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METROLOGICAL HISTORY ANALYSES OF PRESSURE STANDARDS FOR DETERMINATION OF THEIR METROLOGICAL CAPABILITIES

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Abstract − The knowledge of metrological history of pressure standards is of a big importance for determination of their metrological capabilities. When providing traceability to lower metrological levels it is essential to determine the uncertainty of generated reference pressure. The estimation of the uncertainty of generated reference pressure can be done only by analysing metrological history of selected standard and estimation of all parameters that have the influence on the generated reference pressure uncertainty. Analyses of selected LMPS (Laboratory of Measurements in Process Engineering) pressure standards (mechanical and electromechanical manometers only) are showing non-negligible deviations of estimated measurement capabilities from declared accuracy for selected standards. These deviations are a source for changed best metrological capabilities and therefore require all necessary attention.

Keywords: pressure standards, measurement uncertainty, best measurement capability.

1. INTRODUCTION

Assuring traceability and in this frame also dissemination of a conventional true value of a pressure from reference standards to working standards and calibration items on the lowest level is a key issue in calibration in general and as such also in field of calibration of manometers.

Many users consider the single most important specification of a pressure standard to be the uncertainty claimed on pressure defined by the manufacturer itself. The fact is that the final uncertainty budget is highly dependant on influences that vary with conditions of operation, many of which are beyond the control of the instrument manufacturer. Therefore, uncertainty specifications provided without documenting the assumptions made in deriving them are of a little use. They cannot be used to compare one instrument to another or to reliably predict the actual global uncertainty in pressure that will be obtained in the final application.

For every calibration point the results of calibration can be given in following form:

$$p_{rss} = p_{ci} + C + U_C \tag{1}$$

meaning: p_{rss} conventional true value of pressure,
p_{ci} measured value of pressure of calibration item,
C correction and
U_C uncertainty of measurement of correction.

Determination of measurement uncertainty of correction is crucial for dissemination of a conventional true value of a pressure.

When calibrating mechanical and electromechanical manometers the uncertainty budget of measurement uncertainty of correction depends on:

- uncertainty of generated reference pressure of a reference standard used,
- uncertainty of fluid head height (u_h),
- uncertainty of reading from calibration item (u_{ci}),
- uncertainty of zero drift (u_{fo}),
- uncertainty of repeatibility (u_b),
- uncertainty of hysteresis and
- uncertainty of other influences at pressure generation (u_x).

Standard measurement uncertainty (u) of correction can be expressed as:

$$u = \pm\sqrt{\left(\frac{\partial C}{\partial p_{rss}}\right)^2 \cdot u_{\mathrm{rss}}{}^2 + \left(\frac{\partial C}{\partial p_{ci}}\right)^2 \cdot u_{\mathrm{ci}}{}^2 + u_{f0}^2 + u_b^2 + u_x^2} \tag{2}$$

or shorter:

$$u = \pm\sqrt{u_{rss}^2 + u_{ci}^2 + u_{fo}^2 + u_b^2 + u_x^2}\ . \tag{3}$$

Composed standard measurement uncertainty of reference standard's system (u_{rss}) depends on uncertainty of reference standard's generated pressure (u_{rs}) and the contribution of uncertainty influenced by hydrostatic pressure (u_h):

$$u_{rss} = \sqrt{u_{rs}^2 + u_h^2}\ . \tag{4}$$

Uncertainty of generated reference standard's pressure can be, considering reference standard metrological capabilities, assumed as reference standard accuracy.

Information about uncertainty of conventional true value of reference standard's generated pressure is crucial for metrological correct estimation of combined measurement uncertainty of correction.

The selection of a adequate reference standard, considering the criteria of its actual accuracy, measurement range and the pressure media, can be sufficient that the contribution of reference standard uncertainty in the total uncertainty budget of correction is relatively small, but we have to take in account that this is the major source of uncertainty on which we have the influence (by selection of reference standard).

Determination of the uncertainty of reference standard's generated pressure requires detailed analyses of all prior calibration results of analysed reference and working standards. Only such kind of analyse can give us a certain degree of reliability when defining accuracy of reference (or working) standards used in calibration process and defining their calibration intervals, based on cost benefit analyses, as well.

2. DETERMINATION OF MEASUREMENT CAPABILITY OF MECHANICAL AND ELECTROMECHANICAL MANOMETERS

Estimation of measurement uncertainty for reference standards can be given for a total measurement range or for a defined part of measurement range separately.

As data base for analysis of metrological history of standard last five calibration certificates are used. Data can be used to observe trends of standards behaviour. For estimation of standard's best metrological capability results from last two calibration certificates shall be processed. The method of presentation of metrological history and resulting determination of best metrological capability depends on the way the accuracy for the standard is presented:

- in absolute pressure units or in % of upper range value,
- in % of measured value of the pressure.

If the accuracy of the manometer is declared as combination of accuracy given in % of measured value and in absolute values, for example, the best measurement accuracy declaration must consider smooth matching between ranges. If this cannot be achieved, the ranges can be redefined or adequate measurement capability for a selected range can be changed.

Special attention shall be paid to estimation of item stability parameter (reproducibility with time).

Stability (reproducibility with time) can be generally expressed in two different ways as:

- in time or time interval in which metrological characteristic is changed for a certain value or
- in size of metrological characteristic change in certain time interval.

Stability parameter can't always be predictable and is generally not taken in account when defining metrological capabilities of measurement equipment, but its estimation is crucial when determining calibration interval.

2.1 *Estimation of measurement capability for manometers with accuracy given in absolute value of pressure or in % of upper range value*

For calculation of best measurement capability U_s the following equation is used:

$$U_s = 2 \cdot \sqrt{u_c{}^2 + u_r^2 + \left(\frac{D_{\max}}{\sqrt{3}}\right)^2 + u_h} + C_{\max}\,, \qquad (5)$$

meaning:

u_c	standard measurement uncertainty of last calibration,
C_{max}	the maximum correction of the last calibration,
u_r	standard uncertainty of reading,
D_{max}	estimation of the maximum of the drift between last two calibrations and,
u_h	standard uncertainty of head correction.

Standard measurement uncertainty of the last two calibrations u_c must include at least measurement uncertainty of reference standard system (of generated pressure), uncertainty of reading, uncertainty of hysteresis and uncertainty of repeatability.

Contributions of uncertainty of readings, uncertainty of hysteresis (u_h) and uncertainty of repeatability (u_b) are calculated according to [1] and [2]. If the value of u_b can't be calculated from last calibration certificate, assumption that value of u_b equals value of u_h is considered.

D_{max} is determined as maximum difference between characteristics of two successive calibrations. The difference between the "same" calibration points should be considered. If the calibration points in certificates are not the same, the closest points are compared.

Corrections from last two calibration certificates for LMPS manometer WIKA 600 bar (declared accuracy ±0,6 bar), are presented in Figure 1.

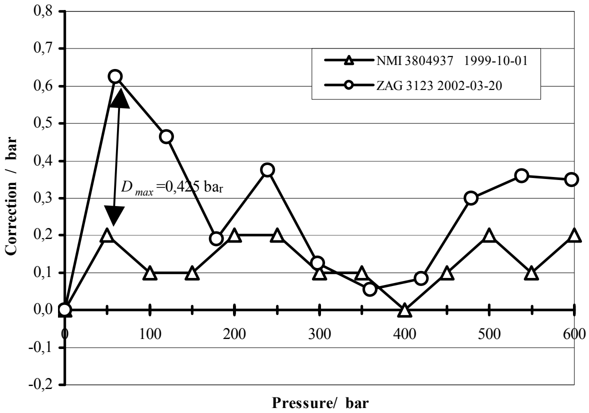

Fig. 1. Presentation of corrections from last two calibration certificates (WIKA 600 bar)

Based on data from last two calibration certificates, in range from 0 bar to 600 bar, the following parameters can be determined:

u_c = 0,24 bar,
C_{max} = 0,65 bar,
u_r = 0,2309 bar,
u_h = 0,00051 bar,
D_{max} = 0,45 bar.

Calculated best measurement capability in range from 0 bar to 600 bar (equation 5) is 1,495 bar.

Similar we can calculate BMC in reduced range from 200 bar to 600 bar. Based on data from last two calibration certificates the following parameters can be determined:

u_c = 0,24 bar,
C_{max} = 0,335 bar,
u_r = 0,2309 bar,
u_{phem} = 0,00051 bar,
D_{max} = 0,235 bar.

Calculated best measurement capability in range from 200 bar to 600 bar (equation 5) is 1,045 bar, which is significantly less than for a whole range.

2.2 Estimation of measurement capability for manometers with accuracy given in % of measured value

For calculation of best measurement capability U_s in % of measured value the following equation is used:

$$U_{rs} = \max\left\{ \frac{2}{P_i} \cdot \left(\sqrt{u_{c,i}^{\;2} + u_{r,i}^2 + \left(\frac{D_i}{\sqrt{3}}\right)^2} + C_i \right) \cdot 100 \text{ \%MV} \right\} \quad (6)$$

i = 1,..,N,

where the following notation is used:

i index of calibration point,
N number of calibration points,
$u_{c,i}$ standard measurement uncertainty of the last calibration,
C_i correction of the last calibration,
$u_{r,i}$ uncertainty of reading,
D_i drift during last two calibrations.

Determination of D_i and $u_{c,i}$ is done according the procedure for determination of D_{max} and u_c respectively, as described in 2.1.

The following example is showing determination of best measurement capability for manometers with accuracy given in % of measured value and is made for LMPS pressure standard calibrator Druck DPI 605.

Corrections from last two calibration certificates are presented in Figure 2.

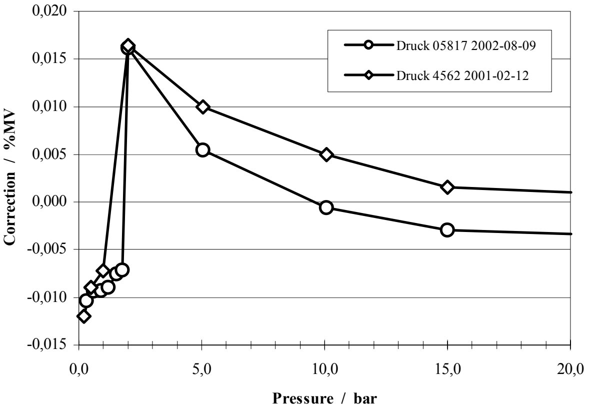

Fig. 2. Presentation of corrections from last two calibration certificates (Druck DPI 605)

Measurement range from 0,2 bar to 20 bar is analysed in 11 calibration points. Declared accuracy is 0,05 % of measured value of pressure. Based on data from last two calibration certificates the values for uncertainty contributions are presented in Table 1.

TABLE 1. Uncertainty contributions for calculating best measurement capability for DPI 605

i	$u_{c,i}$ bar	$u_{r,i}$ bar	D_i bar	u_{phem} bar	C_i bar	$U_{e,i}$ %MV
1	2,996E-05	2,887E-06	-7,000E-06	8,88E-07	-3,100E-05	3,057E-02
2	4,007E-05	2,887E-06	-1,100E-05	1,10E-06	-5,600E-05	2,285E-02
3	5,045E-05	2,887E-06	-1,200E-05	1,30E-06	-8,400E-05	2,062E-02
4	5,096E-05	2,887E-06	-3,500E-05	1,51E-06	-1,070E-04	1,806E-02
5	5,948E-05	2,887E-06	-4,460E-04	1,72E-06	-1,160E-04	4,180E-02
6	6,039E-05	2,887E-06	-4,560E-04	1,91E-06	-1,260E-04	3,751E-02
7	5,100E-05	2,887E-06	-5,000E-06	2,07E-06	3,250E-04	2,126E-02
8	1,266E-04	2,887E-05	-2,290E-04	4,15E-06	2,760E-04	1,280E-02
9	2,582E-04	2,887E-05	-5,600E-04	7,62E-06	-6,000E-05	8,825E-03
10	3,838E-04	2,887E-05	-6,700E-04	1,04E-05	-4,400E-04	1,021E-02
11	5,000E-04	2,887E-05	-8,700E-04	1,46E-05	-6,700E-04	1,043E-02

Calculated best measurement capability (U_s) in range from 0,2 bar to 20 bar (equation 6) is 4,18E-02 % of measured value of pressure.

3. ANALYSES OF BEST MEASUREMENT CAPABILITIES OF PRESSURE WORKING AND REFERENCE STANDARDS IN LMPS

The results of analyses of best measurement capabilities for selected mechanical and electromechanical manometers of LMPS are presented. Table 2 includes declared accuracy for standards (from manufacturer) and estimated value of actual measurement capability taking in account all influencing parameters.

TABLE 2. Estimation of best measurement capabilities of LMPS pressure standards

Pressure standard	**Declared accuracy**	**Estimated measurement capability**	**Difference in %**
WIKA 600 bar	0,6 bar	1,1 bar	+ 83 %
WIKA 10 bar	0,01 bar	0,015 bar	+ 50 %
WIKA 25 bar	0,025 bar	0,040 bar	+ 60 %
WIKA 60 bar	0,06 bar	0,089 bar	+ 48 %
WIKA 100 bar	0,1 bar	0,085 bar	- 15 %
WIKA 250 bar	0,25 bar	0,31 bar	+ 24 %
DPI 605 (0,2–20 bar)	0,05 %MV	0,039 %MV	- 22 %
Transducer DPI 605 40-200 bar	0,1 %MV	0,058 %MV	- 42 %
DPI 510 (14-70 bar)	0,04 %MV	0,061 %MV	+ 52 %
DPI 510 (0,8 – 1,15 bar abs)	0,15 mbar	0,15 mbar	0 %

3. CONCLUSIONS

Estimation of uncertainty of generated reference pressure can be based only on analysing metrological history of the standard used and on estimation of all parameters that have direct influence on the uncertainty.

With this aim actual measurement capabilities for all LMPS working and reference pressure standards were well analysed and documented.

As the presented analyses of LMPS reference pressure standards is showing, the deviations of estimated metrological capabilities from declared accuracies are not negligible.

This kind of deviations are leading to improvement or worsening of metrological capabilities and thus we shall pay them a great importance and attention.

The selection of a measurement range to be analysed is an important factor when calculating best measurement capabilities for a certain standard, so it is recommended to pay special attention to analysing of working ranges.

It is also important that best measurement capabilities for every standard are updated after each calibration performed.

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