PROJECT COOMET NO. 589/UA/12
COOMET.M.P-S1

Supplementary comparison of COOMET

Supplementary comparison of national measurement standards of gauge pressure in the range from 1 MPa to 10 MPa

Technical Report

Pilot-laboratory:
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Date of the project creation: 2014-01-24
The subject of the project is performance of the supplementary COOMET comparison in the area of the gauge pressure within the range from 1 MPa to 10 MPa for determination of the equivalency level of national standards in the area of pressure and provision of capability of CMC-lines publication in the database of the International Bureau of Weights and Measures.

This comparison is performed for determination of the equivalency level of national standards participating in the comparison relatively to the datum value of the effective area of the transfer standard.

1 Participants

<table>
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<tr>
<th>№</th>
<th>NMI</th>
<th>Address</th>
<th>Abbreviation of NMI</th>
<th>Contact person</th>
<th>E-mail, telephone, fax</th>
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</thead>
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<tr>
<td>1</td>
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<td>5</td>
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<td>6</td>
<td>State enterprise “Vilnious Metrological center”</td>
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<tr>
<td>7</td>
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2 Organization of comparisons

The principle of comparison is to determine the transfer standard effective area of the piston according to the method of cross-float equilibrium of transfer standard and national standards NMI-participants comparisons piston-cylinder assembly’s.
2.1 Graph comparisons

<table>
<thead>
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<th>Time</th>
<th>NMI</th>
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<tr>
<td>January 2014</td>
<td>NSC IM (initial investigation)</td>
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<tr>
<td>March 2014</td>
<td>VNIIM</td>
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<td>June 2014</td>
<td>BelGIM</td>
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<td>Сентябрь 2014</td>
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<td>September 2014</td>
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<tr>
<td>June 2015</td>
<td>NISM</td>
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<tr>
<td>September 2015</td>
<td>NSC IM (final investigation)</td>
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</table>

Graph comparisons can be specified depending on the willingness of NMI-participants.

Transfer standard shipping date to be confirmed before shipping.

Request to each participant - keep transfer standard according to the specified schedule. In case of any delay or circumstances that would lead to a delay, the participant must report the problem the pilot laboratory and the laboratory, which should come transfer standard.

2.2 Transfer standard (TS)

As TS applied piston-cylinder assembly (PCA) with a simple piston proposed NSC IM. Identification number 12.

PCA consist of:
1. Body of PCA;
2. Cylinder;
3. Bush;
4. Piston with a head and weight carrier;
5. Screw-nut clamping cylinder in the body;

Main technical characteristics of PCA:
- measurement range from 1 MPa to 10 MPa;
- nominal effective area of piston 1 sm²;
- working liquid – kerosene (it is also allowed to use other liquids non-aggressive to the material of the PCA as a working medium. Recommended dynamic viscosity is not over than 30 mPa·sec);
- piston fall rate in kerosene for pressures 10 MPa – 0,11 mm/min;
- duration of rotation in kerosene for pressures 1 MPa – 28 min;
- reference level – lower face of TS piston (at working position of piston – 8 mm above its rest position);
- material of piston and cylinder – tungsten carbide;
- thermal expansion coefficients of the piston material \((\alpha) – 4,5 \cdot 10^{-6} \, \text{K}^{-1}\);
- thermal expansion coefficients of the cylinder material \((\beta) – 4,5 \cdot 10^{-6} \, \text{K}^{-1}\);
- Young’s modulus \((E) – 621 \, \text{GPa}\);
- Poisson’s coefficient \((\mu) – 0,31\);
- mass of piston with a head and weight carrier \(\sim 1,623 \, \text{kg}\).

This PCA was manufactured 1998 and therefore is considered to be sufficiently old to have a stable value of its effective area in the period of the comparison. The relative deviations of the zero-pressure effective area observed by the pilot laboratory did not exceed \(2 \cdot 10^{-6}\) for last four years. Thus, the TS stability allows conducting quality comparisons. Nevertheless, the TS stability will be checked by comparing the results of former calibrations at the initial and at the final investigations.

### 2.3 TS transportation

Every participant is responsible for dispatch of the TS to the next participant according to the comparison schedule.

The TS is transported assembled. It must be clearly indicated on package that the equipment can be unpacked only by the qualified personnel. After arrival the TS first must be checked visually. For this purpose it is necessary to disassemble the PCA, check the condition of all assembly parts, especially the piston and cylinder working parts. Deviation from the PCA make-up (see p. 2.2) or any detected damages, if available, shall be registered and informed to the pilot laboratory.

TS shall be carefully packed with the original packing materials and containers. To avoid sealing the piston and cylinder working parts shall be lubricated with the working liquid.

### 2.4 Expenses

Every participant shall pay expenses for performance of his own measurements, any customs expenses, transportation expenses for the TS dispatch to the next participant and the expenses at loss or damage of the TS within the territory of his country.

### 3 Methods of measurements performance

#### 3.1 Conditions of measurements carrying out

Conditions of measurements carrying out:
- ambient temperature is from 18°C to 22 °C (the temperature control during each measurement);
- variation of the ambient temperature is not over 0,5 °C;
- relative humidity of the ambient air is up to 60 %;
- air flow speed in the place of the measurements carrying out is not over 0,2 m/sec;
- absence of vibration and shaking.
3.2 Manhandling with the transfer standard

During stay of the comparison standard in the laboratory, when the measurements are not carried out, the PCA of the comparison standard shall be kept in the place protected from dust, moisture and condensate formation.

The temperature stabilization before performance of the PCA measurements shall be withstood in normal conditions sufficient for its temperature stabilization (not less than 2 days from the date of its arrival).

3.3 Carrying out of the measurements

The comparison is performed on the p-method (without a preliminary equilibration of piston-cylinder assembly’s of TS and NMI national standard) or \( \Delta p \)-method (with a preliminary equilibration).

Five cycles of measurements carried out at the points according to the nominal pressure of the series (1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 10, 9, 8, 7, 6, 5, 4, 3, 2, 1) MPa. Thus, a total of 100 conducted measurements. Between the two measurements at 10 MPa is needed interval for at least 15 minutes.

For each value of the pressure calculated effective area of piston \( (A_p) \) TS. \( A_p \) is calculated for the normal temperature of 20 °C.

The design equation for p-method is the following:

\[
A_{pi} = \frac{\sum m_i g \left(1 - \frac{\rho_{oa}}{\rho_0} + \frac{\rho_{oa} - \rho_a}{\rho_i}\right) + 2 \sigma \sqrt{\pi A_{0n}}}{P_i \left[1 + (\alpha + \beta)(t_i - t_0)\right]},
\]

where:
\( \sum m_i \) is total masses of the piston, the weight carrier and the mass pieces placed on the weight carrier of TS at \( i^{th} \) measurement;
\( g \) is local gravity acceleration;
\( \rho_i \) is densities of the parts with masses \( m_i \);
\( \rho_a \) is air density;
\( \rho_{oa} \) is conventional value of the air density (1.2 kg/m\(^3\));
\( \rho_0 \) is conventional value of the mass density (8000 kg/m\(^3\));
\( \sigma \) is surface tension of the TS working liquid;
\( A_{0n} \) is nominal effective area of TS;
\( P_i \) is pressure generated by the laboratory standard at the TS reference level (lower face of TS piston), at \( i^{th} \) measurement;
\( \alpha, \beta \) are thermal expansion coefficients of the piston and cylinder materials for TS;
\( t_i \) is temperature of TS at \( i^{th} \) measurement;
\( t_0 \) is reference temperature (20 °C);
The design equation for $\Delta p$-method is the following:

$$A_{pi} = A_{nps} \frac{m_{2i} + M_2(\alpha_2 + \beta_2)(t_2 - t_{2i})[1 + (\alpha_1 + \beta_1)(t_{1i} - t_0)][1 + \lambda_i P_{in}]}{m_{1i} + M_1(\alpha_1 + \beta_1)(t_1 - t_{1i})[1 + (\alpha_2 + \beta_2)(t_{2i} - t_0)]},$$

(2)

where:

- $A_{nps}$ is zero-pressure effective area of NMI standard;
- $m_{1i}, m_{2i}$ are masses imposed on weight carrier device NMI standard and TS at $i$th measurement after the preliminary equilibration;
- $M_1, M_2$, are masses of mobile part and weights NMI standard and TS at a preliminary equilibration;
- $\alpha_1, \beta_1$ are thermal expansion coefficients of the piston and cylinder materials for NMI standard;
- $\alpha_2, \beta_2$ are thermal expansion coefficients of the piston and cylinder materials for TS;
- $t_1, t_2$ are temperature of NMI standard and TS at a preliminary equilibration;
- $t_{1i}, t_{2i}$ are temperature of NMI standard and TS at $i$th measurement;
- $t_0$ is reference temperature (20°C);
- $\lambda_i$ is pressure distortion coefficient of the NMI standard piston-cylinder assembly;
- $P_{in}$ is nominal value of pressure at $i$th measurement.

The average value of the effective area of the TS piston at each rated pressure value is calculated according to the equation:

$$\bar{A}_p = \frac{\sum_{i=1}^{k} A_{pi}}{k},$$

(3)

where $k$ is the number of measurements at each pressure rated value.

### 3.4 Uncertainty budget

Type A standard uncertainty at the same nominal pressure:

$$u_A(\bar{A}_p) = \frac{1}{\sqrt{k(k-1)}} \sum_{i=1}^{k} (A_{pi} - \bar{A}_p)^2$$

(4)

Type B standard uncertainty at the same nominal pressure:

$$u_B(\bar{A}_p) = \sqrt{\sum u^2_B(A_{pi})},$$

(5)

where $u_B(A_{pi})$ is the uncertainty components conditioned by influence of systematic factors at measurements (determined by the comparisons participants self-sufficiently).
Combined standard uncertainty at the same nominal pressure:

\[ u(A_p) = \sqrt{u^2(A_p) + u^2(B_p)} \]  \hspace{1cm} (6)

3.5 Report form

The report about the results shall contain the information about delivery and dispatch of the comparison standard:

- the date of supply, the description of damages (if available);
- the date of the measurements beginning;
- the date of the measurements finishing;
- the date of dispatch, the way of dispatch (by mail, with a courier).

Each NMI must provide the pilot laboratory data of its national standard form attached as Annex 1.

Each NMI indicates the method by which the measurements were (p or Δp). The measurement results are served in the form of Annexes 2 and 3.

Additionally, given the value of the zero pressure effective area of the piston TS \( A_0 \), the pressure distortion coefficient of the piston and the cylinder TS \( \lambda \), which are associated with \( A_p \) by formula:

\[ A_p = A_0 (1 + \lambda P) \]  \hspace{1cm} (7)

and based on the results of all 100 measurements, as well as their combined standard uncertainty \( u(A_0) \) and \( u(\lambda) \), and given how they were calculated.

Data with the results of the measurements shall be provided to the pilot laboratory within two months after the measurement.

4 Evaluation method of the comparisons results

The pilot laboratory collaboratively evaluates the comparisons basing on the reports about results submitted by the participants. The reference value will be evaluated as the results average value obtained by the comparisons participants. Processing of the results will be carried out according to the COOMET recommendation R/GM/11:2008. More detailed information will be given in the first draft report about the comparisons results.

After completion of the whole program by all the participants the pilot laboratory collaboratively will prepare the draft report about the comparisons (draft A). The draft report will be sent to the participants for consideration and discussion. After agreement the final project of the report about comparisons (draft B), which will be represented at the regular meeting TC 1.6 COOMET “Mass and values connected with it” will be prepared. After approval of the project B of TC 1.6 COOMET the results and the report will be directed to the COOMET Secretariat. The report will represent the Technical Supplement for the publication in Metrologia.
Annex 1

NMI standard and measurement conditions

The uncertainties here should be expressed as the standard ones.

<table>
<thead>
<tr>
<th>Manufacturer</th>
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<tbody>
<tr>
<td>Measurement range in MPa</td>
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<tr>
<td>Material of piston</td>
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<td>Material of cylinder</td>
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</table>

Zero-pressure effective area ($A_0$) at reference temperature in $\text{sm}^2$

Relative uncertainty of $A_0$ in $10^{-6}$

Pressure distortion coefficient ($\lambda$) in $\text{MPa}^{-1}$

Uncertainty of $\lambda$ in $\text{MPa}^{-1}$

Relative uncertainty of mass pieces in $10^{-6}$

Linear thermal expansion coefficient of piston ($\alpha$) $\text{in } ^\circ\text{C}^{-1}$

Linear thermal expansion coefficient of cylinder ($\beta$) $\text{in } ^\circ\text{C}^{-1}$

Reference temperature ($t_0$) in $^\circ\text{C}$

Local gravity ($g$) in $\text{m/s}^2$

Relative uncertainty of $g$ in $10^{-6}$

Height difference between NMI standard and TS ($h$, positive if NMI standard is higher than TS) in mm

Uncertainty of $h$ in mm

In addition, the methods to determine $A_0$ and $\lambda$ as well as their uncertainties should be reported.
Annex 2

Results in individual cycles

NMI name : 

Date (period) : 

Cycle number : 

Average relative air humidity and its uncertainty :

<table>
<thead>
<tr>
<th>Meas. no.</th>
<th>Nominal pressure (MPa)</th>
<th>$t$ (°C)</th>
<th>$t_{amb}$ (°C)</th>
<th>$P_{amb}$ (kPa)</th>
<th>$P_i$ (MPa)</th>
<th>$t_i$ (°C)</th>
<th>$A_{pi}$ (sm²)</th>
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$t$ – temperature of the NMI standard;

$t_{amb}$ – temperature of ambient air;

$p_{amb}$ – pressure of ambient air;

$p_i$ – pressure generated by the NMI standard at the TS reference level;

$t_i$ – temperature of TS;

$A_{pi}$ – effective area of TS at the reference temperature 20 °C.

The formula to calculate $P_i$ must be reported.
Annex 3

Summary of all cycles

NMI name : 

Date (period) : 

<table>
<thead>
<tr>
<th>Nominal pressure (MPa)</th>
<th>Typical min. adjusted mass (mg)</th>
<th>Average of $\bar{A}_p$ (sm²)</th>
<th>Standard uncertainty $u_A(\bar{A}_p)/\bar{A}_p$ ($10^{-6}$)</th>
<th>Standard uncertainty $u_B(\bar{A}_p)/\bar{A}_p$ ($10^{-6}$)</th>
<th>Combined standard uncertainty $u(\bar{A}_p)/\bar{A}_p$ ($10^{-6}$)</th>
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1) the smallest mass adjusted on TS to unbalance TS and NMI standard;

2) average of the values measured at the same nominal pressure;

3) type A standard uncertainty at the same nominal pressure;

4) type B standard uncertainty at the same nominal pressure;

5) combined standard uncertainty at the same nominal pressure.

In addition, a calculation of type B standard uncertainty budget for pressures 1 MPa and 10 MPa must be presented.

All the uncertainties should be expressed as the standard ones.