertainty of this difference, compare visualized data in Fig. 84. Data are for both meters 1 and 2 at all measured pressures and flow rates.

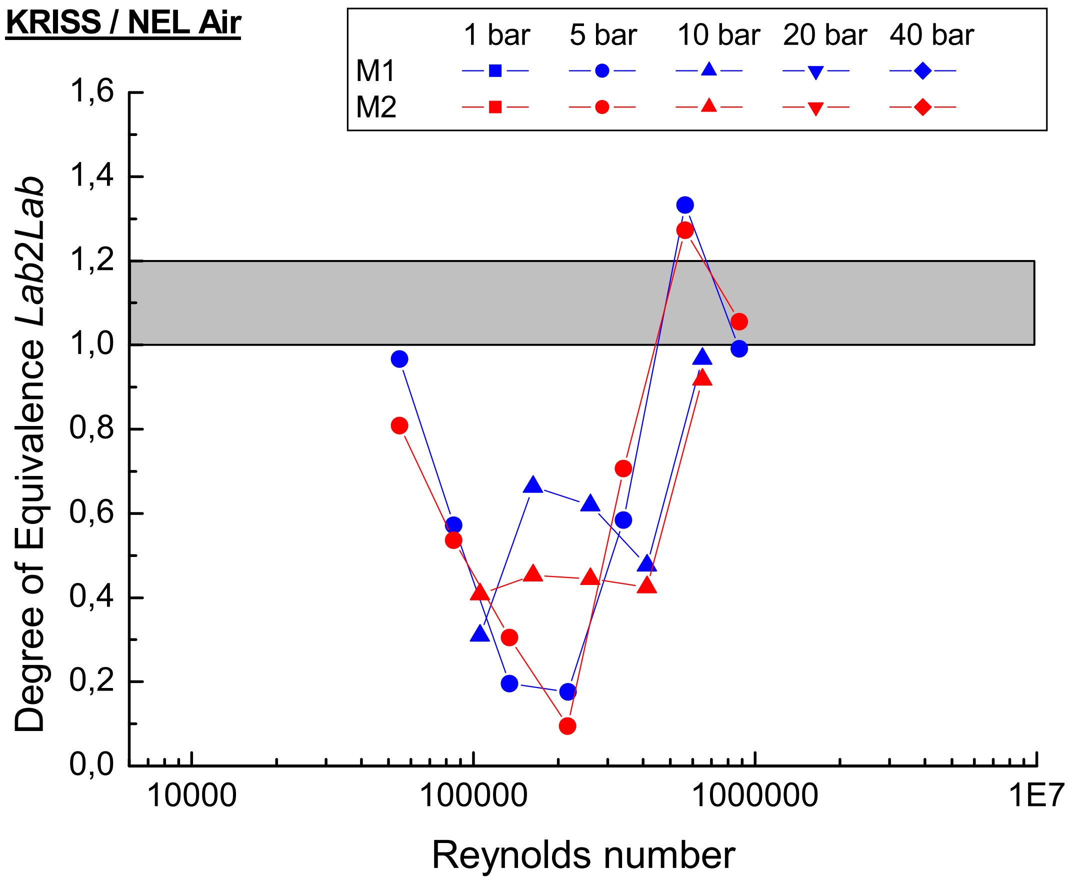

Fig. 86: Visualized degree of equivalence En of meter readings between KRISS and NEL (air) for both meters 1 and 2. Data are shown for all pressure stages and flow rates according to Fig. 84.

$En_{KRISS,NELAir} = abs(d_{KRISS,NELAir})/U(d_{KRISS,NELAir})$										
Flow rate m³/h	*p* = 5 bar		*p* = 10 bar		*p* = 20 bar		*p* = 40 bar		En Flow
	M1	M2	M1	M2	M1	M2	M1	M2	
65	0,97	0,81	0,31	0,41					**0,56**
100	0,57	0,54	0,66	0,45					**0,55**
160	0,2	0,31	0,62	0,45					**0,36**
250	0,18	0,09	0,48	0,43					**0,24**
400	0,58	0,71	0,97	0,92					**0,78**
650	1,33	1,27							**1,30**
1000	0,99	1,06							**1,02**
En(*p*)	**0,54**		**0,53**						***0,54***

Fig. 87: Tabulated results for the degree of equivalence between KRISS and NEL for air for both meters 1 and 2 and for all pressures and flow rates, compare the visualized data in Fig. 86.

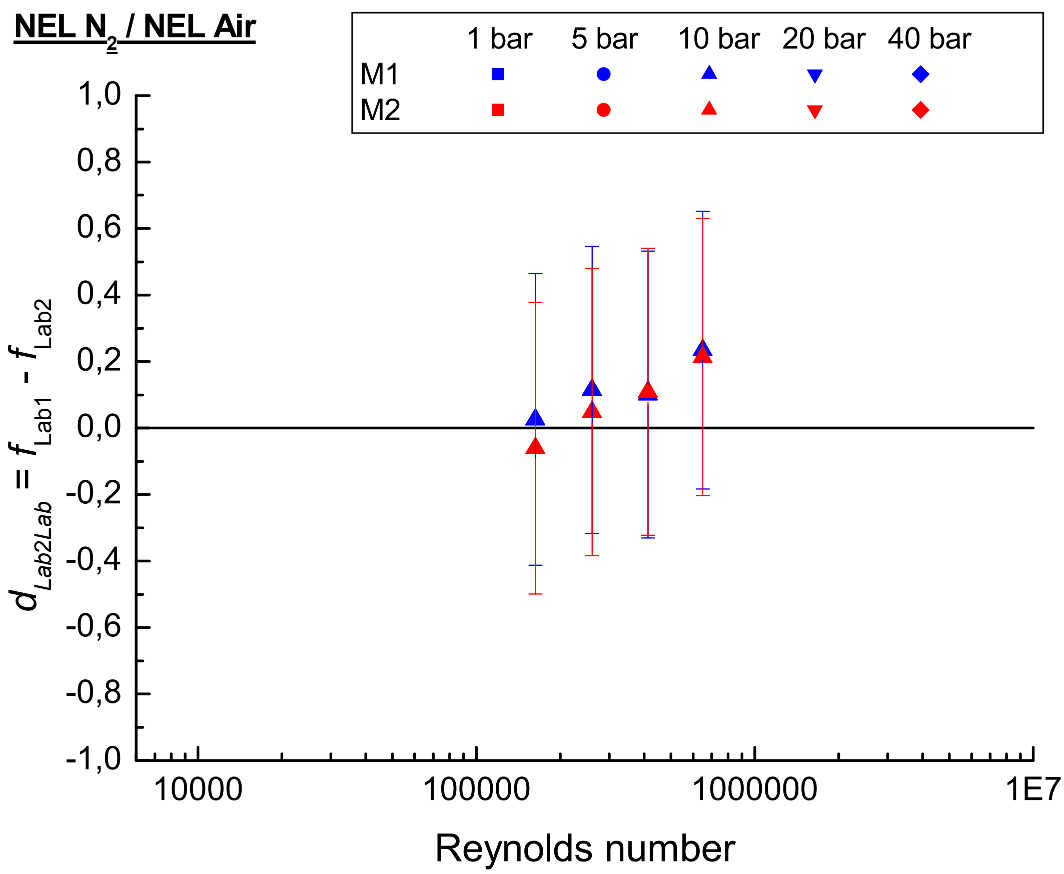

Fig. 88: Visualized differences of meter readings between NEL (N2) and NEL (air) (in %) for both meters 1 and 2. Data are shown for all pressure stages and flow rates. Compare Figs. 15 - 26

$d_{NELN2,NELAir} = f_{NELN2} - f_{NELAir}$								
Flow rate m^3/h	*p* = 5 bar		*p* = 10 bar		*p* = 20 bar		*p* = 40 bar	
	M1	M2	M1	M2	M1	M2	M1	M2
65								
100			0,03	-0,06				
160			0,11	0,05				
250			0,1	0,11				
400			0,23	0,21				
650								
1000								

$U(d_{NELN2,NELAir})$ (k = 2)								
Flow rate m^3/h	*p* = 5 bar		*p* = 10 bar		*p* = 20 bar		*p* = 40 bar	
	M1	M2	M1	M2	M1	M2	M1	M2
65								
100			0,44	0,44				
160			0,43	0,43				
250			0,43	0,43				
400			0,42	0,42				
650								
1000								

Fig. 89: Tabulated differences of measurements between NEL air and NEL N2 and the associated uncertainty of this difference, compare visualized data in Fig. 88. Data are for both meters 1 and 2 at all measured pressures and flow rates.

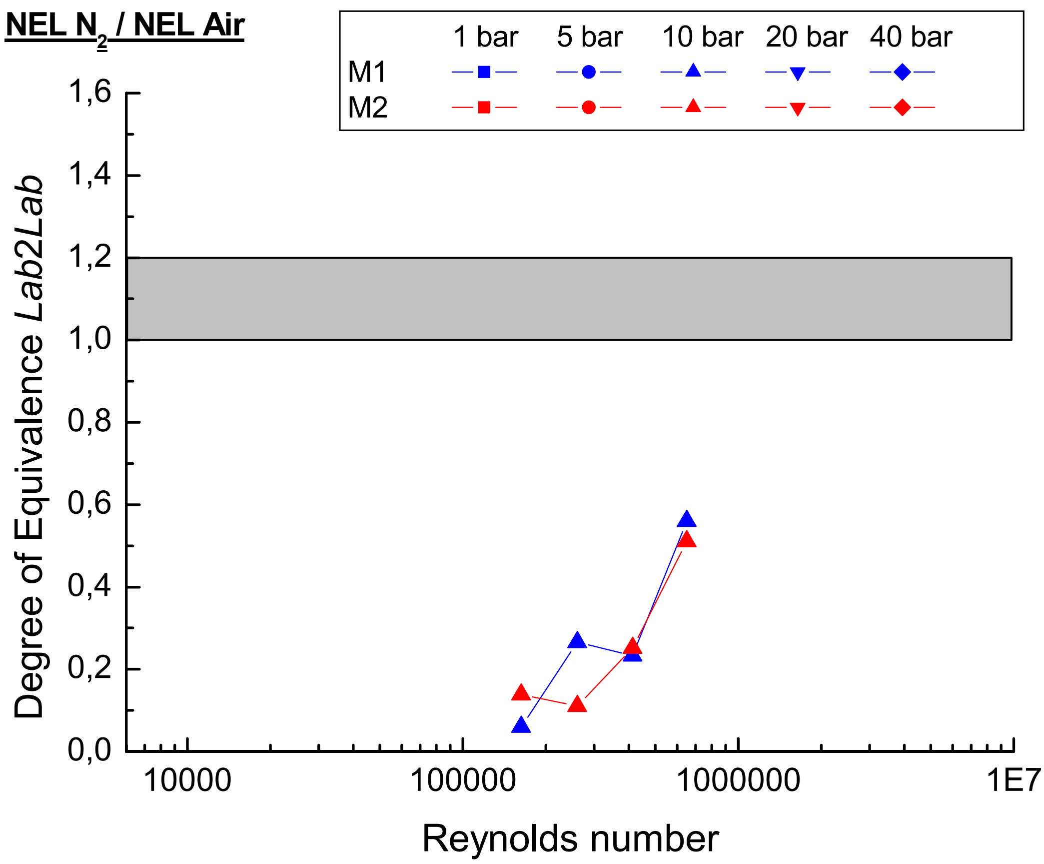

Fig. 90: Visualized degree of equivalence En of meter readings between NEL (air) and NEL (N2) for both meters 1 and 2. Data are shown for all pressure stages and flow rates according to Fig. 88.

$En_{NELN2,NELAir} = abs(d_{NELN2,NELAir})/U(d_{NELN2,NELAir})$									
Flow rate m^3/h	p = 5 bar		p = 10 bar		p = 20 bar		p = 40 bar		En Flow
	M1	M2	M1	M2	M1	M2	M1	M2	
65									
100			0,06	0,14					**0,09**
160			0,27	0,11					**0,17**
250			0,23	0,25					**0,24**
400			0,56	0,51					**0,54**
650									
1000									
En(p)			**0,21**						***0,21***

Fig. 91: Tabulated results for the degree of equivalence between NEL air and NEL N2 for both meters 1 and 2 and for all pressures and flow rates, compare the visualized data in Fig. 90.

6 SUMMARY, FINAL REMARKS and OUTLOOK

All comparisons showed complete agreement of the participants with the KCRV as well as among each other. For the KCRV we have chosen the weighted average of all results.

The degrees of overall equivalence are as follows:

LNE-LADG: En_{total} = ***0,37***;
CMS: En_{total} = ***0,38***;
KRISS: En_{total} = ***0,13***;
NEL N2: En_{total} = ***0,19***;
NEL Air: En_{total} = ***0,67***;

As all En values are far below 1,0 on the average, the flow community can accept all facilities for compressed air and Nitrogen as equivalent.

The claimed uncertainties are all in agreement with the KCRV and can be confirmed by this KC.

LNE-LADG:	Uclaimed = ***0,25*** %;
CMS:	Uclaimed = ***0,18*** %;
KRISS:	Uclaimed = ***0,20*** %
NEL N2:	Uclaimed = ***0,26 – 0,32*** %
NEL Air:	Uclaimed = ***0,30*** %
PTB air	Uclaimed = ***0,08*** % (not a participant, pilot lab only)

7 RFERENCES

[1] Guidelines for CIPM key comparisons, 1999, (appendix F to MRA [2])

[2] CIPM MRA 1999: Mutual Recognition of National Measurement Standards and of Calibration and Measurement Certificates Issued by National Metrology Institutes, *Comité International des Poids et Measures*, October 1999, Paris, France.

[3] CCM formalities for KCs, CCM2002-11: Formalities required for the CCM Key Comparisons (2nd Revised Draft), *CIPM Consultative Committee for Mass and Related Quantities*, CCM/2002-11, June, 2001, Submitted by M. Tanaka.

[4] *M.G. Cox*: “The evaluation of key comparison data”. In: Metrologia, 2002, **39**, pp. 589-595

[5] *W. Wöger*: “Remarks on the En-Criterion Used in Measurement Comparisons”; PTB-Mitteilungen 109, 1/1999, p.24-27

[6] ISO/IEC Guide 43-1 Proficiency testing by interlaboratory comparison part 1: Development and operation of proficiency testing schemes, 2nd edition 1997

and

EAL Interlaboratory Comparisons EAL-P7 edition 1, March 1996

[7] *W. Pöschel:* “Testing The Repeatability of Flow Meter Calibration Devices”, Proceedings of 2nd Brazilian Symposium on Flow Measurement, 20th to 23rd March 1995, pp 171-181.