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EXPERIENCE WITH FORCE-BALANCED PISTON GAUGE AS A TRANSFER-STANDARD

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Abstract − This report describes the comparisons of five European National Metrology Institutes (CMI, INRIM, LNE, MIKES and PTB) in low gauge, negative gauge and absolute pressure in gas. The main intention was to state equivalence of the low pressure standards, in particular those based on the technology of force-balanced piston gauges. All the participants successfully proved their equivalence. The comparison also demonstrated the ability of FPG8601 to serve as a transfer standard.

Keywords: equivalence of national standards, pressure metrology, interlaboratory comparison, force-balanced piston gauge

1. INTRODUCTION

The digital non-rotating pressure balance FPG8601 manufactured by Fluke/DH-Instruments is based on a 10 cm^2 non-rotating tungsten-carbide piston-cylinder with a conical gap, see [1]. It is used for gauge and absolute pressures in the range from 1 Pa to 15 kPa, but with some modifications it can be used also for the negative gauge pressures in the same range.

The claimed uncertainties of this instrument (e.g. CMI: 0.02 Pa + 28 ppm, both for absolute and gauge) are rather low, so it is not easy to find a suitable transfer standard to prove them. To use this instrument itself for this purpose was the only solution. There was already some experience gained during EURAMET.M.P-S2, see [2]. Hence CMI decided to pilot a series of bilateral comparisons to state equivalence of the national low pressure standards, in particular those based on the technology of force-balanced piston gauges such as e.g. FRS by Furness Controls and FPG8601.

2. ABSOLUTE AND GAUGE PRESSURE COMPARISON

Starting as a EURAMET Project No. 1047, it was agreed to be converted in a key/supplementary comparison in the range from 1 Pa to 15 kPa of absolute and gauge pressure in gas, denoted as EURAMET.M.P-K4.2010. The comparison in absolute mode serves as a EURAMET Key Comparison which can be linked to CCM.P-K4 and CCM.P-K2 via PTB. The comparison in gauge mode is a supplementary comparison. The comparison was carried out from September 2008 till October 2012. CMI agreed to be the pilot laboratory and provide a transfer standard (TS) for the comparison. This TS is also laboratory standard (LS) of CMI at the same time which resulted in a star comparison scheme. Each LS was evaluated in its own institute, so that they were considered to be independent. The nominal pressure points were 1 Pa (optional), 3 Pa, 10 Pa, 30 Pa, 100 Pa, 300 Pa, 1 kPa, 3 kPa, 10 kPa and 15 kPa both absolute and gauge. Measurements were performed in two cycles for gauge and two cycles for absolute pressure. Each cycle was performed on a different day. The pressure transmitting medium was dry nitrogen (dry is the gas entering FPG stand, however the FPG adjusts relative humidity of the gas to approximately 50 % via its internal reservoir of water).

The participating laboratories were the following: CMI-Brno, INRIM-Torino, LNE-Paris, MIKES-Espoo, PTB-Berlin (absolute pressure 1 kPa and below) and PTB-Braunschweig (absolute pressure 1 kPa and above and gauge pressure). Four laboratories utilized a digital non-rotating piston gauge FPG8601 in this comparison. These were CMI [3], INRIM, LNE [4] and MIKES [5]. Their effective areas were determined by the cross-floating techniques in all cases. CMI and INRIM added also the evaluations by the measurement of the piston-cylinder geometry. PTB-Braunschweig used their force compensated digital piston gauge FRS5 manufactured by Furness Controls [6] in the gauge mode which is traceable to the PTB primary Hg-manometer. PTB-Braunschweig also covered the absolute mode above 1 kPa with their modified commercial dual-cistern Hg-manometer described in detail in [7-10]. PTB-Berlin used their modified FRS5 in the range from 30 Pa to 1 kPa which is not only traceable to the PTB primary Hg-manometer, but also evaluated geometrically [11]. Below 30 Pa, PTB-Berlin utilized a static expansion system, described in detail in [12-14]. The primary standards of PTB, mainly the Hg-manometer and the static expansion system were crucial for this comparison, because they represented different physical principles of the primary standards.

3. PROCEDURE OF THE ABSOLUTE AND GAUGE PRESSURE COMPARISON

The comparison measurements were performed using a differential 1 torr (133 Pa) fullscale capacitance diaphragm gauge (CDG) as a zero indicator and as a separator between both standards by comparisons with the force-balanced piston gauges and the static expansion, see Fig. 1 and 2. There was no need of using the CDG by comparison with the Hg-manometer. The CDG was provided by CMI with a calibration for both plus and minus indications with an emphasis on the range around zero. However, during the measurements the CDG indication was kept as near to zero as possible.

The pressure defined from the TS (based on the CMI data and corrected for TS zero drift) in combination with the CDG reading was used to predict the pressure of the LS. This predicted value was compared to the value evaluated from the LS itself (also corrected for its zero drift). The head pressure had a significant value only in the comparison with FRS5 in gauge mode. For nominal pressures lower than 100 Pa in absolute mode, the thermal transpiration corrections had to be applied.

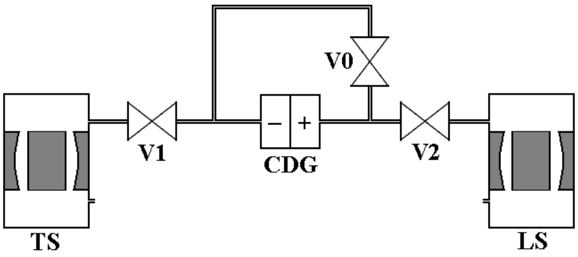

Fig. 1. Arrangement in the gauge mode.

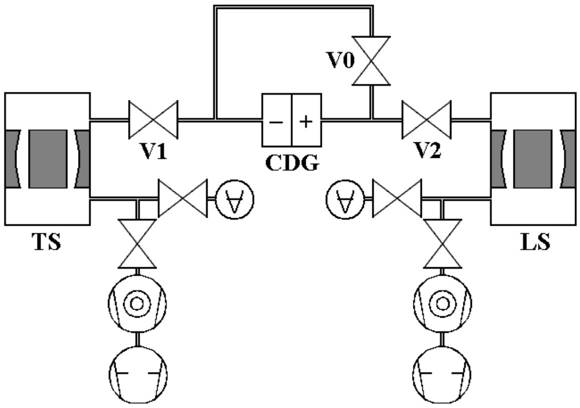

Fig. 2. Arrangement in the absolute mode.

3.1. Notes to comparisons with the FPGs

A bypass line with a valve V0 connected the two sides of the zero pressure indicator to control its zero pressure reading. The zero indicating CDG was heated during absolute mode measurements, but not heated (however long term stabilized) during gauge mode measurements. The CDG was connected to both standards via tubing (bellows) that were as similar to each other as possible concerning their diameters and volumes. The by-pass valve V0 of the CDG did not induce large changes of pressure. For gauge mode measurements, both reference ports of TS and LS were left fully open to atmosphere. For absolute mode measurements; it was recommended to check (calibrate) the reference vacuum gauges by a vacuum meter at real working reference pressure value. It was performed by a spinning-rotor gauge or another suitable vacuum gauge mounted between interconnected reference ports of TS and LS. The same gauge was used for zero checking of both TS and LS.

Both TS and LS were switched on at least 24 h before the start of the comparison. Linearity of the mass comparators of both the TS and the LS were checked before the start of the comparison measurements. Before the start of the comparison measurements both standards were zeroed and then calibrated internally. (Check of the internal calibration was repeated every four hours.) Then both instruments were zeroed again and the zero was checked and recorded. Then the isolation valve (V1 or V2) between both standards was closed (but with CDG by-pass valve V0 remaining open). Only after this, the target nominal pressure was set by an FPG that was not connected to the CDG at the moment. Then the generated target pressure was set by the other FPG (filling also CDG). After stabilization, the zero of the CDG was read at the open by-pass valve V0. Then the by-pass valve V0 was closed and the isolating valve (V1 or V2) opened. After a stabilization of reading, 5 successive readings were taken by averaging outputs of FPGs and CDG during at least 1 min. After measuring a point, a check of the CDG zero drift (if sufficiently stable this checking did not need to be performed after every point) and check of the zero drifts of both standards were done. The results were corrected for these drifts.

3.2. Notes to comparisons with the FRS5 in gauge mode

The TS was operated with moist nitrogen, whereas dry nitrogen was used in the LS. The experimental set-up was analogical to Fig. 1. Several tests were carried out with different configuration of the reference ports of the TS and the LS to minimise instability of their readings caused by the ambient pressure fluctuations. Finally, it was decided to let the reference ports of both instruments opened to atmosphere. However, in this configuration, the instability of readings was considerable.

4. RESULTS OF THE ABSOLUTE AND GAUGE PRESSURE COMPARISON

The degrees of equivalence to the reference value in gauge mode were always better than 0.63. The bilateral equivalences of the participants in gauge mode were always better than 0.83. The degrees of equivalence to reference value in absolute mode were always better than 0.82. The bilateral equivalences of the participants in absolute mode were always better than 0.93. Finally, the link for the results in absolute mode to CCM.P-K4 and CCM.P-K2 was to be determined. (The comparison in gauge mode is a supplementary comparison.) Such points can be utilised which share the same LS for their determination. There are four such points: 3 Pa, 10 Pa and 30 Pa for CCM.P-K4 and 10000 Pa for CCM.P-K2. All the participating labs were also equivalent with reference values of CCM.P-K4 and CCM.P-K2, while the corresponding degrees of equivalence were always smaller than 0.56 in this case, see Fig. 3 - 6.

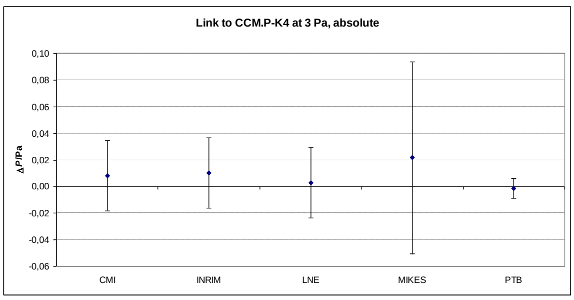

Fig. 3. The differences to the CCM.P-K4 reference value at 3 Pa.

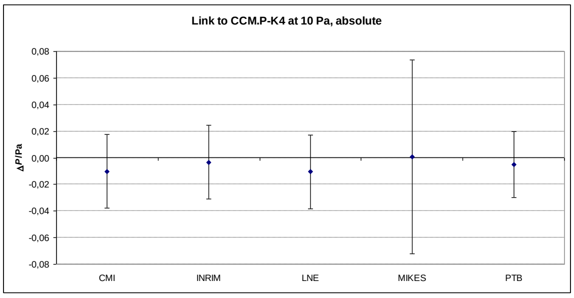

Fig. 4. The differences to the CCM.P-K4 reference value at 10 Pa.

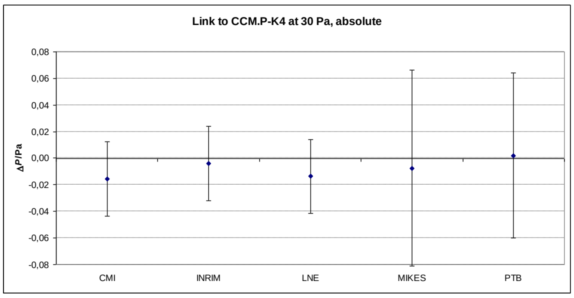

Fig. 5. The differences to the CCM.P-K4 reference value at 30 Pa.

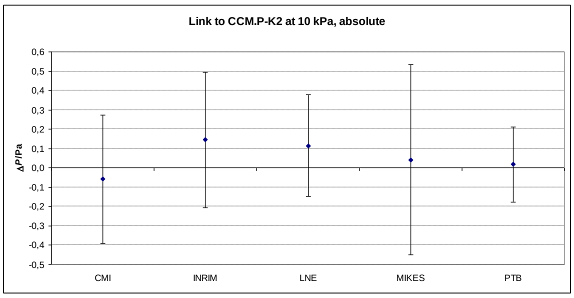

Fig. 6. The differences to the CCM.P-K2 reference value at 10 kPa.

5. NEGATIVE GAUGE PRESSURE COMPARISON

The calibrations of the negative gauge pressures has been a neglected branch of the primary metrology with the lack of the international interlaboratory comparisons [15]. Recently an intercomparison (EURAMET.M.P-S8) was performed [16] and two others are being in progress (EURAMET.M.P-S9, SIM.M.P-S5), but none of these covers the negative gauge pressures lower than 10 kPa.

During the preparation of the visit of INRIM at CMI for the last comparison within the framework of EURAMET.M.P-K4.2010, it was agreed to perform also an additional comparison in the range from 300 Pa to 15 kPa of negative gauge pressure. It was registered as a supplementary comparison (EURAMET.M.P-S12). The measurements were performed in October 2012. The nominal negative gauge pressure points were 300 Pa, 1 kPa, 3 kPa, 10 kPa and 15 kPa. Measurements were performed in two cycles in two different days. Again, nitrogen was used as pressure transmitting medium.

6. PROCEDURE OF THE NEGATIVE GAUGE PRESSURE COMPARISON

In this case a digital pressure controller Fluke/DH-Instruments PPC3-200K was used for pressure regulation of both FPGs instead of the Fluke/DH-Instruments Very Low Pressure Controllers (VLPCs) which is otherwise normally utilized. (When measuring in negative mode, the VLPCs of both FPGs were connected to their FPGs only electrically but pneumatically disconnected and the setting “maximum range” was chosen in the software menus of both FPGs.)

Again the same CDG served as a zero indicator and as a separator between both standards and it was not heated during the measurements. Both reference ports (but in the negative gauge mode the upper port serves as the reference port) of both standards were fully open to atmosphere. There was no height difference between the reference levels of both standards within an uncertainty of about 1 mm. The measurement procedure was an analogy of that for gauge mode.

7. RESULTS OF THE NEGATIVE GAUGE PRESSURE COMPARISON

The bilateral degrees of equivalence were always below 0.84, so that both institutes proved their full equivalence in the range from 300 Pa to 15 kPa of negative gauge pressure, see Fig. 7.

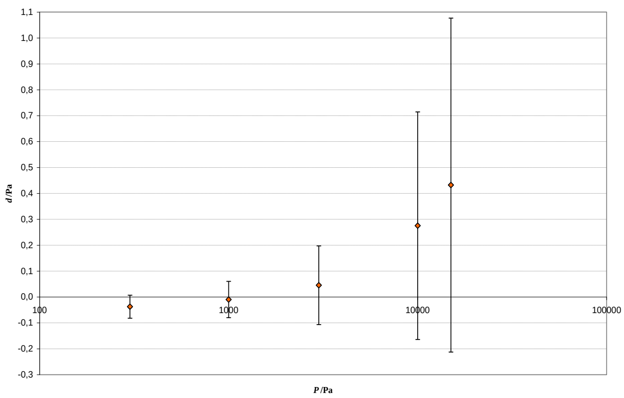

Fig. 7. Mutual equivalence of CMI and INRIM in the negative gauge mode.

8. RECENT EXPERIENCES

Some extra experiments after finishing the mentioned above comparisons also showed that there is no need of a separating CDG if both FPGs are controlled by an only one common VLPC or in the case of negative gauge mode also other controller as can be seen in Fig. 8. All the pressure connections from VLPC are doubled and both FPGs are pneumatically connected to the shared VLPC. The connection of both FPGs is done as in Fig. 1 and 2, but CDG, V0 and V1 are missing now. One FPG is chosen as a controlling one and all the controlling functions of the other are switched off. It is recommended to re-configure the controlling FPG for the new regulation volumes by a built-in automatic procedure.

Fig. 8. Comparing two FPGs without a zero indicator.

Before the beginning of the measurements, both FPGs are zeroed. Then the controlling FPG is set to generate a prescribed pressure point. Because both FPGs are now having the same regulation loop, there is a possibility to compare them directly without any isolating CDG. This set-up can be utilised in all pressure modes.

We compared the results of a customer FPG calibration with and without a CDG and the results were the same within 1 ppm. This method proved to be very practical and eliminates the influence of uncertainty of CDG calibration curve.

9. FUTURE PLANS

Activities of the CMI in this increasingly important pressure range are further supported by other activities. Firstly, it is a key comparison CCM.P-K4.2012 in the absolute pressure range from 1 Pa to 10 kPa [19] which has not been completed yet. Secondly, it is a joint research project "14IND06 – Industrial standards in the intermediate pressure-to-vacuum range" [20] within the framework of the EMPIR programme in which the topic of traceability of the force-balanced piston gauges will have a crucial role.

10. CONCLUSIONS

Both in gauge and absolute pressures all the participating institutes successfully proved their equivalence in bilateral comparisons with CMI and also with respect to the reference value. They all also proved mutual bilateral equivalences in all the points. All the participating labs are also equivalent with the reference values of CCM.P-K4 and CCM.P-K2 in the relevant points. Moreover, CMI and INRIM successfully proved their equivalence in negative gauge pressure. The comparison was demanding and unique from the logistical point of view. More details can be found in [17, 18].

Also the ability of FPG8601 to serve as a transfer standard was proved, although there were some doubts about this before the beginning. During the mentioned above comparisons, the FPG of CMI was transferred to Berlin, Braunschweig, Paris and Torino. On the other hand, the FPGs of INRIM, LNE and MIKES were transported to Brno. No problem was registered concerning the influence of these transports on the state of the instruments. Of course, it is not trivial and an experienced operator is necessary. However, when the instrument is prepared for the transport carefully (The transporting instructions of the manufacturer demand dismounting the piston-cylinder and fixation of the piston-cylinder trapeze by a plastic fixing appliance.) and the best attention is paid for all the checks of tightness, piston-centring and force measurement linearity, the results are satisfying.

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