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Intercomparison in barometric pressure

Range 510 hPa to 1100 hPa

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Abstract

An inter-comparison in the barometric pressure range from 510 hPa to 1100 hPa was arranged in 2008–2009 in Finland by the Centre for Metrology and Accreditation (MIKES). Four accredited pressure calibration laboratories participated in the comparison.

The transfer standard was a set of four Vaisala BAROCAP PTB 110 barometers. The instruments were equipped with voltage output only, without a pressure display. The instruments were provided for the comparison by the Measurement Standards Laboratory of Vaisala Oyj.

All the results from all four laboratories were in a good agreement with the results of MIKES within the limits of the claimed uncertainties.

Tiivistelmä

Mittatekniikan keskus (MIKES) järjesti 2008–2009 paineen vertailumittauksen barometrialueella 510 hPa…1100 hPa. Vertailumittaukseen osallistui neljä akkreditoitua paineen kalibrointilaboratoriota Suomesta.

Kiertävänä vertailulaitteena oli neljän Vaisala BAROCAP PTB110-barometrin paketti. Laitteissa oli ainoastaan jänniteulostulo, ei painenäyttöä. Laitteet luovutti käyttöön Vaisala Oyj:n Mittanormaalilaboratorio.

Kaikkien laboratorioiden kaikki tulokset olivat ilmoitettujen mittausepävarmuuksien puitteissa samoja kuin MIKESin tulokset.

Contents

1 Introduction

The Centre for Metrology and Accreditation (MIKES) has arranged several inter-comparisons for pressure calibration laboratories during the last 15 years, trying to cover the entire pressure range. The barometric range was selected in 2008 as the last comparison in this range was arranged about 10 years ago [1]. In 1995 the transfer standard was equipped with a pressure display. Now the participants had to calculate the pressure values from the voltage output of the instruments.

2 Participants

The following laboratories participated in the comparison:

Finnish Air Force, Air Materiel Command, Tampere
Inspecta Oy, Measuring Technology, Espoo
Oy Beamex Ab, Calibration Laboratory, Pietarsaari
Vaisala Oyj, Measurement Standards Laboratory, Vantaa

All four laboratories are accredited for the barometric pressure range.

3 Reference Laboratory

The reference standard used at MIKES for the inter-comparison is a DH Instruments PG7607 pressure balance s/n 397 for absolute and gauge pressure ranges from 50 hPa to 1930 hPa. The effective area of the piston/cylinder unit, nominally 1960 mm^2, was determined with dimensional measurements at LNE in September – October 2007 (certificate H090649/1) and with pressure measurements at MIKES. The pressure measurements of MIKES are traceable to LNE.

At the time of the comparison the CMC value in the BIPM database for the barometric range of MIKES was 1 Pa + 2,5 x 10^{-5} x p (k = 2, p in Pa).

The results from a pressure comparison between MIKES, LNE and Vaisala in 2007 suggest that this uncertainty value is very conservative [2].

4 Transfer Standard

The transfer standard was a set of four Vaisala BAROCAP Barometers PTB110:

item No. PA12806, s/n C0230008
item No. PA12807, s/n C0230010
item No. PA12808, s/n C0230011
item No. PA12809, s/n C0230012.

The transfer standard barometers were not equipped with a pressure display. The barometric pressure P was calculated from the measured output voltage U_{out} using a simple equation

$$P = 500 \text{ hPa} + (600 \text{ hPa}) / (5 \text{ V}) \cdot U_{out}$$

Each participating laboratory used its own instruments to measure the output voltages.

The authors wish to thank Vaisala Oyj for providing the transfer standard set.

5 Measurement Instructions

The measurement instructions were prepared at Vaisala Oyj by Antero Pitkäkoski (Comparison protocol, dated September 22, 2008). The nominal pressures to be measured were 510 hPa, 600 hPa, 700 hPa, 800 hPa, 900 hPa, 1000 hPa and 1098 hPa. At each nominal pressure, after the stabilisation, the output voltages of the four barometers and reference standard readings were to be recorded ten times.

The transmitting medium was specified as dry air or nitrogen.

A minimum stabilisation time of 2 hours was specified with each barometer connected to a 15 V DC power supply and the pressure connections open to the atmosphere.

The following pre-pressurisation and measurement schedule was stated:

1. 1100 hPa 1 minute
2. 500 hPa 1 minute
3. atmospheric pressure 10 minutes
4. 1100 hPa 10 minutes
5. measurement at 1098 hPa
6. measurements at other specified nominal pressures down to 510 hPa
7. 500 hPa 10 minutes
8. measurement at 510 hPa
9. measurements at other specified nominal pressures up to 1098 hPa
10. atmospheric pressure 25 minutes
11. 1100 hPa 10 minutes
12. repetition of steps 5 to 9.

Two down-and-up pressure cycles were specified. The maximum pressure changing rate was set to 5 hPa/s.

The participants were asked to calculate pressures from output voltages and to present the pressure results as average deviations from laboratory standards.

Further, the participating laboratories were asked to provide their results in their typical calibration certificates with uncertainties estimated using the document EA-4/02 [3] and a coverage factor k = 2.

Following a common inter-comparison practice all laboratories were given letter codes. Each laboratory knows only its own code.

6 Reference Values

The results from MIKES were used as reference values in the comparison. The transfer standard set was calibrated at MIKES three times. The first measurement at MIKES was made on September 24 and 25 [4], just before sending the instruments for circulation to laboratories A, B and C.

The transfer standards were returned to MIKES in the middle of October and the second measurement at MIKES was carried out on October 21, 2008 [5].

The results from laboratories A, B and C were compared to the averages of the results from MIKES 1 and MIKES 2.

Figures 1 to 4 illustrate the results from the two first measurements at MIKES. The differences in the two result sets were small and they were included in the uncertainties of the reference values.

The third measurement at MIKES was carried out on January 13, 2009 [6], just after the measurement at laboratory D. The results indicated that the barometers, especially the item PA12809, had drifted since October. The difficulty in generating the drift models was avoided by repeating the measurements at laboratory D, and the averages of the results D1 and D2 were compared to the results from MIKES 3. Again the differences between the result sets D1 and D2 were small and they were included in the overall uncertainties of laboratory D.

The results D1, D2 and MIKES 3 are shown in Figures 5 to 8.

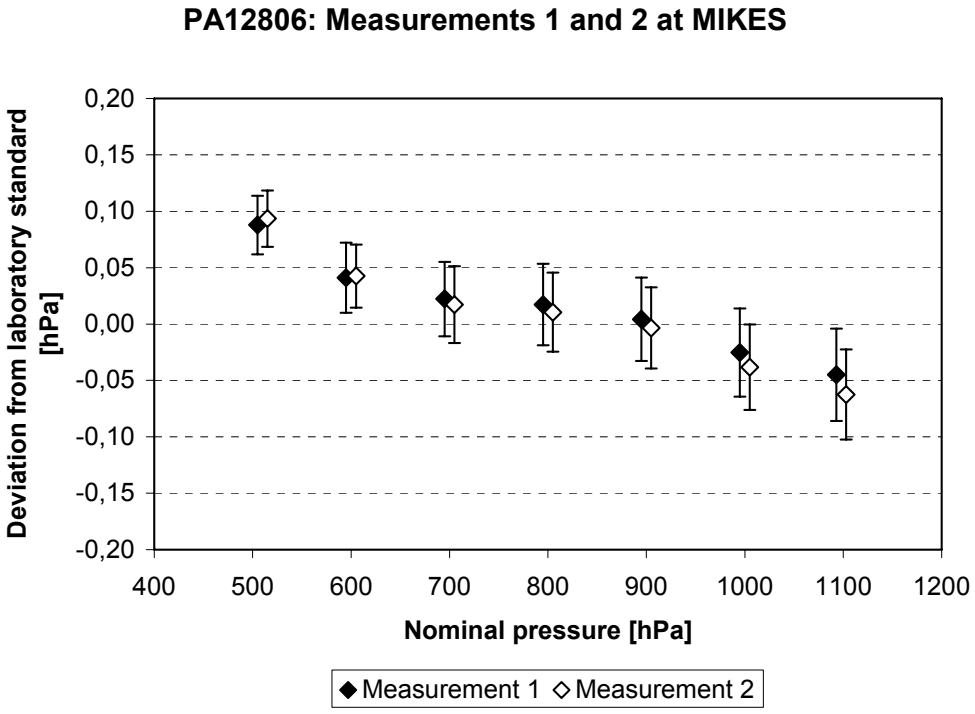

Figure 1. MIKES results 1 and 2 on barometer PA12806.

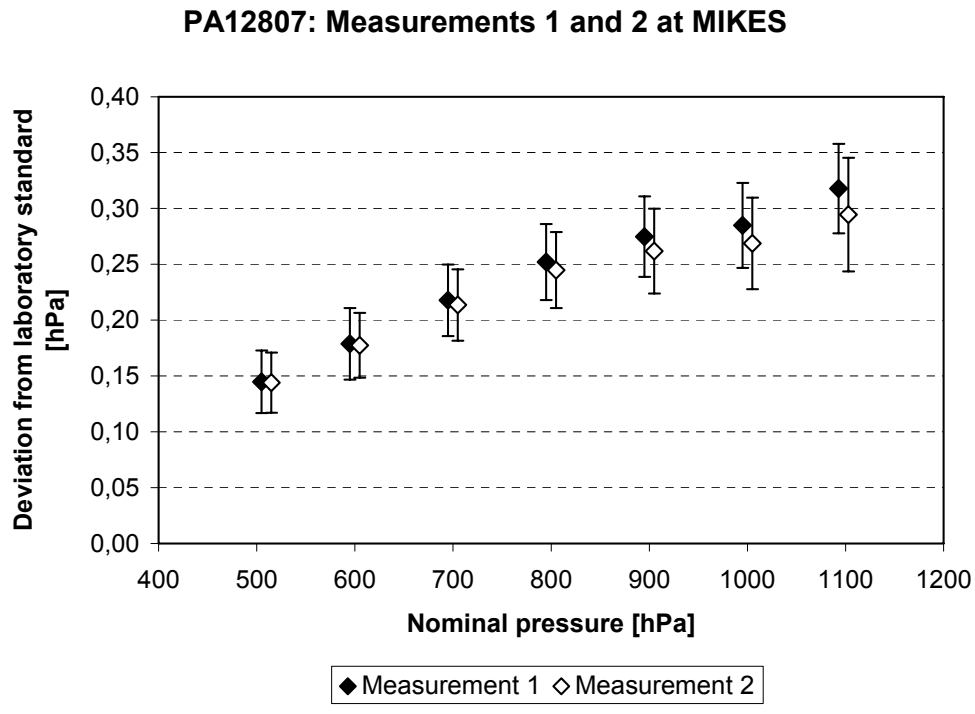

Figure 2. MIKES results 1 and 2 on barometer PA12807.

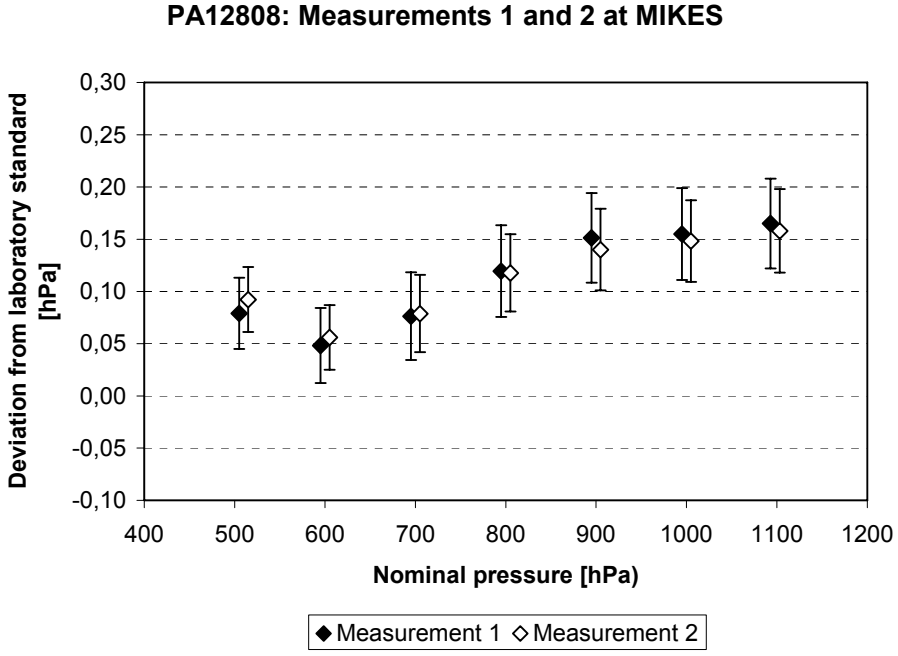

Figure 3. MIKES results 1 and 2 on barometer PA12808.

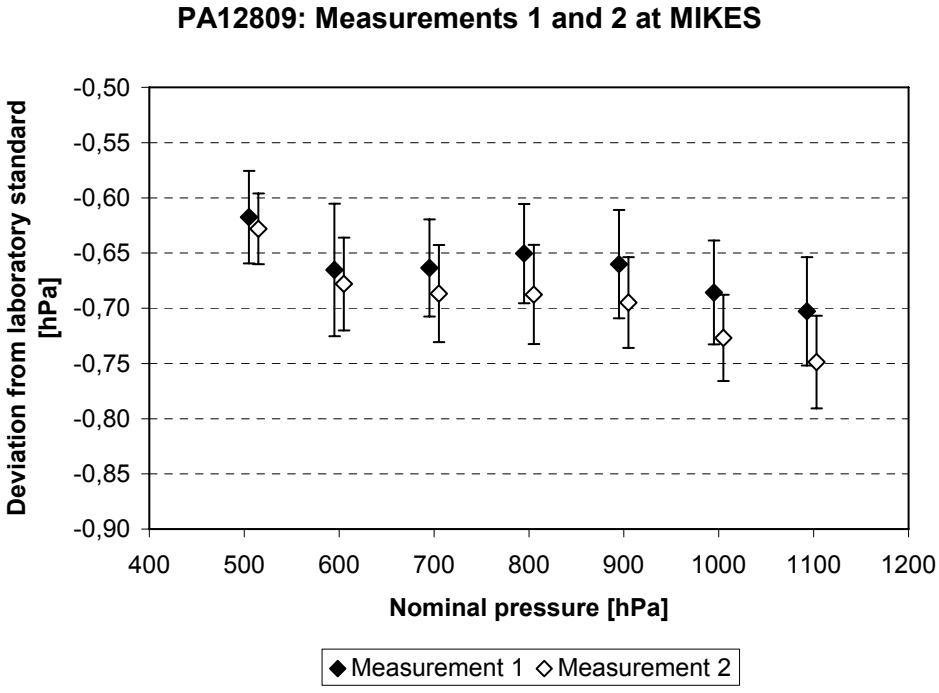

Figure 4. MIKES results 1 and 2 on barometer PA12809.

7 Results

The results from the four participating laboratories on the four barometers are shown in the Appendix.

A tool often used in analysing results from inter-laboratory comparisons is the normalised error E_n, which takes into account both the result and its uncertainty. The normalised error E_n is calculated as

$$E_n = \frac{\left(p_{transfer} - p_{std}\right)_{lab} - \left(p_{transfer} - p_{std}\right)_{ref}}{\sqrt{\left(U_{lab}^2 + U_{ref}^2\right)}}$$

where
$p_{transfer}$ is the pressure indicated by the transfer standard,
p_{std} is the pressure of the laboratory standard,
U_{lab} is the uncertainty of the laboratory result, and
U_{ref} is the uncertainty of the reference value.

The E_n-values calculated for all the results are also shown in the Appendix. A summary of the E_n-values is in Table 1.

The result in an inter-laboratory comparison is regarded as correct within the limits of uncertainty, if the absolute value of the normalised error E_n is less than 1. In this case all E_n-values for all the results from all the laboratories are well inside the limits -1 and +1.

Figure 9 on barometer PA12807 illustrates the uncertainty levels of the participants and MIKES on nominal pressures 510 hPa and 1000 hPa.

Table 1. Summary of the E_n values for the results from four laboratories on four barometers

	Range of values E(n)			
Laboratory	**PA12806**	**PA12807**	**PA12808**	**PA12809**
A	-0,75 … 0,22	0,08 … 0,20	-0,06 … 0,27	-0,70 … -0,20
B	0,10 … 0,20	0,26 … 0,34	0,23 … 0,27	-0,01 … 0,23
C	-0,06 … 0,05	-0,07 … 0,04	-0,12 … 0,11	-0,16 … -0,07
D	0,14 … 0,32	-0,03 … 0,59	-0,22 ... 0,51	-0,14 … 0,14

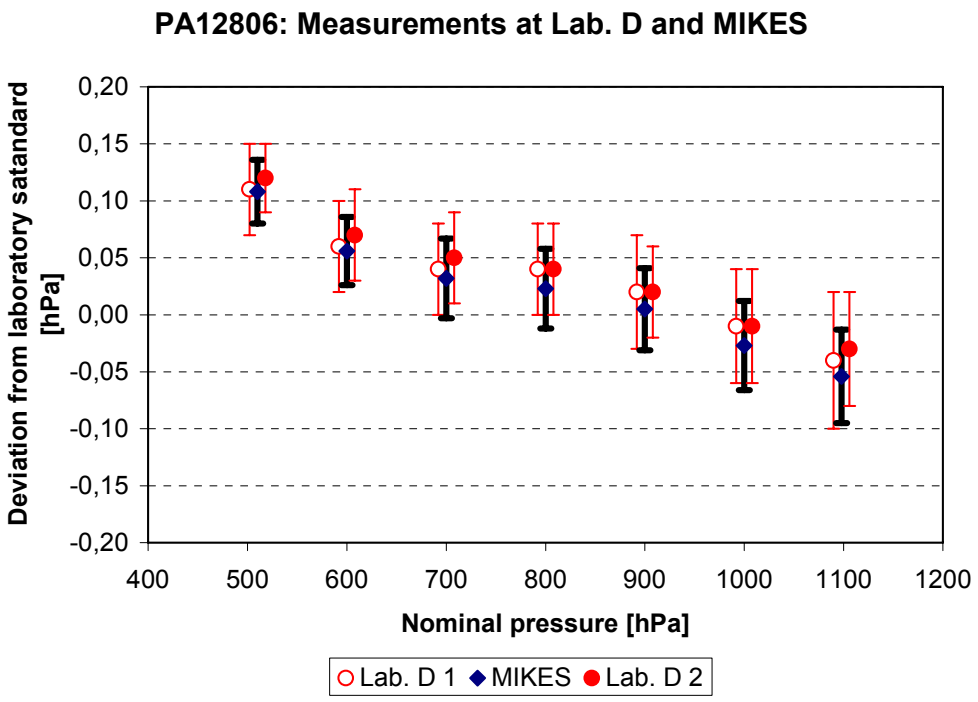

Figure 5. Results from laboratory D and MIKES on barometer PA12806.

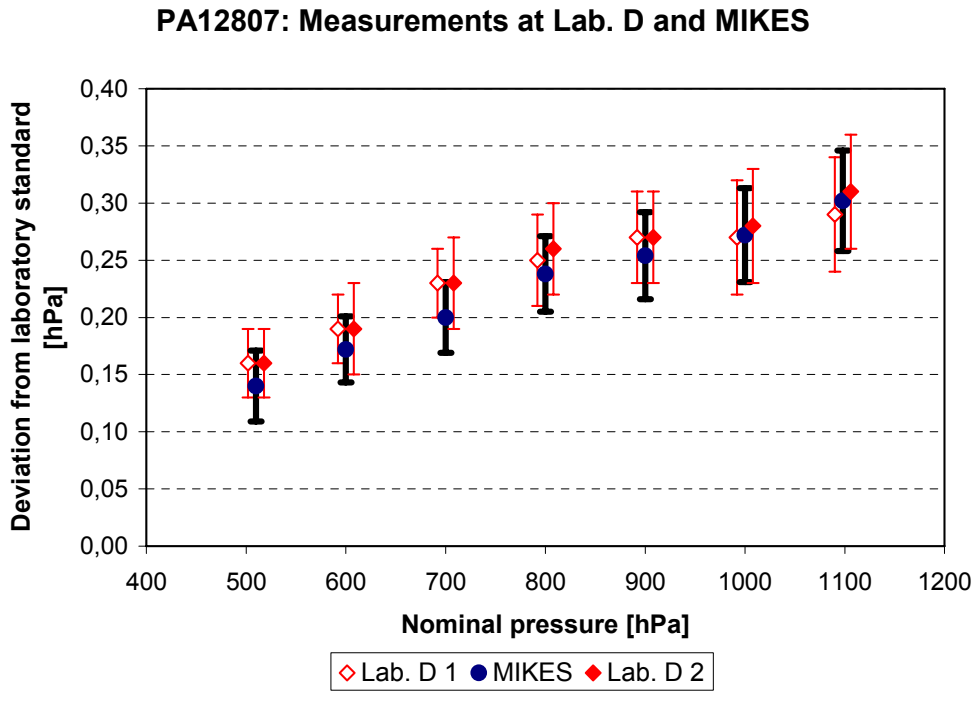

Figure 6. Results from laboratory D and MIKES on barometer PA12807.

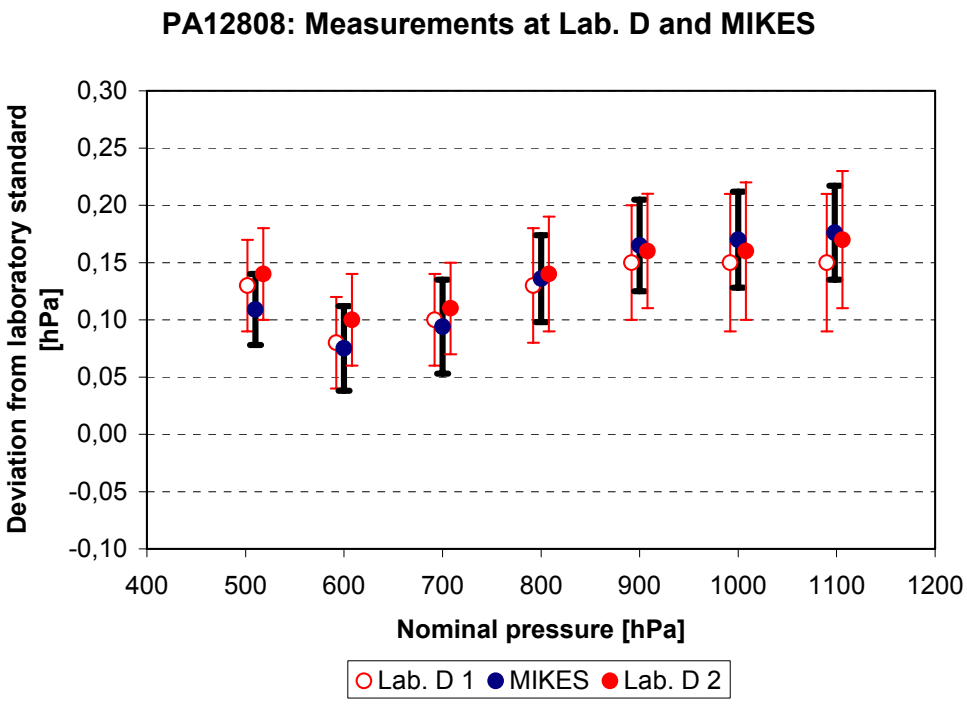

Figure 7. Results from laboratory D and MIKES on barometer PA12808.

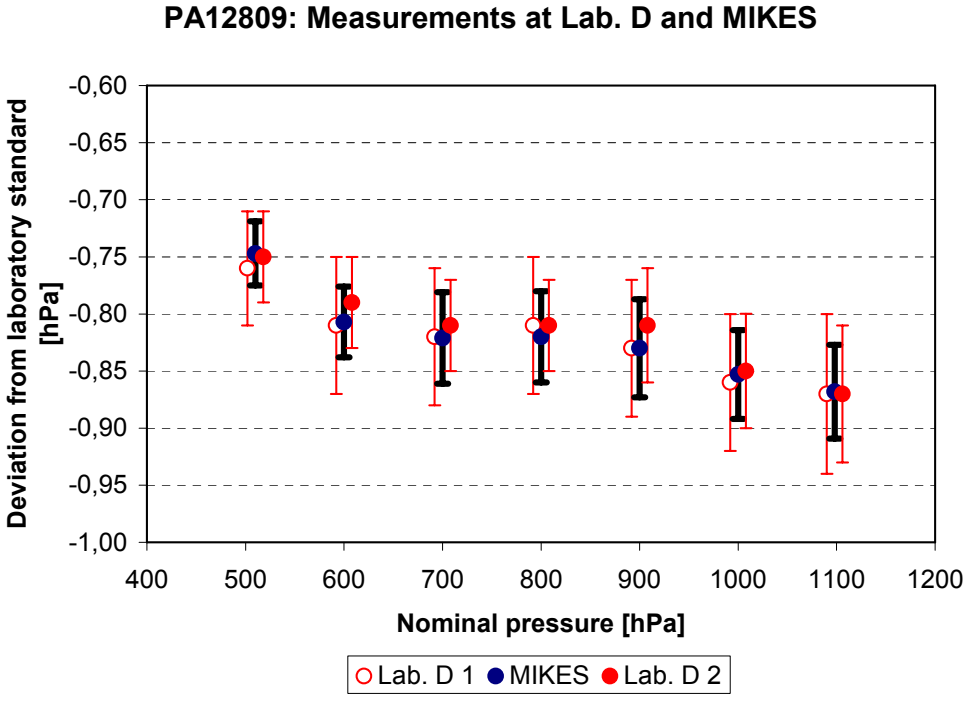

Figure 8. Results from laboratory D and MIKES on barometer PA12809.

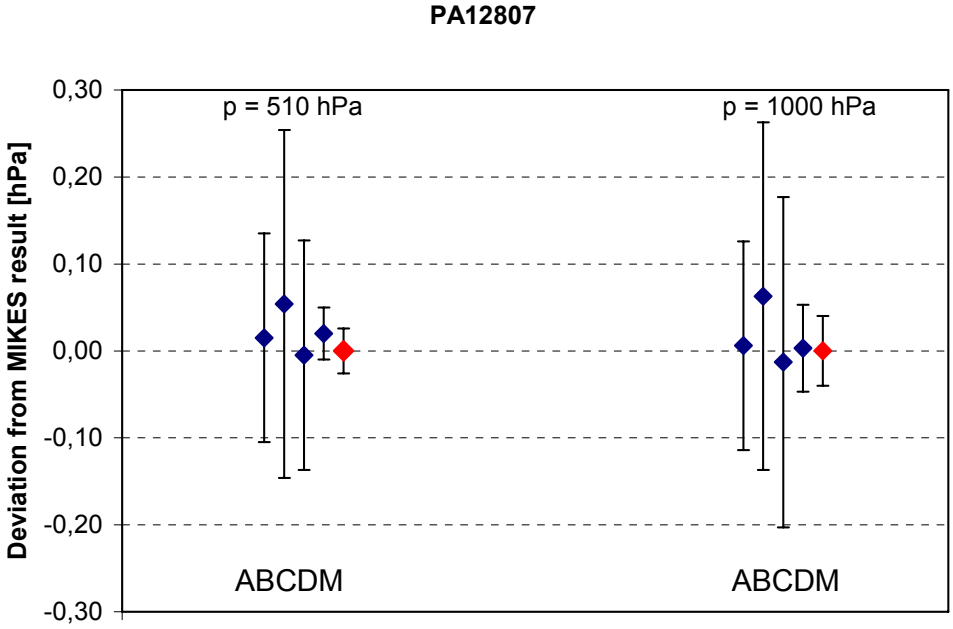

Figure 9. Uncertainties at nominal pressures 510 hPa and 1000 hPa on barometer PA12806. M = Reference value from MIKES.

8 Conclusions

Four accredited pressure calibration laboratories participated in an inter-comparison in the barometric pressure range from 510 hPa to 1100 hPa during October 2008 and January 2009.

All results from the participating laboratories were in a good agreement with the reference values from MIKES.

The transfer standard, a set of four Vaisala BAROCAP Barometers PTB110, was found to be suitable for an inter-comparison at this level.

9 References

[1] Rantanen, M: Nordic intercomparison in barometric pressure. Absolute pressure range 95 … 105 kPa. MIKES Publication J1/1999

[2] Rantanen, M., Semenoja, S., Pitkäkoski, A. and Goguel, F.: Barometric pressure comparisons between MIKES, Vaisala and LNE. MIKES Publication J1/2008

[3] EA-4/02: Expression of the Uncertainty of Measurement in Calibration

[4] Certificates of Calibration M-08P100, M-08P101, M-08P102 and M-08P103. Centre for Metrology and Accreditation
[5] Certificates of Calibration M-08P109, M-08P110, M-08P111 and M-08P112. Centre for Metrology and Accreditation
[6] Certificates of Calibration M-09P003, M-09P004, M-09P005 and M-09P006. Centre for Metrology and Accreditation

Appendix : Summary of results from each participating laboratory

Laboratory A

Trans-mitter	Nominal pressure hPa	Laboratory result hPa	Laboratory uncertainty hPa	MIKES result hPa	MIKES uncertainty hPa	Deviation from MIKES result hPa	E(n)
PA12806	510	0,109	0,080	0,091	0,026	0,018	0,22
	600	0,021	0,077	0,042	0,031	-0,021	-0,25
	700	-0,006	0,082	0,020	0,034	-0,026	-0,29
	800	-0,032	0,086	0,014	0,036	-0,046	-0,49
	900	-0,039	0,090	0,000	0,037	-0,039	-0,40
	1000	-0,097	0,120	-0,032	0,040	-0,065	-0,52
	1098	-0,135	0,099	-0,054	0,042	-0,081	-0,75
PA12807	510	0,159	0,12	0,144	0,028	0,015	0,12
	600	0,191	0,096	0,178	0,032	0,013	0,13
	700	0,224	0,098	0,216	0,032	0,008	0,08
	800	0,258	0,11	0,248	0,034	0,010	0,08
	900	0,291	0,11	0,268	0,039	0,023	0,20
	1000	0,283	0,12	0,277	0,042	0,006	0,05
	1098	0,325	0,11	0,306	0,053	0,019	0,15
PA12808	510	0,119	0,12	0,086	0,035	0,033	0,27
	600	0,071	0,12	0,052	0,036	0,019	0,15
	700	0,084	0,12	0,078	0,042	0,007	0,05
	800	0,128	0,12	0,119	0,044	0,009	0,07
	900	0,161	0,12	0,146	0,043	0,015	0,12
	1000	0,143	0,14	0,152	0,044	-0,009	-0,06
	1098	0,165	0,14	0,162	0,043	0,004	0,02
PA12809	510	-0,641	0,080	-0,623	0,042	-0,018	-0,20
	600	-0,699	0,077	-0,672	0,060	-0,027	-0,28
	700	-0,716	0,082	-0,675	0,046	-0,041	-0,43
	800	-0,722	0,086	-0,669	0,050	-0,053	-0,53
	900	-0,739	0,090	-0,677	0,053	-0,062	-0,59
	1000	-0,787	0,120	-0,706	0,053	-0,081	-0,62
	1098	-0,805	0,099	-0,726	0,056	-0,079	-0,70

Laboratory B

Trans-mitter	Nominal pressure hPa	Laboratory result hPa	Laboratory uncertainty hPa	MIKES result hPa	MIKES uncertainty hPa	Deviation from MIKES result hPa	E(n)
PA12806	510	0,130	0,20	0,091	0,026	0,039	0,20
	600	0,070	0,20	0,042	0,031	0,028	0,14
	700	0,057	0,20	0,020	0,034	0,037	0,18
	800	0,046	0,20	0,014	0,036	0,032	0,16
	900	0,024	0,20	0,000	0,037	0,024	0,12
	1000	-0,003	0,20	-0,032	0,040	0,029	0,14
	1098	-0,034	0,20	-0,054	0,042	0,020	0,10
PA12807	510	0,198	0,20	0,144	0,028	0,054	0,27
	600	0,238	0,20	0,178	0,032	0,059	0,29
	700	0,284	0,20	0,216	0,032	0,068	0,34
	800	0,305	0,20	0,248	0,034	0,057	0,28
	900	0,321	0,20	0,268	0,039	0,053	0,26
	1000	0,340	0,20	0,277	0,042	0,063	0,31
	1098	0,364	0,20	0,306	0,053	0,058	0,28
PA12808	510	0,140	0,20	0,086	0,035	0,055	0,27
	600	0,105	0,20	0,052	0,036	0,053	0,26
	700	0,124	0,20	0,078	0,042	0,046	0,23
	800	0,171	0,20	0,119	0,044	0,052	0,25
	900	0,198	0,20	0,146	0,043	0,052	0,25
	1000	0,202	0,20	0,152	0,044	0,050	0,24
	1098	0,212	0,20	0,162	0,043	0,050	0,24
PA12809	510	-0,575	0,20	-0,623	0,042	0,048	0,23
	600	-0,655	0,20	-0,672	0,060	0,016	0,08
	700	-0,656	0,20	-0,675	0,046	0,019	0,09
	800	-0,652	0,20	-0,669	0,050	0,017	0,08
	900	-0,660	0,20	-0,677	0,053	0,018	0,09
	1000	-0,701	0,20	-0,706	0,053	0,006	0,03
	1098	-0,728	0,20	-0,726	0,056	-0,002	-0,01

Laboratory C

Trans-mitter	Nominal pressure hPa	Laboratory result hPa	Laboratory uncertainty hPa	MIKES result hPa	MIKES uncertainty hPa	Deviation from MIKES result hPa	E(n)
PA12806	510	0,082	0,133	0,091	0,026	-0,009	-0,06
	600	0,041	0,140	0,042	0,031	-0,001	-0,01
	700	0,020	0,161	0,020	0,034	0,000	0,00
	800	0,014	0,171	0,014	0,036	0,000	0,00
	900	0,003	0,180	0,000	0,037	0,003	0,01
	1000	-0,025	0,190	-0,032	0,040	0,007	0,03
	1098	-0,043	0,200	-0,054	0,042	0,011	0,05
PA12807	510	0,139	0,132	0,144	0,028	-0,005	-0,04
	600	0,184	0,142	0,178	0,032	0,006	0,04
	700	0,217	0,160	0,216	0,032	0,001	0,01
	800	0,242	0,170	0,248	0,034	-0,006	-0,04
	900	0,259	0,180	0,268	0,039	-0,009	-0,05
	1000	0,264	0,190	0,277	0,042	-0,013	-0,07
	1098	0,292	0,200	0,306	0,053	-0,014	-0,07
PA12808	510	0,100	0,131	0,086	0,035	0,014	0,11
	600	0,062	0,142	0,052	0,036	0,010	0,07
	700	0,071	0,161	0,078	0,042	-0,007	-0,04
	800	0,111	0,172	0,119	0,044	-0,008	-0,04
	900	0,131	0,181	0,146	0,043	-0,015	-0,08
	1000	0,129	0,191	0,152	0,044	-0,023	-0,12
	1098	0,136	0,200	0,162	0,043	-0,026	-0,12
PA12809	510	-0,637	0,200	-0,623	0,042	-0,014	-0,07
	600	-0,682	0,200	-0,672	0,060	-0,010	-0,05
	700	-0,700	0,200	-0,675	0,046	-0,025	-0,12
	800	-0,701	0,200	-0,669	0,050	-0,032	-0,16
	900	-0,702	0,200	-0,677	0,053	-0,025	-0,12
	1000	-0,727	0,200	-0,706	0,053	-0,021	-0,10
	1098	-0,752	0,200	-0,726	0,056	-0,026	-0,13

Laboratory D

Trans-mitter	Nominal pressure hPa	Laboratory result hPa	Laboratory uncertainty hPa	MIKES result hPa	MIKES uncertainty hPa	Deviation from MIKES result hPa	E(n)
PA12806	510	0,115	0,040	0,108	0,028	0,007	0,14
	600	0,065	0,040	0,056	0,030	0,009	0,18
	700	0,045	0,040	0,032	0,035	0,013	0,24
	800	0,040	0,040	0,023	0,035	0,017	0,32
	900	0,020	0,050	0,005	0,036	0,015	0,24
	1000	-0,010	0,050	-0,027	0,039	0,017	0,27
	1098	-0,035	0,060	-0,054	0,041	0,019	0,26
PA12807	510	0,160	0,030	0,140	0,031	0,020	0,46
	600	0,190	0,040	0,172	0,029	0,018	0,36
	700	0,230	0,040	0,200	0,031	0,030	0,59
	800	0,255	0,040	0,238	0,033	0,017	0,33
	900	0,270	0,040	0,254	0,038	0,016	0,29
	1000	0,275	0,050	0,272	0,041	0,003	0,05
	1098	0,300	0,051	0,302	0,044	-0,002	-0,03
PA12808	510	0,135	0,040	0,109	0,031	0,026	0,51
	600	0,090	0,042	0,075	0,037	0,015	0,27
	700	0,105	0,040	0,094	0,041	0,011	0,19
	800	0,135	0,050	0,136	0,038	-0,001	-0,02
	900	0,155	0,050	0,165	0,040	-0,010	-0,16
	1000	0,155	0,060	0,170	0,042	-0,015	-0,20
	1098	0,160	0,061	0,176	0,041	-0,016	-0,22
PA12809	510	-0,755	0,050	-0,747	0,028	-0,008	-0,14
	600	-0,800	0,061	-0,807	0,031	0,007	0,10
	700	-0,815	0,060	-0,821	0,040	0,006	0,08
	800	-0,810	0,060	-0,820	0,040	0,010	0,14
	900	-0,820	0,061	-0,830	0,043	0,010	0,13
	1000	-0,855	0,060	-0,853	0,039	-0,002	-0,03
	1098	-0,870	0,070	-0,868	0,041	-0,002	-0,02

Recent publications

J1/2007 M. Heinonen, J. Järvinen, A. Lassila, A. Manninen (Eds.), *Finnish National Standards Laboratories Annual Report 2006*

J2/2007 M. Rantanen, S. Semenoja, G. Peterson, J. Busk, *Low gauge pressure comparisons between MIKES, Metrosert and FORCE Technology Range -2000 Pa to +2000 Pa*

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J4/2007 M. Rantanen, S. Semenoja, M. Ackerholm, A. Condereys, Z. Krajicek, W. Sabuga, J. Verbeek, C. Wüthrich, *High pressure comparisons between seven European National Laboratories - Range 50 MPa to 500 MPa. Report on EUROMET Project 881*

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J7/2007 T. Weckström, *Termoelementtivertailu*

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J3/2008 S. Sillanpää, *Thermodynamic studies in flow metrology* (Doctoral dissertation)

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