EURAMET.M.P-S16:

Bilateral comparison in high gauge pressure 250 MPa

(EURAMET Project No. 1375)

Final Report

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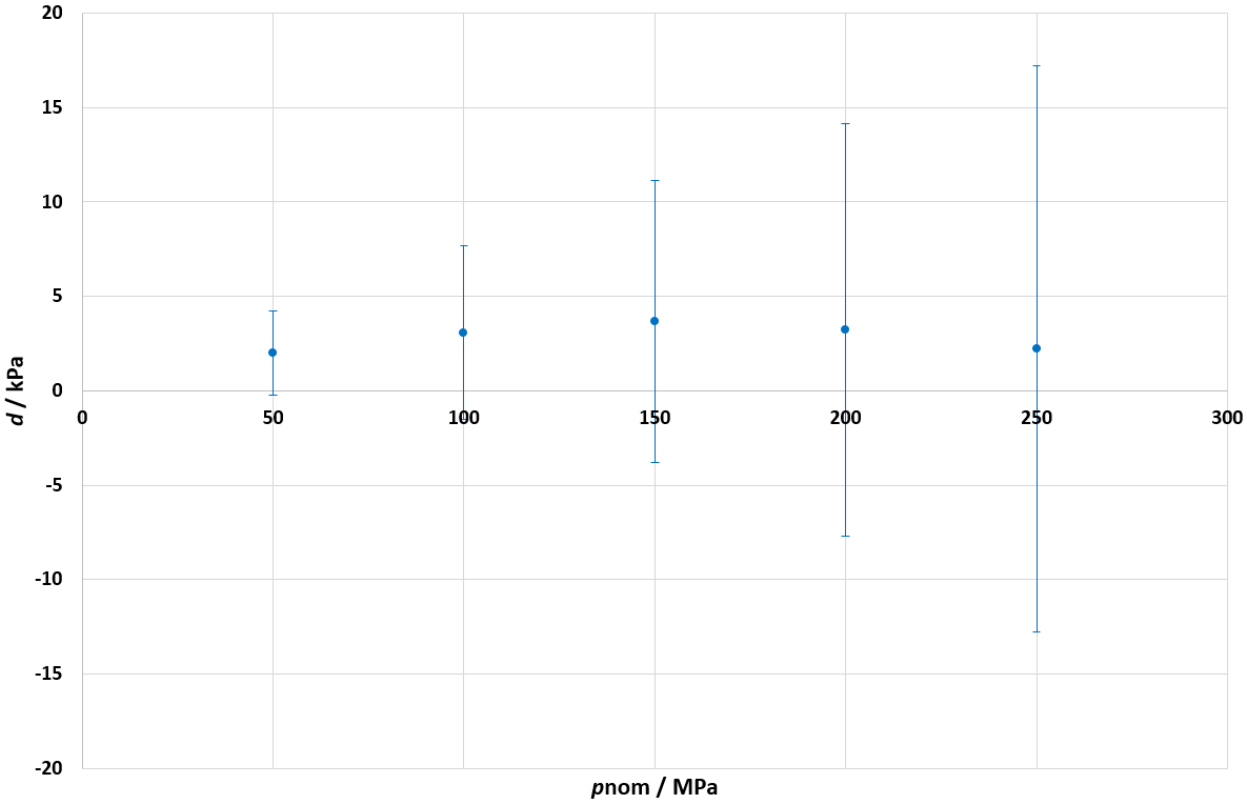
Abstract:

CMI and GUM agreed a bilateral comparison in high gauge pressure up to 250 MPa in oil medium. This comparison was initiated as EURAMET Project No. 1375 and obtained a designation EURAMET.M.P-S16. A direct comparison method was used – a pressure balance of GUM reference standard was compared to a pressure balance of CMI. There were no discrepant measurements (with the resultant standardised equivalence degrees between 0.15 and 0.88) and CMI and GUM confirmed their equivalence.

Graphical Summary of Results: The difference of the CMI and GUM values with 95 % confidence level error bars for its uncertainty at each nominal pressure point of the comparison.



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1. Introduction

In October 2005 the Polish Central Office of Measures (GUM) established its CMC entry for high pressure (up to 250 MPa) equal to $2.0 \cdot 10^{-4} \cdot p$ based on the old piston cylinder unit of MP-2500 pressure balance. However, this level of uncertainty was definitely unsatisfactory, so it was decided to replace aged standard with a new one. As a result, new pressure balance was purchased and installed in GUM, in the end of 2013 year. EURAMET.M.P-S16 (EURAMET Project 1375) bilateral comparison with Czech Metrology Institute (CMI) in high gauge pressure up to 250 MPa was aimed to demonstrate the competence of GUM and mutual equivalence of the standards of CMI and GUM to give a basis for a CMC entry update.

2. List of Participants, Facilities Used, Circulation Scheme

The participants were GUM (pilot) and CMI, see Tab. 1 for the contact details. Comparison was performed at CMI laboratories in Brno in October 2015. Transportation of the standard of GUM to and from CMI was performed by GUM staff, using a company car. Both standards were compared directly. They used the piston-cylinder units (PCUs) of different manufacture and independent traceability but with equal nominal value of effective area, see Tab. 2 for the details.

Table 1 *- The participant contacts*

	CMI	**GUM**
Contact	Dominik Pražák	Adam Brzozowski
Address	Okružní 772/31 63800	Elektoralna 2 00-139 Warszawa
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Phone	+420545555226	+48225819085

Table 2 *- The standards used*

	CMI	**GUM**
Type	Pressure balance	Pressure balance
Manufacturer	DHI	Desgranges et Huot
Model	PG 7302	CPB 6000 HX
Range	(5 to 500) MPa	(5 to 250) MPa
Pressure medium	Oil (sebacate)	Oil (sebacate)
Material of piston	tungsten carbide	special stainless-steel (Cr-Ni)
Material of cylinder	tungsten carbide	tungsten carbide
Effective area at 20 °C without pressure (m^2)	$1.961612 \cdot 10^{-6}$	$1.961574 \cdot 10^{-6}$
Pressure distortion coefficient (Pa^{-1})	$6.2 \cdot 10^{-13}$	$8.4 \cdot 10^{-13}$
Thermal expansivity coefficient of the PCU ($°C^{-1}$)	$9.0 \cdot 10^{-6}$	$14.5 \cdot 10^{-6}$
Serial no.	PG 7302 / 200 (stand) / 2077 (mass set) / 1637 (piston-cylinder)	13091/13088
Traceability	To the geometrically evaluated $10cm^2$ gas-operated PCUs of the CMI	LNE Calibration Certificate No P116846/2, date 18.11.2013
Comparisons	EUROMET.M.P-K4, 10 – 100 MPa, 1999, [1,2] unpublished bilateral comparisons till 2000, [3] bilateral comparison, 20 – 200 MPa, 2005, [4] EURAMET.M.P-K7, 50 – 500 MPa, 2005, [5,6] EURAMET.M.P-S14, 50 – 500 MPa, 2013, [7,8]	EURAMET.M.P-S13, 10 – 100 MPa, 2015, [9]
CMC uncertainty (k = 2)	$1.9 \cdot 10^{-13} \cdot p^2 + 2.3 \cdot 10^{-5} \cdot p + 9$ Pa (p in Pa)	$3.2 \cdot 10^{-5} \cdot p + 310$ Pa (p in Pa)

3. Comparison Protocol, Methods and Conditions

The comparison protocol was written by GUM. Method used for measurements was direct comparison of GUM and CMI pressure balances by cross-floating. The following gauge pressure points were chosen: (50; 100; 150; 200; 250) MPa of increasing pressure (only in loading) in five measurement series. The real pressures had to lie within 1 % of the nominal value. Due to only five pressure points across the comparison range, it was possible to perform all five series within one day (15th October 2015). Immediately after the completion of the measurements, the CMI filled in an Excel sheet prepared by the pilot and provided it to the GUM. Expanded uncertainty (k = 2) U_{CMI} of the gauge pressure measured by CMI p_{CMI} was calculated according to the ordinary procedure of CMI. Expanded uncertainty (k = 2) U_{GUM} of the gauge pressure measured by GUM p_{GUM} is the claimed uncertainty of GUM.

The comparison method was the cross-float method using the piston fall rates as the equilibrium criterion. The pressure transmitting medium was the di(2)-ethyl-hexyl-sebacate oil provided by GUM, its surface tension was taken to be 0.031 N/m. Both standards were located close to each other to keep the pressure line between the two instruments as short as possible. The height difference was leveled within 1 mm. Horizontality of both standards was checked with the built-in spirit levels and on the top level of the mass loading bells after the significant changes of the loaded mass. The measurements were performed at the CMI pressure lab at usual laboratory conditions, the local acceleration due to gravity was (9.809273 ± 0.000010) $\mathrm{m{\cdot}s^{-2}}$, the ambient temperature spanned from 20.1 °C to 20.4 °C, the atmospheric pressure from 975.4 hPa to 979.0 hPa and the relative humidity from 46 % to 51 %. Each standard had its own measurement of temperature of its PCU. In the case of the CMI standard it spanned from 20.20 °C to 20.45 °C and in the case of the GUM standard it spanned from 19.28 °C to 19.61 °C.

For each standard, the generated pressures were calculated based on the noted data, according to the following equation:

$$p = \frac{m\left(1 - \frac{\rho_{\mathrm{a}}}{\rho_m}\right) g + \sigma c}{A_0(1 + \alpha[T - T_{\mathrm{r}}])(1 + \lambda p)},$$

where:

p gauge pressure measured at the bottom of the piston,

m total mass applied on the piston,

g local acceleration due to gravity,

ρ_{a} density of air,

ρ_m density of the total mass,

σ surface tension of the oil,

c circumference of the piston,

A_0 effective area of the piston-cylinder unit at base conditions,

λ distortion coefficient of the PCU,

α linear thermal expansion coefficient of the PCU,

T temperature of the PCU,

T_r reference temperature (20 °C).

4. Results

The pressure values determined by the standards of CMI and GUM for each nominal pressure and each of five series are listed in Table 3. For each measurement point, the average value of difference between GUM and CMI d was calculated from five series differences d_i. These can be found in Table 4, together with the reported uncertainties and type-A uncertainty $u_A(d)$ of d (this uncertainty is not significant and was not used in further calculations). The results are also summarised graphically in Figure 1.

Table 3 *– Comparison values*

p_{nom}	p_{CMI1}	p_{GUM1}	p_{CMI2}	p_{GUM2}	p_{CMI3}	p_{GUM3}	p_{CMI4}	p_{GUM4}	p_{CMI5}	p_{GUM5}
MPa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa
50	49989549	49991071	49989063	49991174	49989099	49991279	49989149	49991062	49989106	49991251
100	99976331	99979360	99976397	99979295	99976488	99979616	99976548	99979855	99976470	99979511
150	149960263	149963964	149960275	149964080	149960452	149964257	149960460	149964125	149960382	149963781
200	199941517	199944880	199941473	199944645	199941805	199944978	199941745	199945163	199941569	199944569
250	249919619	249921388	249919601	249921958	249920057	249922446	249919929	249922132	249919713	249922106

Table 4 *– Resulting differences*

p_{nom}	U_{CMI}	U_{GUM}	d_1	d_2	d_3	d_4	d_5	d	$u_A(d)$
MPa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa
50	1155	1910	1522	2111	2180	1913	2145	1974	122
100	2975	3509	3029	2898	3128	3307	3041	3081	67
150	5467	5109	3701	3805	3805	3665	3399	3675	74
200	8629	6708	3363	3172	3173	3418	3000	3225	75
250	12462	8308	1769	2357	2389	2203	2393	2222	118

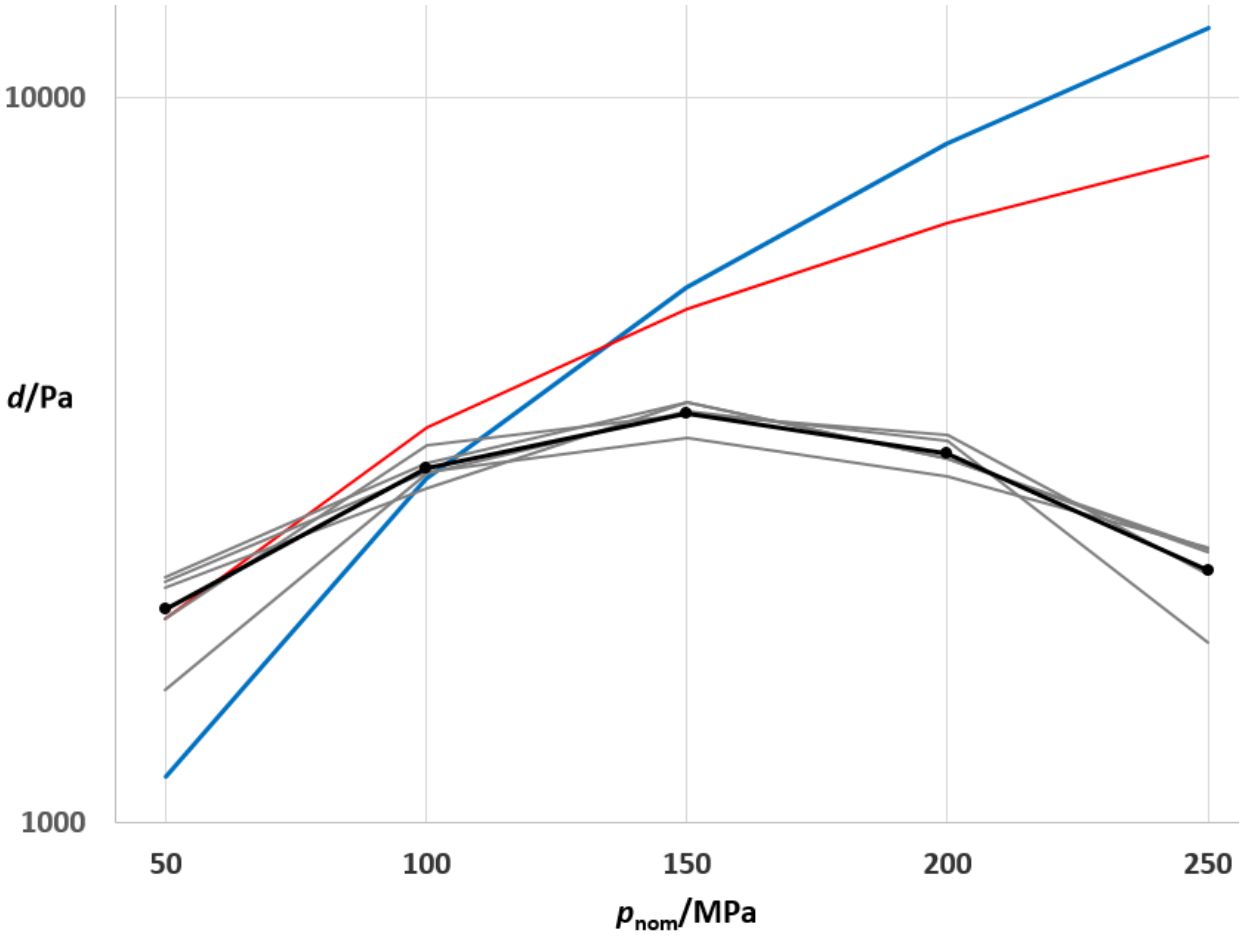

Figure 1 – The comparison results, d_i - grey, d - black, U_{CMI} - blue, U_{GUM} - red

5. Degrees of Equivalence

The comparison results (see also Table 5) were evaluated as the standardised equivalence degrees, using the following equation:

$$E_{\mathrm{n}} = \frac{d}{\sqrt{{U_{\mathrm{CMI}}}^2 + {U_{\mathrm{GUM}}}^2}}.$$

Table 5 *– The resultant equivalence between CMI and GUM*

p_{nom}	U_{CMI}	U_{GUM}	d	E_{n}
MPa	Pa	Pa	Pa	-
50	1155	1910	1974	0.88
100	2975	3509	3081	0.67
150	5467	5109	3675	0.49
200	8629	6708	3225	0.30
250	12462	8308	2222	0.15

This supplementary comparison was not aimed (and due to the time elapsed since [1] and [6] even not meaningful) to be linked with any key comparison. However, GUM participated in a supplementary comparison [9] in pressures up to 100 MPa in approximately the same time period. Hence, it is meaningful to check a consistency with this comparison at the relevant pressure points. To perform a "link" to the "reference value" of [9] it is necessary to increase d by 600 Pa at 50 MPa and to decrease d by 1300 Pa at 100 MPa. If we look in Table 28 in [9] for the respective comparison reference value uncertainties, they are 4800 Pa at 50 MPa and 5700 Pa at 100 MPa. The resultant values of E_{n} are in such case (1974 + 600)/$(4800^2 + 1155^2)^{1/2}$ = 0.24 and (3081 - 1300)/$(5700^2 + 2975^2)^{1/2}$ = 0.50.

6. Summary

The bilateral supplementary comparison EURAMET.M.P-S16 for gauge pressure from 50 MPa to 250 MPa between CMI and GUM was conducted in October 2015. The differences were even below the sole uncertainty of GUM in most pressure points. There were no discrepant measurements (with the resultant standardised equivalence degrees between 0.15 and 0.88) and the equivalence of CMI and GUM was confirmed.

7. References

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