Infrastructure Commission (INFCOM)
Standing Committee on Measurements, Instrumentation and Traceability (SC-MINT)
Expert Team on Quality, Traceability and Calibration (ET-QTC)

Calibration of Pressure Instruments

Part-5: Calculation of Uncertainty Budget (2)

Holger Doerschel (DWD)
Françoise Montariol (Météo-France)

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Content

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- Introduction to this topic and historical information
- Concepts and definitions

Part 2:

- Methods of measurement
- Pressure standards in calibration laboratory

Part 3:

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Measurement uncertainty contributions

- Type B: $u(\delta_{interpolSB})$

  - the SB was calibrated at given points but it is used at any point over its calibration range
  - the uncertainty due to the modelling (typically linear interpolation) of the corrections between 2 calibration points of the SB has to be investigated and taken into account
  - this can be done using the calibration data of the SB

Measurement uncertainty contributions

- Type B: $u(\delta_{interpolSB})$
  - following RM Aero 802 02 for linear interpolation between 2 calibration points:
    - the standard deviation sd_i of the corrections is calculated at each pressure level p_i of the calibration where repeatability was also calculated (depending on procedure see CG17)

$$u(\delta_{interpolSB}) = \sqrt{2} * \max(sd_i)$$

Measurement uncertainty contributions

- Type B: $(\delta_{\mathrm{hystSB}})$, $(\delta_{\mathrm{repeatSB}})$

  - repeatability and hysteresis are calculated using the CG-17 formulas in 22a, 23a and 24 and 28 respectively
  - in the calibration process applied here, there is no zero correction for barometers, so the formulas simplify accordingly:

$$b'_{upj} = max\begin{Bmatrix} |p_{DUT,3j} - p_{DUT,1j} - p_{Ref,3j} + p_{Ref,1j}|, \\ |p_{DUT,5j} - p_{DUT,1j} - p_{Ref,5j} + p_{Ref,1j}|, \\ |p_{DUT,5j} - p_{DUT,3j} - p_{Ref,5j} + p_{Ref,3j}| \end{Bmatrix} \quad b'_{dnj} = max\begin{Bmatrix} |p_{DUT,4j} - p_{DUT,2j} - p_{Ref,4j} + p_{Ref,2j}|, \\ |p_{DUT,6j} - p_{DUT,2j} - p_{Ref,6j} + p_{Ref,2j}|, \\ |p_{DUT,6j} - p_{DUT,4j} - p_{Ref,6j} + p_{Ref,4j}| \end{Bmatrix}$$

$$b'_{meanj} = \frac{max\{b'_{upj}, b'_{dnj}\}}{\sqrt{3}}$$

Measurement uncertainty contributions

- Type B: $(\delta_{\mathrm{hystSB}})$, $(\delta_{\mathrm{repeatSB}})$

mean values Standard Barometer hPa						
M1_up	M2_down	M3_up	M4_down	M5_up	M6_down	mean
602,648	602,647	602,645	602,645	602,644	602,643	602,645
653,093	653,090	653,091	653,090	653,090	653,087	653,090
703,674	703,673	703,673	703,672	703,671	703,669	703,672
754,563	754,563	754,562	754,560	754,559	754,558	754,561
794,920	794,919	794,919	794,917	794,916	794,914	794,918
845,501	845,501	845,500	845,499	845,497	845,495	845,499
895,473	895,473	895,472	895,471	895,468	895,467	895,471
945,848	945,848	945,846	945,846	945,843	945,843	945,846
996,357	996,356	996,355	996,354	996,351	996,350	996,354
1045,531	1045,530	1045,529	1045,528	1045,524	1045,524	1045,528
1095,975	1095,974	1095,973	1095,972	1095,969	1095,969	1095,972

mean values device unter test hPa						
M1_up	M2_down	M3_up	M4_down	M5_up	M6_down	mean
602,700	602,694	602,696	602,687	602,684	602,682	602,690
653,138	653,125	653,123	653,140	653,130	653,130	653,131
703,713	703,711	703,703	703,709	703,712	703,712	703,710
754,605	754,601	754,599	754,592	754,592	754,602	754,598
794,966	794,960	794,960	794,961	794,955	794,957	794,960
845,541	845,544	845,538	845,538	845,534	845,538	845,539
895,507	895,512	895,510	895,512	895,498	895,504	895,507
945,883	945,882	945,878	945,877	945,876	945,878	945,879
996,387	996,391	996,385	996,385	996,382	996,382	996,385
1045,557	1045,554	1045,548	1045,551	1045,547	1045,551	1045,552
1096,005	1096,001	1095,996	1095,995	1095,989	1095,994	1095,997

$$h_j = \frac{\frac{1}{3}\sum_{m=1}^{n}\left|p_{DUT,2m,j} - p_{DUT,2m-1,j} - p_{Ref,2m,j} - p_{Ref,2m-1,j}\right|}{\sqrt{3}}$$

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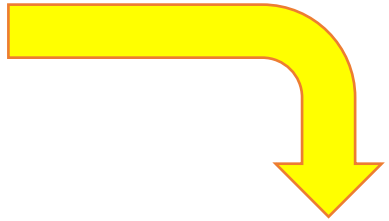
Measurement uncertainty contributions

- Type B: $(\delta_{\mathrm{hystSB}})$, $(\delta_{\mathrm{repeatSB}})$

mean values Standard Barometer hPa						
M1_up	M2_down	M3_up	M4_down	M5_up	M6_down	mean
602,648	602,647	602,645	602,645	602,644	602,643	602,645
653,093	653,090	653,091	653,090	653,090	653,087	653,090
703,674	703,673	703,673	703,672	703,671	703,669	703,672
754,563	754,563	754,562	754,560	754,559	754,558	754,561
794,920	794,919	794,919	794,917	794,916	794,914	794,918
845,501	845,501	845,500	845,499	845,497	845,495	845,499
895,473	895,473	895,472	895,471	895,468	895,467	895,471
945,848	945,848	945,846	945,846	945,843	945,843	945,846
996,357	996,356	996,355	996,354	996,351	996,350	996,354
1045,531	1045,530	1045,529	1045,528	1045,524	1045,524	1045,528
1095,975	1095,974	1095,973	1095,972	1095,969	1095,969	1095,972

mean values device unter test hPa						
M1_up	M2_down	M3_up	M4_down	M5_up	M6_down	mean
602,700	602,694	602,696	602,687	602,684	602,682	602,690
653,138	653,125	653,123	653,140	653,130	653,130	653,131
703,713	703,711	703,703	703,709	703,712	703,712	703,710
754,605	754,601	754,599	754,592	754,592	754,602	754,598
794,966	794,960	794,960	794,961	794,955	794,957	794,960
845,541	845,544	845,538	845,538	845,534	845,538	845,539
895,507	895,512	895,510	895,512	895,498	895,504	895,507
945,883	945,882	945,878	945,877	945,876	945,878	945,879
996,387	996,391	996,385	996,385	996,382	996,382	996,385
1045,557	1045,554	1045,548	1045,551	1045,547	1045,551	1045,552
1096,005	1096,001	1095,996	1095,995	1095,989	1095,994	1095,997



Hysteresis hPa	Repeat. up max hPa	Repeat. down max hPa	Repeat. max hPa
0,005	0,012	0,008	0,012
0,010	0,013	0,014	0,014
0,004	0,011	0,006	0,011
0,007	0,009	0,014	0,014
0,004	0,007	0,003	0,007
0,003	0,003	0,003	0,003
0,005	0,008	0,005	0,008
0,002	0,004	0,005	0,005
0,002	0,001	0,004	0,004
0,004	0,007	0,004	0,007
0,003	0,010	0,004	0,010

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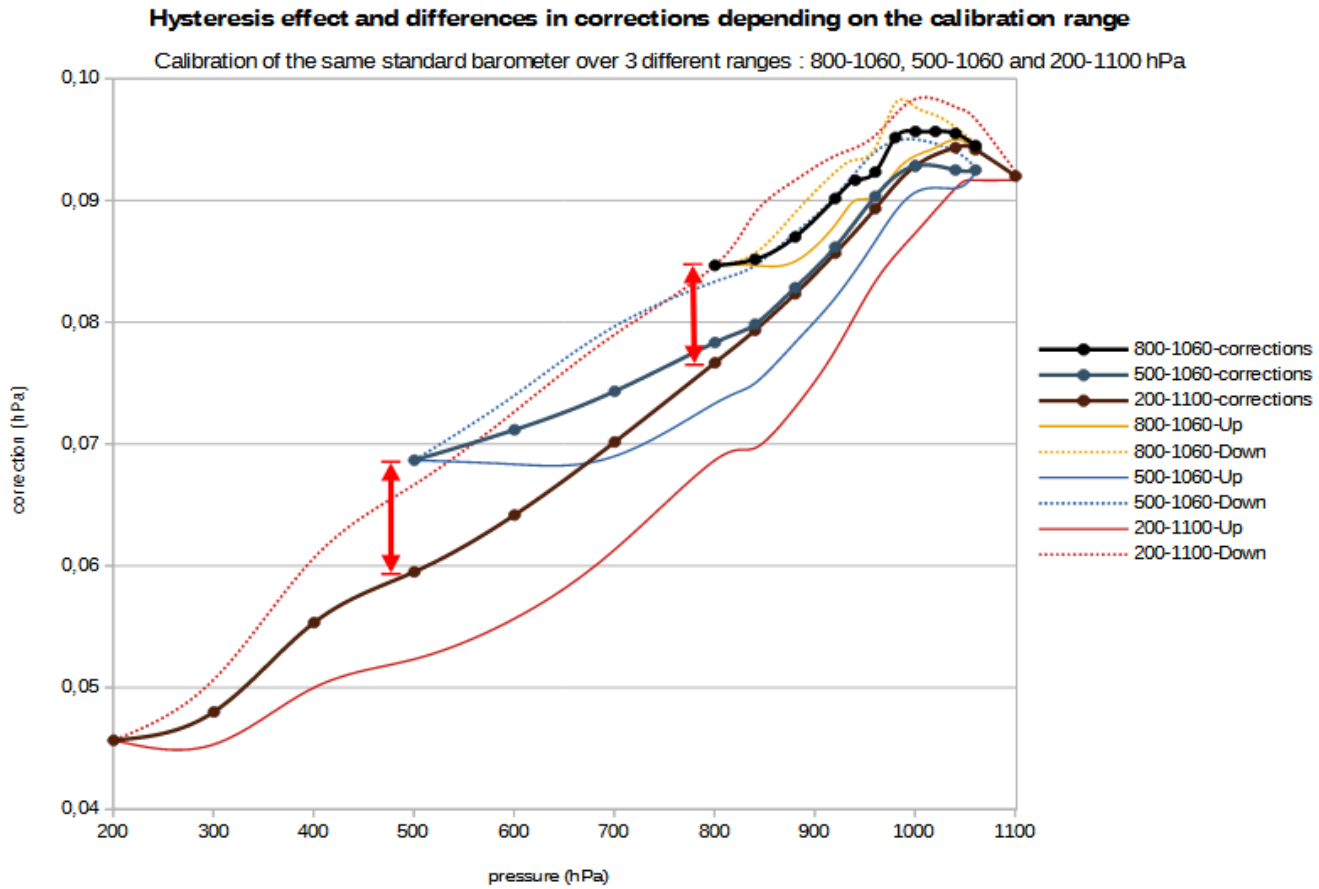
Measurement uncertainty contributions

- Type B: $(\delta_{\mathrm{hystSB}})$ (pressure controller)
  - in most cases, the SB is used to calibrate over reduced ranges



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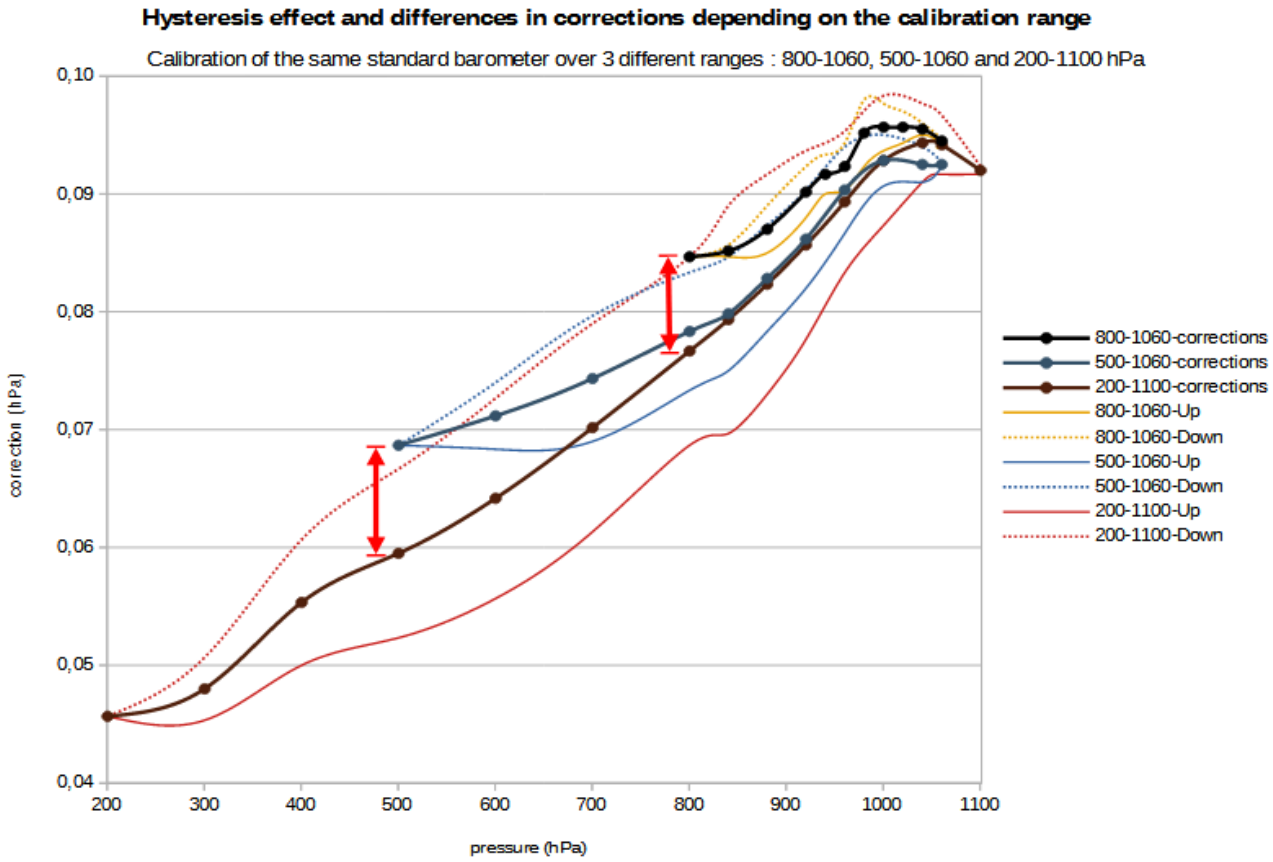
Measurement uncertainty contributions

- Type B: $(\delta_{\mathrm{hystSB}})$ (pressure controller)
  - due to the hysteresis of the SB, this induces an uncertainty as shown



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Measurement uncertainty contributions

- Type B: $(\delta_{\mathrm{hystSB}})$ (pressure controller)
  - this is typically the case with the uncertainty due to the hysteresis of the SB, being an absolute pressure controller, (but not for piston pressure gauges)
  - the deviation $(\delta_{\mathrm{hystSB}})$ to be added to the final U is half of the calculated hysteresis:

$$(\delta_{\mathrm{hystSB}}) = \frac{hysteresis}{2}$$

Measurement uncertainty contributions

- all numbers are fictional for unit

name	best estimate hPa	width of the distribution hPa	distribution	degrees of freedom	standard uncertainty hPa	sensitivity coefficient	uncertainty contribution hPa
P_{SB}	996.354		normal	359	0.0000559	-1	0.00000000312
δ_{tempSB}	0.0	0.003	rectangular	∞	0.001732	1	0.000003
δ_{calSB}	0.0	0.0366	normal	∞	0.018300	1	0.000335
$\delta_{driftSB}$	0.0	0.02	rectangular	∞	0.011547	1	0.000133
δ_{hystSB}	0.0	0.003	rectangular	∞	0.001732	1	0.000003
$\delta_{repeatSB}$	0.0	0.003	rectangular	∞	0.001732	1	0.000003
$\delta_{resolSB}$	0.0	0.0005	rectangular	∞	0.000289	1	0.000000
$\delta_{interpolSB}$	0.0	0.004	rectangular	∞	0.002309	1	0.000005
P_{DUT}	996.385		normal	359	0.00169	1	0.00000285
$\delta_{tempDUT}$	0.0	0.004	rectangular	∞	0.002309	1	0.000005
δ_{altDUT}	0.0	0.005	rectangular	∞	0.002887	1	0.000008
$\delta_{resolDUT}$	0.0	0.005	rectangular	∞	0.002887	1	0.000008
$\delta_{hystDUT}$	0.0	0.004	rectangular	∞	0.002309	1	0.000005
$\delta_{repeatDUT}$	0.0	0.004	rectangular	∞	0.002309	1	0.000005
δ_{PStab}	0.0	0.0001	rectangular	∞	0.000058	1	0.000000

Measurement uncertainty contributions

- combined uncertainty

$$u_c(y) = \sqrt{\sum_{i=1}^{N} (c_i \cdot u(x_i))^2}$$

$$u_c(y) = \sqrt{\begin{array}{c} u(\delta p_{DUT})^2 + u(\delta_{tempDUT})^2 + u(\delta_{altDUT})^2 + u(\delta_{hystDUT})^2 + u(\delta_{repeatDUT})^2 + u(\delta_{resolDUT})^2 + \\ u(\delta p_{SB})^2 + u(\delta_{tempSB})^2 + \\ u(\delta_{calSB})^2 + u(\delta_{driftSB})^2 + u(\delta_{hystSB})^2 + u(\delta_{repeatSB})^2 + u(\delta_{resolSB})^2 + u(\delta_{interpolSB})^2 + u(\delta_{Pstab})^2 \end{array}}$$

$$U = u_c(y) \cdot k_p$$

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Measurement uncertainty contributions

name	best estimate hPa	width of the distribution hPa	distribution	degrees of freedom	standard uncertainty hPa	sensitivity coefficient	uncertainty contribution hPa
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$\delta_{hystDUT}$	0.0	0.004	rectangular	∞	0.002309	1	0.000005
$\delta_{repeatDUT}$	0.0	0.004	rectangular	∞	0.002309	1	0.000005
δ_{PStab}	0.0	0.0001	rectangular	∞	0.000058	1	0.000000
					sum of squares		0.000518
					square root		0.02276
					correction at 996.385 hPa		-0.031 hPa
					expanded measurement uncertainty (k=2)		0.046 hPa

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- Measurement uncertainty contributions part #2
- **References and links**

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References and links

- JCGM 200:2012

  International Vocabulary of Metrology - Basic and general concepts and associated terms (2012)

  https://www.bipm.org/en/committees/jc/jcgm/publications

- JCGM 100:2008(E) – in English

  Evaluation of measurement data - **Guide to the expression of uncertainty in measurement** (2008)

  https://www.bipm.org/en/committees/jc/jcgm/publications

References and links

- Guide to Instruments and Methods of Observation (WMO-No. 8)

https://library.wmo.int/records/item/41650-guide-to-instruments-and-methods-of-observation?offset=4

- EURAMET Calibration Guidelines on Mass and Related Quantities

https://www.euramet.org/publications-media-centre

  - No. 3 Calibration of Pressure Balances
  - No. 17 Guidelines on the Calibration of Electromechanical and Mechanical Manometers

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References and links

- Germany:
  - Guideline **DKD-R 6-1** Calibration of Pressure Gauges (in English)

https://www.ptb.de/cms/fileadmin/internet/dienstleistungen/dkd/archiv/Publications/Guidelines/DKD-R_6-1_Revision_3_2020_en.pdf

References and links

- France (documents in French) :
  - RM Aero 802 02, Estimation of uncertainties on pressure measurements, Bureau de Normalisation de l'Aéronautique et de l'Espace, BNAE, 1997
  - RM Aero 802 41, Calibration and check of electromechanical manometers, BNAE, 1993
  - RM Aero 802 42, Pressure generators and controllers, BNAE, 1995
    - This document is very useful as it also explains how to characterize a pressure controller to calculate uncertainty due to its stability.
  - Cofrac LAB GTA 11, technical guidelines to accreditation: pressure measurements

Calibration of Pressure Instruments
End of Part 5

Thank you.

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