2023 CCM & IMEKO TC16 7th International Conference on Pressure and Vacuum Metrology
IMEKO TC-16 2023
Washington DC, U.S.A., May 15-19, 2023

TEMPERATURE INHOMOGENEITY IN THE MSL PRIMARY PRESSURE STANDARD DURING OPERATION

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Abstract:

We report on our initial investigations into directly measuring the temperature gradient across a DHi piston-cylinder unit. A PRT in contact with the top of the piston was compared to measurements taken in the mounting post that houses the cylinder. The temperature difference between the two PRT's was used to estimate the temperature gradient across the piston-cylinder unit. Effects of rotating the piston and operating under vacuum, and their impact on the piston-cylinder temperature, were investigated. The results can be used to inform the uncertainty budget for temperature inhomogeneity in the MSL primary pressure standard.

1. INTRODUCTION

The Measurement Standards Laboratory of New Zealand's (MSL) primary pressure standard is based on dimensional measurement of a piston-cylinder unit. Previous realisations, carried out by MSL, have achieved diameter measurements with standard uncertainty of around 1 ppm. Due to ongoing refurbishments of the MSL dimensional laboratory, dimensional traceability had to be obtained externally, resulting in slightly increased diameter (and therefore area) measurement uncertainty of our primary piston-cylinder unit. This prompted us to revisit some of the other uncertainty components in our pressure realisation to make up for the increased uncertainty in area and thereby maintain our current CMC.

Within our uncertainty budget there are three dominant terms that contribute to the CMC of our primary realisation: piston-cylinder area, loading mass uncertainty and temperature of the piston-cylinder unit. The uncertainty in area is somewhat fixed for now. The loading masses are heavily used for calibrations as well as primary realisations which contributes to an increased uncertainty in their instability over time. This is not easily addressed without obtaining more masses. Therefore, we focused on the temperature of the piston-cylinder unit during operation. Specifically, the uncertainty contribution due to the temperature gradient across the piston-cylinder unit which is the focus of this abstract.

In the MSL setup, temperature of the piston-cylinder is inferred from a single platinum resistance thermometer (PRT) located in the mounting post. The major uncertainty components from these measurements are: the resolution of the bridge used to read the resistance, in our case a DHi terminal, the uncertainty from the PRT calibration and the dominating term, an estimation of a possible temperature gradient between the PRT position and the piston-cylinder unit. Because the unique environment and apparatus around which each piston-cylinder is used in different laboratories affects its temperature differently, there is no standard approach to assigning an associated uncertainty that is common to all realisations. Estimates of the size of the temperature variation across a piston-cylinder unit can vary by an order of magnitude between different realisations [1-3]. We have assumed, for our setup, a maximum possible temperature gradient of 0.20 K which corresponds to a standard uncertainty in generated pressure of around 1.8 ppm. In the absence of any reliable data for our system, this value is somewhat conservative.

This extended abstract describes our initial experiments to empirically measure the temperature gradient across the piston-cylinder unit while in use. We use these initial results to test the validity of our previous assumptions of temperature inhomogeneity in the piston-cylinder unit. Furthermore, this work is used to inform potential strategies for reducing the uncertainty contribution due to temperature inhomogeneity in MSL's primary pressure standard.

2. METHODS

We measured the temperature gradient across the piston-cylinder unit mounted on one side of a customised twin pressure balance setup, see figure 1. The setup is based around the DHi PG 7601 10 kPa/kg gas pressure balance. Control electronics and piston rotation mechanism were mounted under the table away from each piston-cylinder unit to reduce their heat load impact on the temperature of

Figure 1: MSL twin pressure balance arrangement.

the piston-cylinder. A more detailed description of the MSL twin pressure balance setup is given elsewhere [4].

The temperature gradient across the piston-cylinder unit was assessed by observing variations between temperature measurements taken in the mounting post and the top of the piston. A small hole was drilled through the bolt connecting the cap to the top of a 15 mm diameter DHi piston. A PRT was then placed in contact with the top of the piston (figure 2). Using a Greisinger GMH 3750 battery-operated temperature logger mounted to the piston cap, we were able to take temperature readings near the top of the piston while the piston was rotating and compare them to readings taken by the PRT in the mounting post.

The PRT in the mounting post was fully immersed into a hole of depth 85 mm with an annular gap of ~0.03 mm. Similarly, the PRT at the top of the piston was immersed through a 30 mm deep hole in the piston cap bolt with an annular gap of ~0.03 mm except for the final 3.5 mm where the annular gap increased to ~1 mm. All gaps between the PRT and the piston/mounting post were bridged using thermal paste. Both PRTs were calibrated using similar immersion depths to what was used here. We have not added any additional uncertainty components from their calibrated values. The PRTs had a resolution of 0.01 K and standard uncertainties of 0.0081 K (top of piston) and 0.0046 K (mounting post).

3. RESULTS

The temperature gradient across the vertical separation of the two PRT's was assumed to be linear. A baseline measurement with the pressure balance not in use showed a minimal gradient across the piston-cylinder unit (figure 3). Prior to these measurements the piston-cylinder unit was left in the mounting post to equilibrate overnight. Measurements were taken in air but with the bell jar covering the pressure balance to insulate it from rapid fluctuations in ambient conditions and convections. A temperature difference of around 0.01 K was observed over a timespan of approximately 80 minutes. This observed temperature difference is on the order of the combined uncertainty of the two PRT's indicating there is no (or at least a minimal) gradient being created by the ambient conditions of the laboratory.

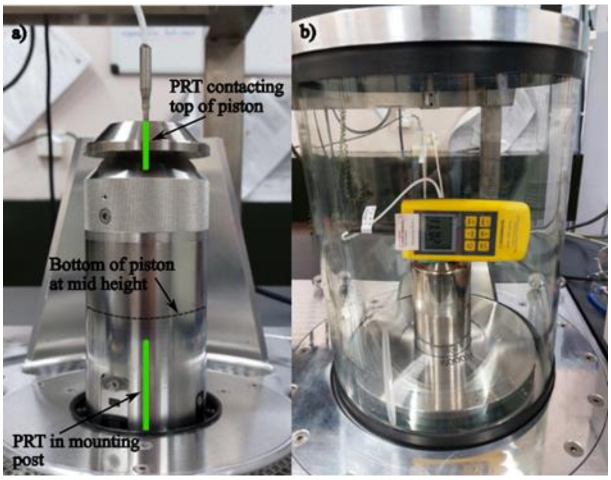

Figure 2: a) Relative positions of the two PRT's mounted inside the mounting post and contacting the top of the piston. b) Photo of the temperature logger mounted to the top of the piston-cylinder unit under vacuum.

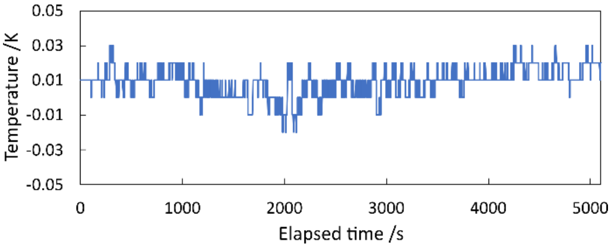

Figure 3: Temperature difference between the mounting post and the top of the piston with the pressure balance not in use.

We observed a temperature gradient across the piston-cylinder unit when operating in gauge mode. In this situation the mounting post tended to be warmer than the top of the piston. No discernible temperature change was observed when floating the piston. However, we did observe an effect on the temperature after engaging the piston rotation mechanism. This is assumed to be due to the heat load resulting from operating the motor driving the piston rotation mechanism. The motor drive is located closer to the mounting post than the top of the piston creating an unequal heating load on the two PRT's thus leading to the observed temperature gradient across the piston-cylinder unit. Figure 4 shows the temperature difference between the two PRT's over time. The temperature difference increases once the piston is floated and begins to rotate and appears to stabilise at around 0.05 K. The pressure balance was generating around 388 kPa. This appears to be in good agreement with specifications for this type of pressure balance as published by the manufacturer [5].

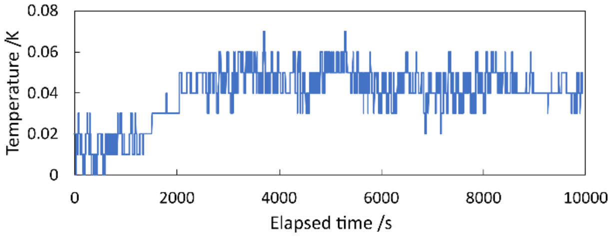

Figure 4: Temperature difference between the mounting post and top of the piston while operating in gauge mode.

Placing the pressure balance under vacuum created a larger temperature gradient across the piston-cylinder unit. With the pressure balance stationary and not pressurised, the space in the bell jar above the pressure balance was evacuated using an 80 Ls^{-1} turbo pump backed by an oil filled rotary pump. The effect of turning on the vacuum pumps was to cool the piston-cylinder unit. However, the PRT contacting the top of the piston cooled more rapidly than the mounting post. This is assumed to be because it is exposed to convective cooling effects while the bell jar is initially being evacuated. Despite not being exposed directly to the vacuum, the temperature measured by the PRT in the mounting post also decreased when the vacuum pumps were turned on, albeit by a smaller amount. This is assumed to be due to thermal conductance from the parts of the pressure balance that are exposed to the convective cooling. Figure 5 shows the observed temperature difference between the two PRT’s. After the initial rapid cooling when the pumps are turned on (at around 1900 s) the temperature difference between the two PRT’s begins to stabilise before the heating effects of the turbo pump causes the gradient to increase again. After approximately 4.5 hours, the temperature difference across the piston-cylinder unit reaches about 0.15 K.

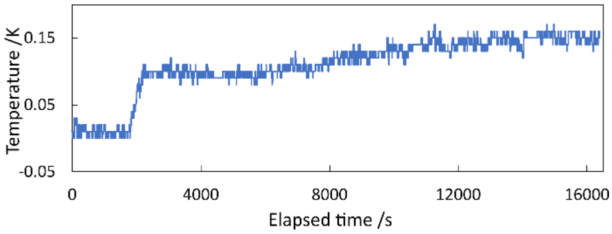

Figure 5: Observed temperature difference between the mounting post and the top of the piston under vacuum while the pressure balance was not floating.

Operating the pressure balance under vacuum, i.e. in absolute mode, we observed similar results to figure 5. The temperature gradient across the piston-cylinder unit resulting from turning on the vacuum pumps appeared to dominate all other effects.

The temperature gradients observed in this initial study were all less than our estimate of maximum temperature inhomogeneity in our primary standard. While this somewhat justifies our estimate of the piston-cylinder temperature uncertainty contribution, it does highlight that it is potentially a conservative estimate. Gauge mode operation was shown to agree with estimates documented by the manufacturer, however, operation under vacuum produces gradients more in line with our assumption of 0.2 K. This suggests there is scope to reduce the uncertainty contribution due to temperature inhomogeneity in the MSL primary pressure balance. This is particularly evident in gauge operation but may require further characterisation in absolute operation to reduce the uneven convective cooling effects on the piston-cylinder due to operation of the vacuum pumps.

4. SUMMARY

We reported on our initial investigations into directly measuring the temperature gradient across a DHi piston-cylinder unit. A PRT in contact with the top of the piston was compared to measurements taken in the mounting post that houses the cylinder. The temperature difference between the two PRT’s was used to estimate the temperature gradient across the piston-cylinder unit. Effects of rotating the piston and operating under vacuum, and their impact on the piston-cylinder temperature, were investigated. The results can be used to inform the uncertainty budget for temperature inhomogeneity in the MSL primary pressure standard.

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