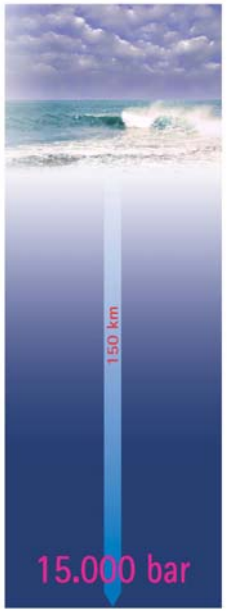
High pressure transducers as transfer standards

Jens Könemann, Alexander Gluschko, Thomas Konczak, Wladimir Sabuga

Physikalisch-Technische Bundesanstalt, Bundesallee 100,

38116 Braunschweig, Germany



Workshop on

High Pressure Metrology for Industry

Brno , Czech Republic, June 14, 2012

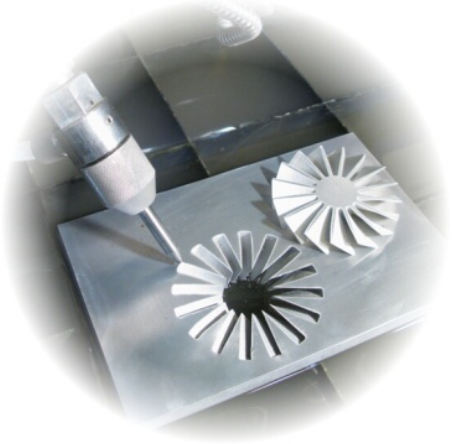
EURAMET
European Association of National Metrology Institutes

Outline

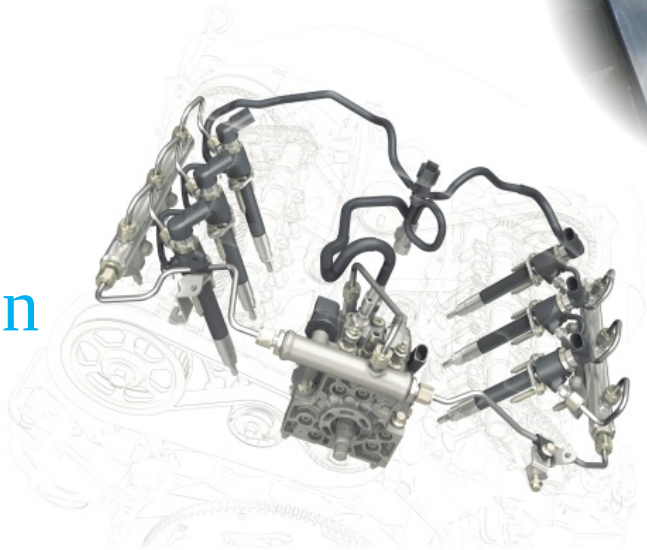
- Motivation
- PTB high-pressure infrastructure
- Calibration of pressure transducers
- Characteristics of pressure transducers
- Pressure transducers as transfer standards up to 1.0 GPa
- Layout of pressure transducers for 1.6 GPa
- Summary

High pressures for industry

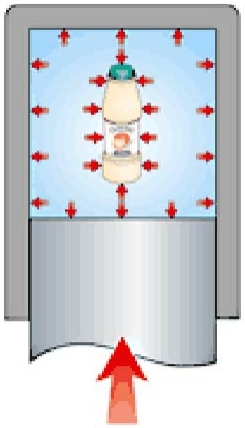
- Water-jet cutting



- Fuel injection



- Food sterilization



Calibration of modern pressure transducers

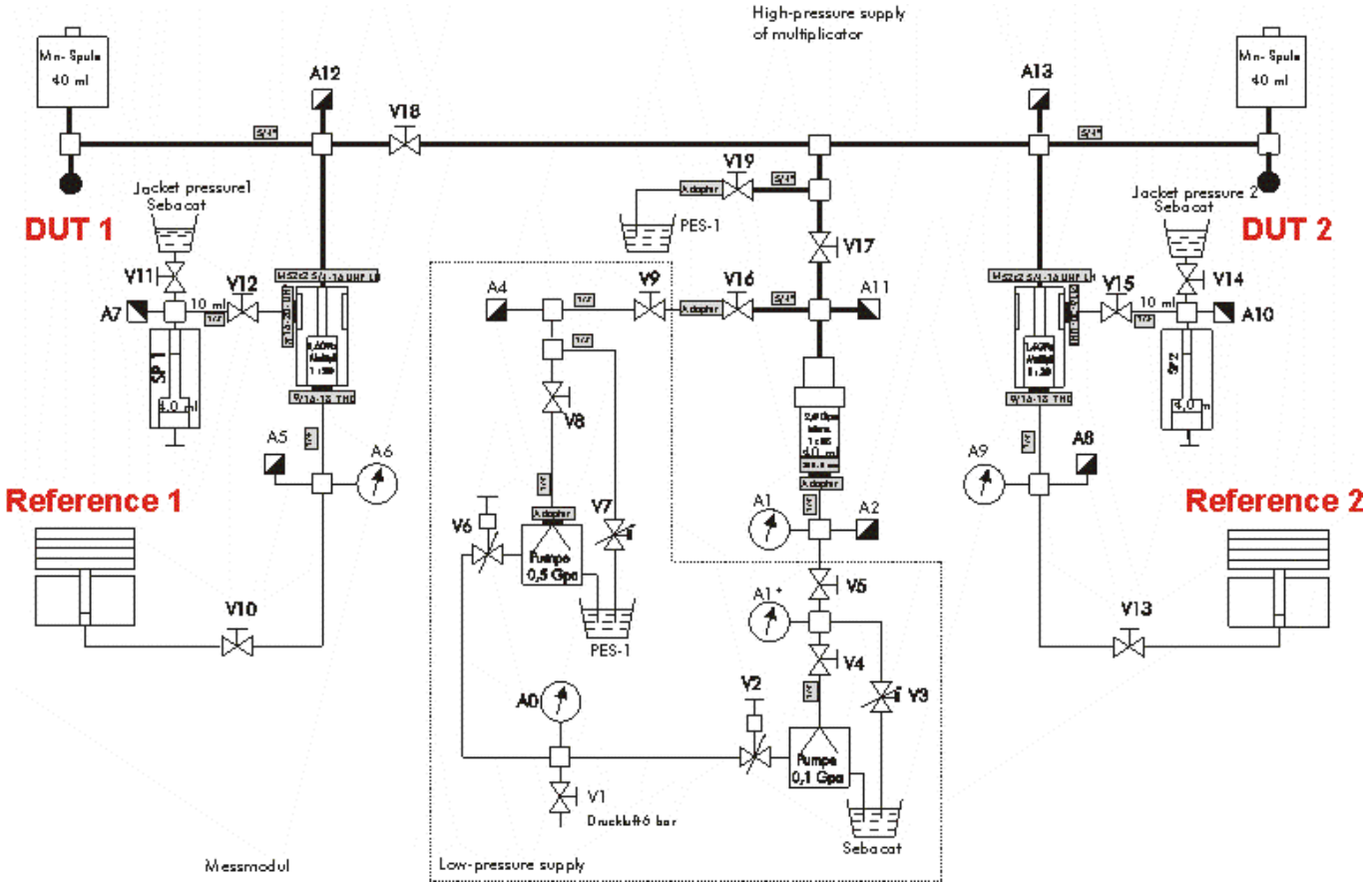
Practical examples

PTB primary standard

- 1 GPa controlled-clearance type pressure balance equipped with 1 GPa piston –cylinder system: its A_0 traceable via calibration chain to three 5 cm^2 10 MPa PCAs and its λ determined by FEA and RUS
- prior state of the art: extension to 1.4 GPa with a manganin manometer
- Sebacate and sebacate-petroleum mix as a pressure-transmitting medium
- Development of pressure generation system and new primary standard up to 1.6 GPa in framework of EMRP IND03

Calibration of pressure transducers I

Block diagram of the pressure generation and measurement system:



Impact on Transducers

- Temperature coefficient/environmental conditions
  constant temperature ($\Delta T<0.1$ K)/humidity, determination of temperature coefficient β
- Long-term shifts of span reading of TS
  statistical evaluation of corrections
- Effect by power source
  power source with voltage of 100 VAC and frequency of 50 Hz used with a power supply regulator, hence negligible effect on the reading
- Effect by altitude and position
  Transducers required to set up in position -> no effect
- Effect by transient response
  relative change in the reading after fifteen min. and after applying pressure change at 1 GPa typically less than 10×10^{-6}

Calibration of pressure transducers II

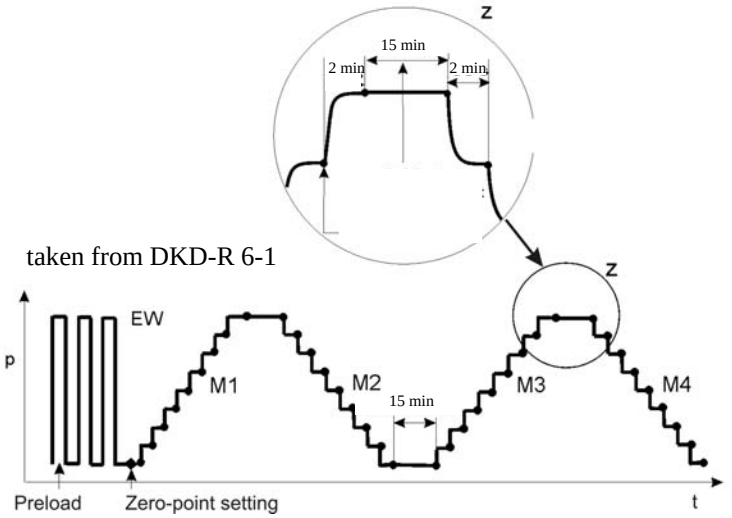
Guidelines according to DKD-R 6-1

Model equation:

$$\langle S \rangle = \frac{\langle V_{read} \rangle / (G V_{fv})}{P_n} \underbrace{K_{zero}}_{(1)} \underbrace{K_{repeat}}_{(2)} \underbrace{K_{reprod}}_{(3)} \underbrace{K_{hyst}}_{(4)}$$

Transfer factor

Correction factors



taken from DKD-R 6-1

(1) Zero point deviation

$$\propto \max\left\{\left|x_{2,0} - x_{1,0}\right|, \left|x_{4,0} - x_{3,0}\right|, \left|x_{6,0} - x_{5,0}\right|\right\}$$

(2) Repeatability

$$\propto \max\left\{\left|\left(x_{3,j} - x_{3,0}\right) - \left(x_{1,j} - x_{1,0}\right)\right|, \left|\left(x_{4,j} - x_{4,0}\right) - \left(x_{2,j} - x_{2,0}\right)\right|\right\}$$

(3) Reproducibility

$$\propto \max\left\{\left|\left(x_{5,j} - x_{5,0}\right) - \left(x_{1,j} - x_{1,0}\right)\right|, \left|\left(x_{6,j} - x_{6,0}\right) - \left(x_{2,j} - x_{2,0}\right)\right|\right\}$$

(4) Hysteresis

$$\propto \frac{1}{n} \cdot \left\{\left|\left(x_{2,j} - x_{1,0}\right) - \left(x_{1,j} - x_{1,0}\right)\right| + \left|\left(x_{4,j} - x_{3,0}\right) - \left(x_{3,j} - x_{1,0}\right)\right| + \left|\left(x_{6,j} - x_{5,0}\right) - \left(x_{5,j} - x_{5,0}\right)\right|\right\}$$

Calibration of pressure transducers II

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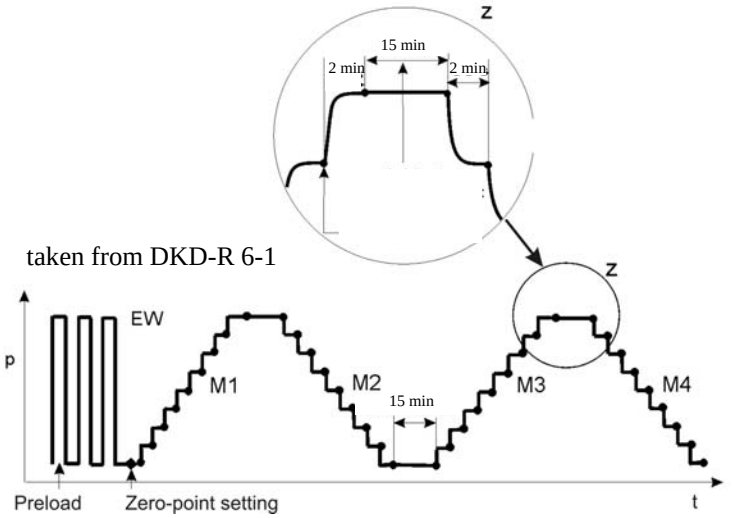
Model equation:

$$\langle S \rangle = \frac{\langle V_{read} \rangle / (G V_{fv})}{P_n} K_{zero} K_{repeat} K_{reprod} K_{hyst}$$

(1) (2) (3) (4)

Transfer factor

Correction factors



taken from DKD-R 6-1

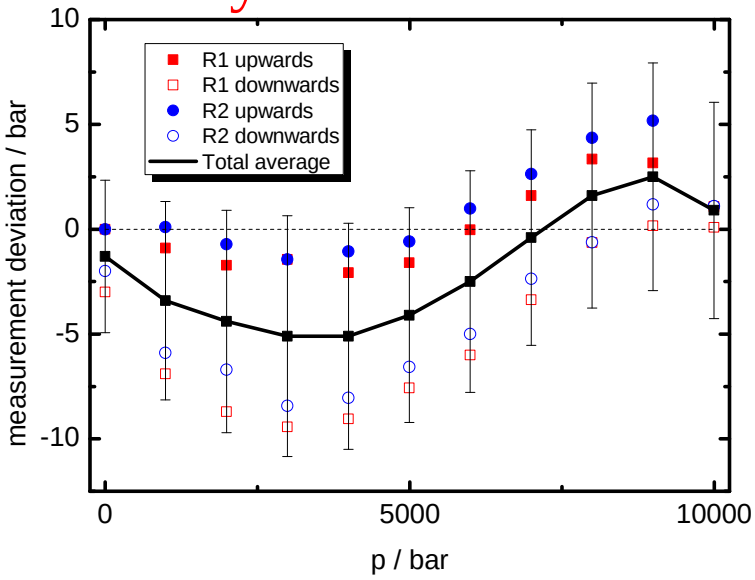
Measurement uncertainty:

$$U = k \cdot \left(\sqrt{u_{LS}^2 + u_{amp}^2 + u_{zero}^2 + u_{repeat}^2 + u_{reprod}^2 + \left| \frac{S_{up\ /\ down} - S'}{S'} \right|^2} \right)$$

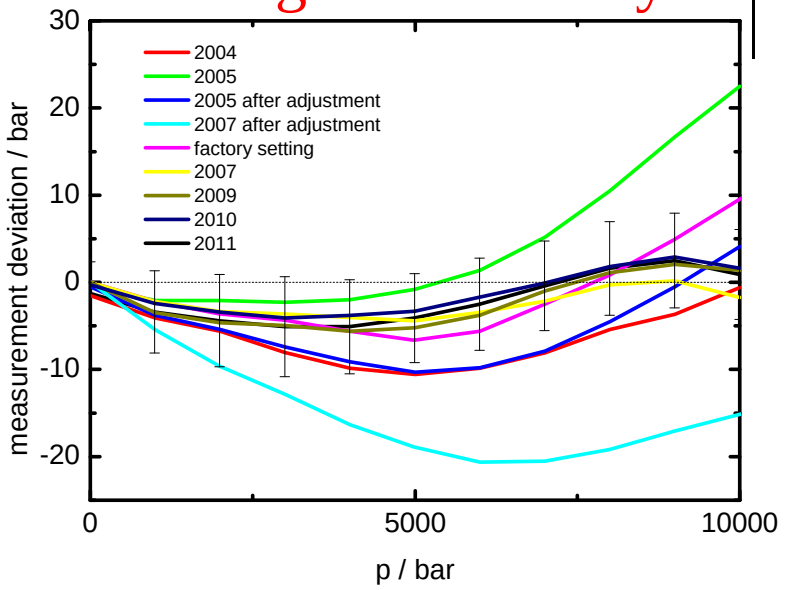
relative systematical deviation with S´ being slope of linear regression line of transducer

Transducer characteristics

Hysteresis behavior



Long-term stability



Transducer characteristics

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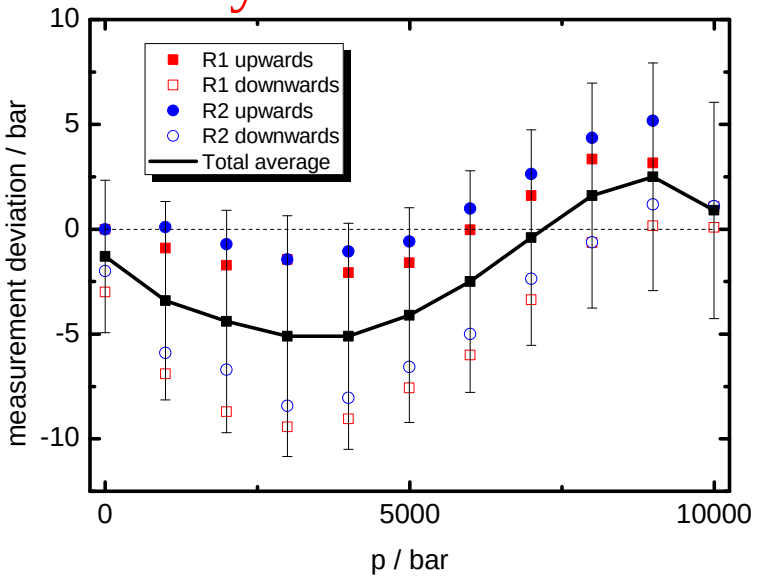

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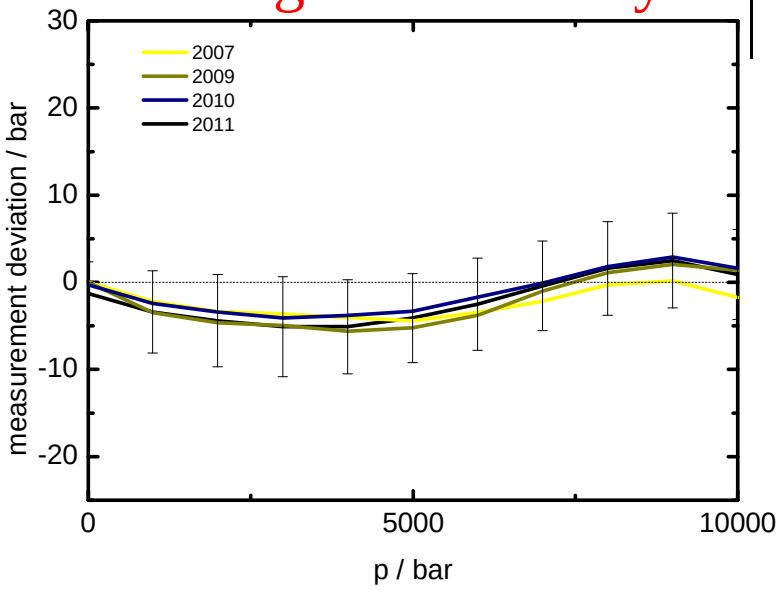
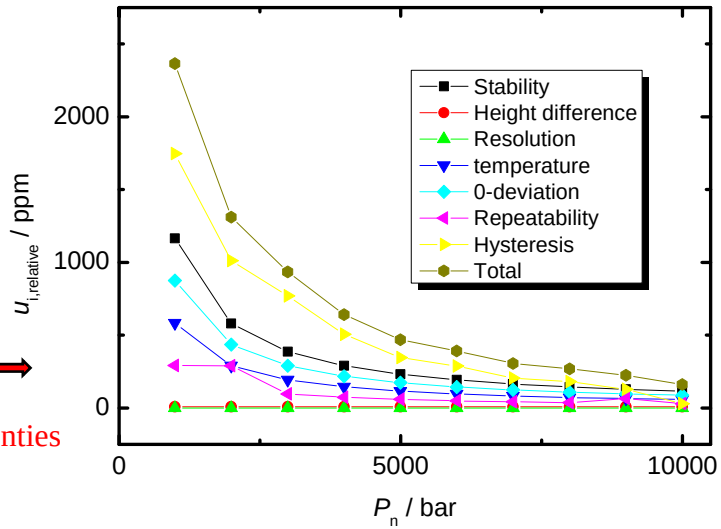


Quantity i	u_i /bar	
	1 kbar	10 kbar
Stability	1.2	1.2
Height difference	2.8e-4	4.7e-7
Resolution	0.57	0.57
Temperature	8.6e-3	8.7e-2
Zero-point deviation	0.87	0.87
Repeatability	0.29	0.29
Hysteresis	1.7	0.29
	2.3	1.6

Uncertainties

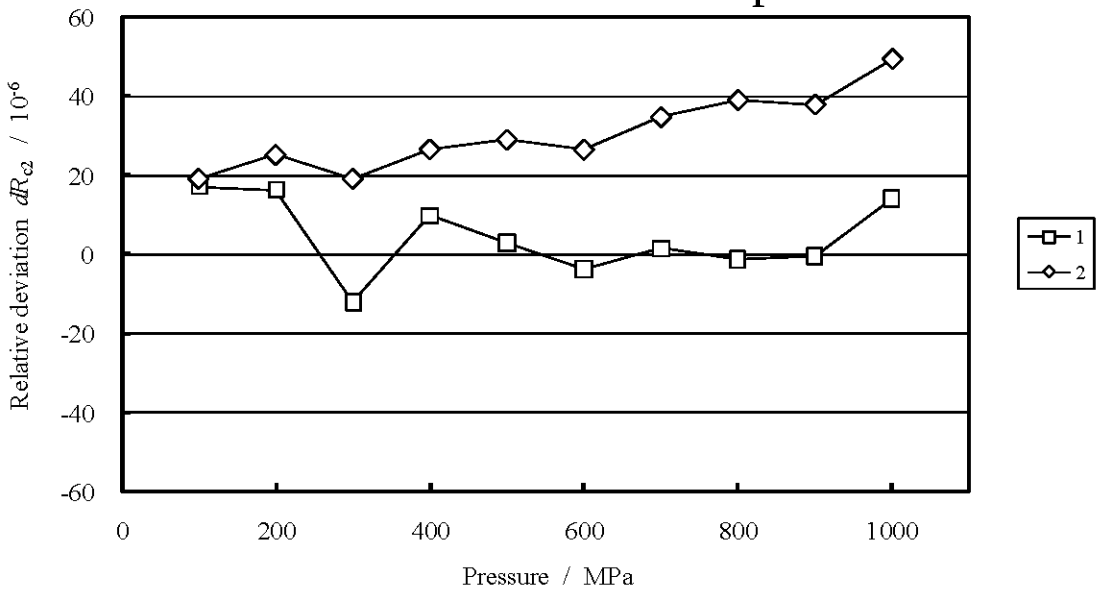


Metrological Investigations of Pressure transducers

Example: APMP.M.P-S8

Long-term shift

taken from *APMP.M.P-S8* report

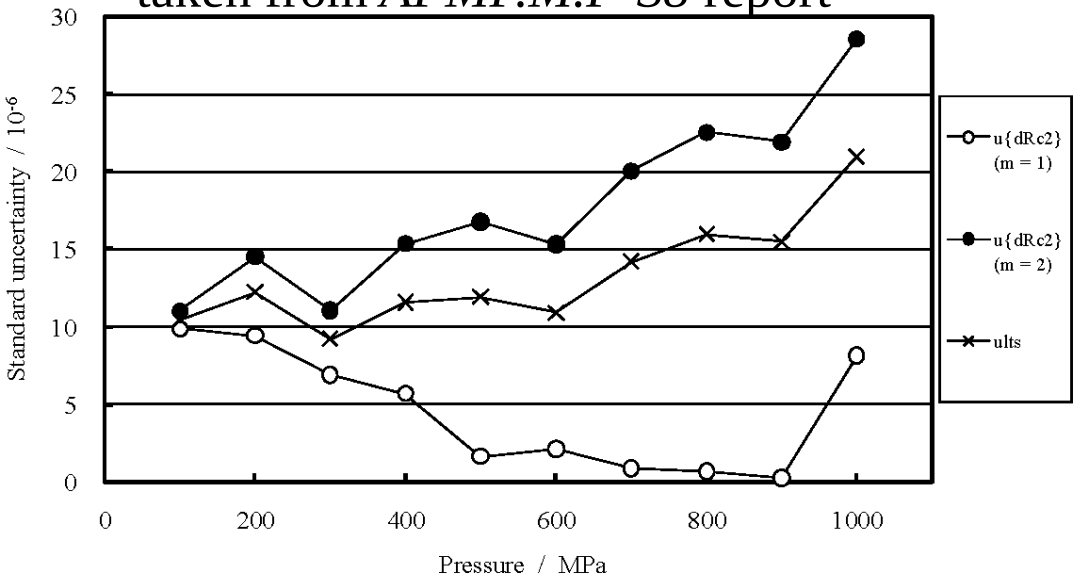


Relative difference of dR_{c2} of the reading of two typical transducers in two consecutive series at the supplementary comparison *APMP.M.P-S8* measured at the pilot institute

Relative difference less than 50 ppm in the whole range

Long-term shift

taken from *APMP.M.P-S8* report

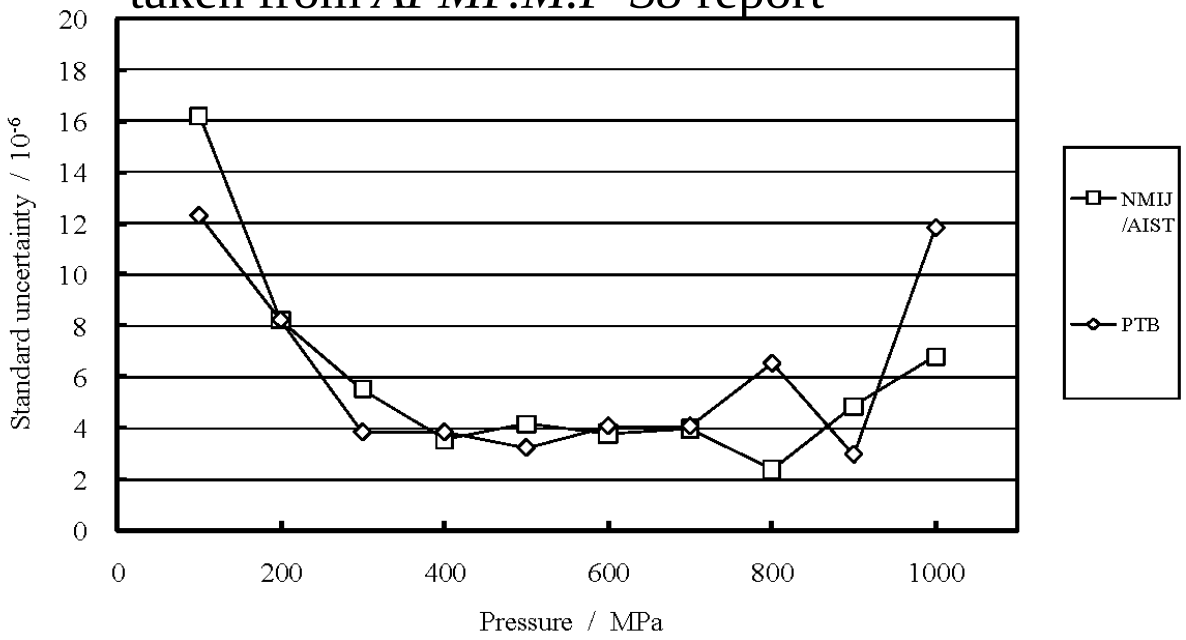


Uncertainty contribution: $u^2_{LTS}(i) = 1/2 \sum_{m/transducer} \frac{dR^2_{c2}(m,i)}{3}$

Uncertainty contribution less than 20 ppm

Short-term random errors

taken from *APMP.M.P-S8* report



Uncertainty contribution: $u_{rdm}^2(i) = \langle \sigma_i^2 \rangle$

σ_i standard deviation of measurement for each $P_n(i)$ related to short-term statistical errors

Uncertainty contribution less than 16 ppm

Temperature coefficient β

Correction for difference between nominal pressure and actual pressure

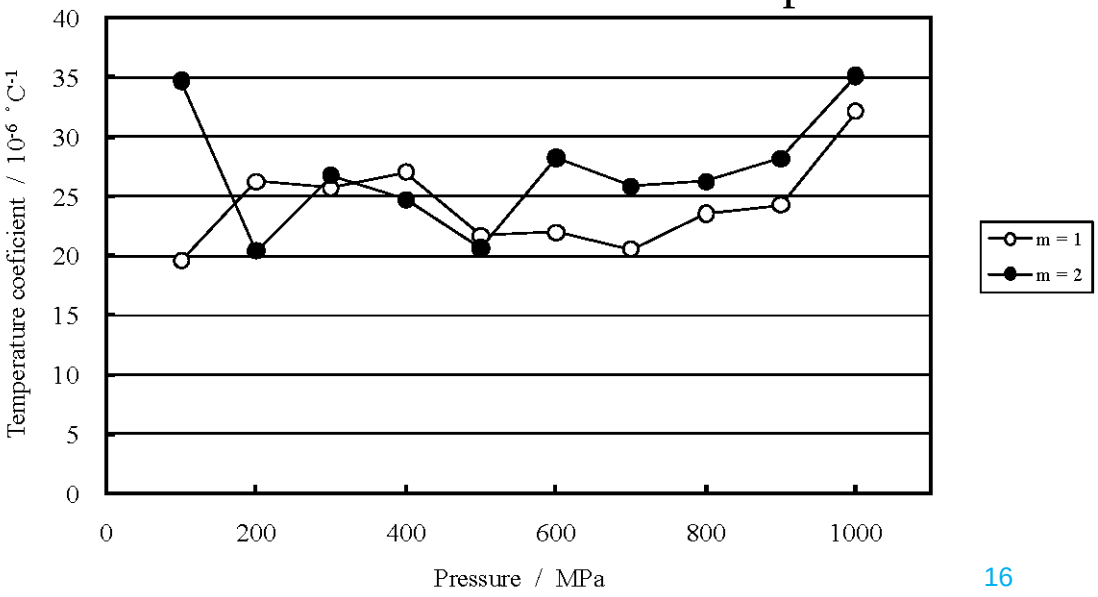
Zero-pressure offset correction

$$\beta(m,i)=\frac{1}{18}\cdot\sum_{q=1}^{3}\sum_{w=1}^{2}\sum_{y=1}^{3}\frac{R_{c1}^{q}(1,m,y,w,i)-R_{c1}^{0}(1,m,y,w,i)}{P_n(i)\cdot\left[t_b^{q}(1,y,w,i)-t_b^{0}(1,y,w,i)\right]}$$

Nominal pressure

t_b^q measured temperature around TS for q corresponding to 20,21,22,23 °C

taken from *APMP.M.P-S8* report

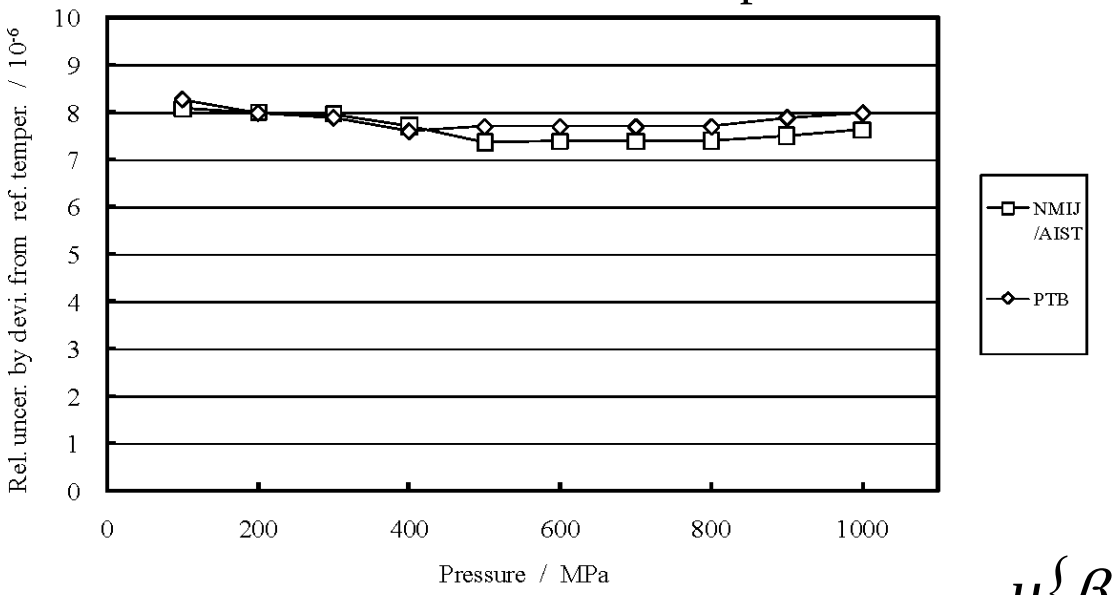


associated standard uncertainty

$$u\{\beta(m)\}=10/\sqrt{3}\times10^{-6}\ \ ^{\circ}\mathrm{C}^{-1}$$

Uncertainty due to temperature deviation

taken from *APMP.M.P-S8* report

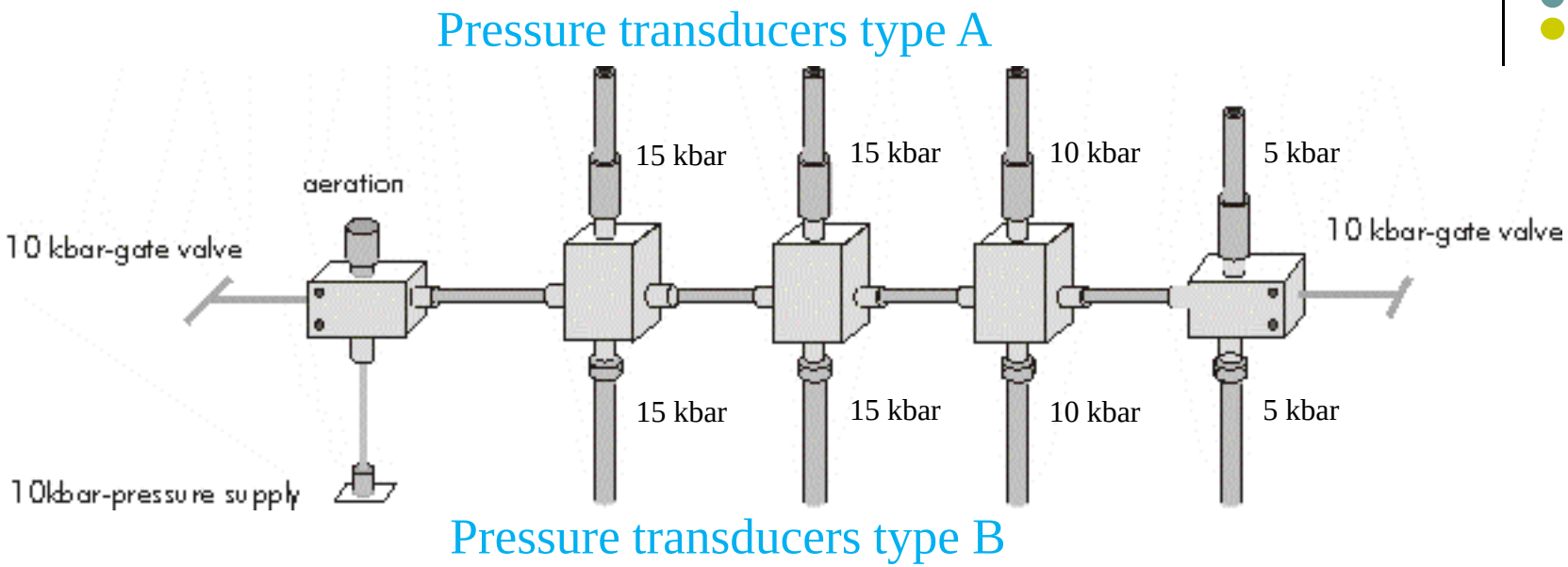


Uncertainty contribution:

$$u_{tem} = \frac{u\{\beta(i)\}}{P_n(i)} \left| \bar{t}(j,i) - t_{ref} \right|$$

Uncertainty contribution less than 8 ppm

Layout of TS



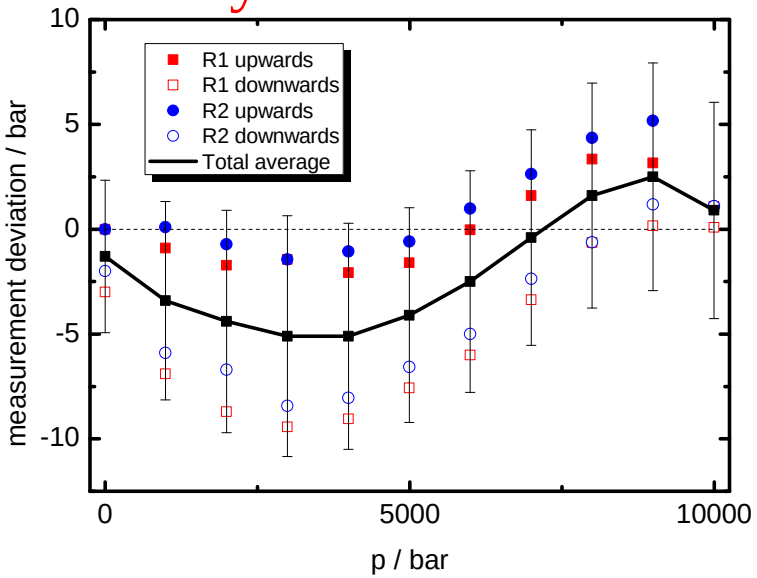
- TS consists of two types of electronic high precision pressure transducers (PTs) to ensure reliability
- Sensing element of PTs based on foil and thin-layer strain gauges
- Three PT pressure ranges (5,10,15) kbar to cover the technical capacities of other NMIs for comparisons
- TS involves measuring amplifier

Summary

- Investigation of the usability of modern pressure transducers for metrological purposes
- Demonstration of calibration of pressure transducers according to DKD-R 6-1 / practical examples
- Suitability of high-pressure transducers as transfer standards in international metrological comparisons
- Outlook: development of a transfer standard up to 1.5 GPa based on modern pressure transducers

Transducer characteristics

Hysteresis behavior



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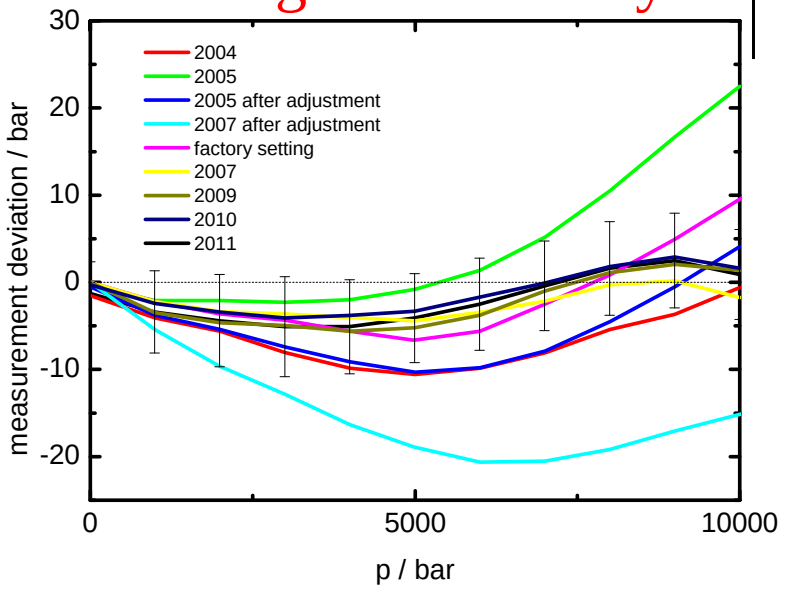

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