Development of a temperature controlled container for high accuracy capacitance manometers

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Abstract. National Institute of Metrology of Turkey (UME) has developed a new temperature-controlled container for high accuracy capacitance manometers (CDG). In the proposed design, due to the direct (metal-metal) contact of the temperature-controlled plate of the container with the aluminum shell of the sensor, the influence of the temperature of the electronics on the pressure sensor is minimized. Inside the aluminum shell, the temperature of the pressure sensor can be controlled at any fixed temperature with stability of ± 2 mK in the temperature range from 15 °C to 30 °C. The use of a pressure sensor inside an appropriate container minimizes the effect of the ambient temperature on the sensor, eliminates the need for correction for the effect of thermal transpiration and thus improves sensor accuracy. CDGs inside containers showed excellent short-term stability at zero pressure, which does not exceed ± 5 mPa as well as a maximum drift rate of 0.03 mPa h⁻¹. The measurement results of ambient temperature influence on CDG’s zero showed a maximum change of 0.001% of full scale per degree Celsius. Control of CDG at ambient temperature significantly reduces the effects of thermal transpiration, which increases slightly to a maximum of 0.3% at the lowest pressures.

1. Introduction
Diaphragm type pressure sensors are widely used devices for the measuring of the pressure in the low and medium vacuum ranges. One of these sensors is a high accuracy CDG, which provides accurate and precise pressure measurement of the gases.

All CDGs are error prone due to minor geometric changes caused in the pressure sensor due to differences in the expansion coefficients of the sensor materials. Despite the fact that all sensor materials have very close thermal expansion coefficients, these coefficients, however, are not identical [1]. Even the smallest changes in the temperature of the sensor can lead to a change in the geometric dimensions of the sensor and, consequently, to an erroneous measurement of the pressure that it measures.

To minimize these effects, several methods have been proposed where the best solution is to place the sensor in an aluminum shell with precise temperature control. In high accuracy CDGs with a pressure sensor located inside a cast aluminum shell with cartridge-type temperature-controlled heaters, temperature coefficients are less than 0.0004% FS/°C at zero and 0.002% Reading/°C on span.

However, when the pressure sensor operates at elevated temperatures, another undesirable side effect appears, known as thermal transpiration [2, 3], which manifested as a non-linear reaction of the sensor at absolute pressures below 100 Pa. When a heated CDG is operated at a temperature of 45 °C, the measurement error for a system controlled at a temperature of 20 °C can typically reach about 4%.
To study the phenomenon of thermal transpiration, a large number of experimental, analytical, and numerical investigations were carried out [4–6]. The most common correction applied to CDG measurements is based on semi-empirical approaches, of which the Takaisi and Sensei equation is most often used [2, 3], although some criticism has also been expressed recently [7, 8].

Some hybrid systems [9, 10] have been developed to date to minimize the effect of thermal transpiration by controlling the temperature of CDG close to the ambient temperature. This included the installation of a CDG into the temperature-controlled enclosure with thermoelectric (TE) modules. Such systems are able to control the temperature inside the enclosure with stability within ± 20 mK when the ambient temperature changes to several degrees.

This article describes the new temperature-controlled container with improved temperature stability for high accuracy CDGs, as well as the results of its preliminary tests. This improved stability of the CDG is achieved by providing precise temperature control of the pressure sensor with stability better than ± 2 mK by direct contact of the temperature-controlled plate of the container with aluminum shell of the pressure sensor. The use of a pressure sensor inside an appropriate container minimizes the effect of the ambient temperature on the sensor, eliminates the need for correction for the effect of thermal transpiration and thus improves sensor accuracy.

2. Container
The temperature-controlled container consists of a temperature control assembly, which is controlled by an external temperature controller, as well as a high accuracy CDG placed inside the container (see figure 1).

![Figure 1. General view of temperature controlled container with CDG inside.](image-url)

In order to achieve better temperature stability of the CDG sensor, the aluminum plate surface of the temperature control assembly should be in direct contact with the upper surface of the aluminum shell. In this case, the upper part of the CDG’s cover body must be removed beforehand. Own CDG heater was not used in this case. An external temperature controller was used to control the electric current to thermoelectric (TE) modules. Such an arrangement made it possible to control the internal temperature of the aluminum shell and the CDG sensor within ± 2 mK when the ambient temperature changes to several degrees.

The temperature-controlled container made it possible to measure using CDG at any fixed temperature in the range from 15 °C to 30 °C with specified temperature stability.

Initially, some preliminary measurements were taken to find out the actual temperatures of the CDG sensor inside the aluminum shell in the temperature range from 15 °C to 30 °C. CDG’s sensor temperatures were measured in the mentioned temperature range using a calibrated temperature sensor that was inserted through the vacuum connection port (figure 2).
The temperature control of the CDG sensor was carried out by the mentioned container at various fixed temperatures in the specified temperature range. After stabilization of the CDG sensor temperature within ± 2 mK (usually after about 6-7 hours), the temperature values set by the temperature controller and the real temperature data of the CDG sensor were taken. Finally, when all the data was taken from two temperature sensors in the specified temperature range and the dependence behavior of two temperature sensors was determined, the temperature controller can be easily adjusted to provide the actual ambient temperature or any other necessary temperature in the specified temperature range.

3. Results and discussion

Two CDGs (A and B), owned by the same manufacturer and used with newly developed temperature-controlled containers (containers 1 and 2), were investigated at UME for instability at zero pressure, zero drift and zero temperature coefficients. In addition, these CDGs were calibrated using the UME primary static expansion system (MSSE1) at different temperatures of 45 ºC (where the own heater was turned on) and 19.8 ºC (inside their own containers). To determine the zero pressure instability of CDG, absolute CDG A (full scale 130 Pa) and CDG B (full scale 1.3 kPa) were placed in containers 1 and 2, respectively. Both CDGs were used with their own control units with the heaters turned off. The temperature control of both CDGs was provided at room temperature 20 ºC with their own temperature-controlled containers. The results of zero pressure instability and changes in room temperature during measurements are presented in figure 3(a) and (b).

Figure 3 shows that even the smallest changes in room temperature within ± 0.1 K affect the zero-pressure stability of CDG. While CDG A demonstrated a maximum drift rate of 0.01 mPa h⁻¹ and ± 1.1 mPa maximum zero-pressure instability over 93 hours, CDG B showed a maximum drift rate of 0.03 mPa h⁻¹ and ± 5 mPa maximum zero-pressure instability over 70 hours.

![Figure 3](image-url)
To find out the effect of ambient temperature on CDG’s zero, the room temperature was raised to 23 °C and then returned to 20 °C, while the CDG was controlled at 20 °C using its own temperature-controlled containers (see figure 4). While CDG A demonstrated a maximum change of 1.3 mPa per degree Celsius, CDG B showed a maximum change of 12.4 mPa/°C.

Figure 4. Plot of influence of room (red) and CDG’s sensor temperature (blue) on zero-pressure stability for CDG A (130 Pa) in the Container 1 (a). Plot of influence of room (red) and CDG’s sensor temperature (blue) on zero-pressure stability for CDG B (1.3 kPa) in the Container 2 (b).

As clearly shown in figure 4, CDG A and CDG B have opposite sign temperature coefficients.

Figure 5. Absolute mode calibration results for (a) CDG A (130 Pa) and (b) CDG B (1.3 kPa) when controlled at a temperature of 45 °C and 19.8 °C.

Figure 5 shows the experimental data for two CDGs calibrated by a static expansion system at different temperatures of 45 °C (where their own heater was turned on) and 19.8 °C (inside their own containers and with heaters off), where the vertical axis is a calibration factor (CF = Indicated Pressure / Generated Pressure). Nitrogen was used as a calibration gas. The same temperature control assembly (TCA2) was used for both CDGs. The upper data sets show that at pressures below 100 Pa the behavior of the heated CDG becomes non-linear due to the effect of thermal transpiration. The two lower data sets for CDG A and CDG B clearly show that controlling CDG at ambient temperature significantly reduces the effects of thermal transpiration, which slightly increases to a maximum of 0.3% at lowest pressures.

4. Conclusions
National Institute of Metrology of Turkey UME has developed and tested temperature-controlled portable containers that can be used to compare vacuum standards operating in the range of 0.05 Pa to 130 Pa. To control the temperature of the CDG sensor, a completely new method has been proposed that allows controlling the temperature of the sensor at any fixed temperature in the range from 15 °C to 30 °C with stability better than ± 2 mK. CDGs inside containers showed excellent short-term zero-
pressure stability, which does not exceed ± 5 mPa and a maximum drift rate of 0.03 mPa h$^{-1}$. The measurement results of ambient temperature influence on CDG’s zero showed a maximum change of 0.001% of full scale per degree Celsius for both CDGs.

The use of a pressure sensor inside the developed container minimizes the effect of the ambient temperature on the sensor, eliminates the need for correction for the effect of thermal transpiration and thus improves sensor accuracy.

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