Temperature controlled transfer standard package for high accuracy pressure transducers with improved temperature stability

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Abstract. A new temperature controlled transfer standard package for absolute and differential pressure transducers has been developed at the Ulusal Metroloji Enstitusu (UME). Due to direct (metal-metal) touching of the temperature controlled plate of the temperature controlled unit with the pressure sensor housing the temperature influence of electronics on the pressure sensor is ruled out. The pressure sensor temperature inside of cast aluminum housing can be controlled at any fixed temperature in the temperature range of 15 °C – 30 °C with stability ± 2 mK. The mentioned transfer standard package minimizes the ambient temperature effects upon the sensor, denies the need to apply a correction for thermal transpiration effect and thereby increases accuracy of the transducer. The transfer standard packages have demonstrated excellent short-term zero stability which does not exceed ± 5 mPa and a maximum drift rate of 0.03 mPa h⁻¹.

1. Introduction
Pressure transducers are widely utilized pressure sensors for low to medium vacuum pressure ranges. One such transducer is the high accuracy capacitance diaphragm gauge (CDG) which provides very precise and accurate pressure measurements of the gases. All CDGs are subject to errors due to minute geometric changes induced in the sensor due to differences in expansion coefficients of the sensor materials. For example, the ceramic forsterite is a common choice as the electrode substrate material because its temperature expansion coefficient is very close to that of Inconel used for the sensor body and diaphragm [1]. However, these coefficients are not identical. Even a small change in sensor temperature can cause enough geometrical changes in the sensor to be detectable in the output. Several things can be done to minimize these effects. Temperature compensation can improve coefficients by using a temperature-sensitive device attached to the sensor to compensate the output signal appropriately for temperature changes. However, this alone does not improve performance appreciably because of thermal lags and nonlinear temperature coefficients. A better method is to enclose the entire sensor in an accurately temperature-regulated environment. This minimizes temperature changes actually seen by the sensor and results in much-improved temperature coefficients. In the highest accuracy models, both techniques are used. Cast aluminum housing with DC proportionally controlled cartridge-type heaters will achieve temperature coefficients less than 0.0004% FS/°C (4 ppm) on zero, and 0.002% Reading/°C (20 ppm) on span.

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However, the operation of a pressure sensor at elevated temperatures gives rise to another undesirable side effect known as thermal transpiration [2, 3], which manifests itself as a non-linear gas-species-dependent response of the gauge at absolute pressures below 100 Pa. When the heated CDG is operated at the temperature of 45 °C, the maximum measurement error for a system controlled at room temperature at 20 °C will is approximately 4%.

A large number of experimental, analytical and numerical investigations were performed to explore the phenomenon of thermal transpiration until now. Numerical calculations have reached a level of sophistication, which shows a high degree of agreement between theory and experiments. The most common correction applied to the CDG measurements are based on semi-empirical approaches, of which Takaishi and Sensui’s [2, 3] equation is the most frequently used – even though some critics have been raised recently.

Various hybrid systems [4] have been developed up to now that minimize this effect by controlling the CDG’s temperature close to room temperature. These systems were able to control the interior temperature of the enclosure at room temperature with stability ± 20 mK for room temperature changes of up to a few degrees.

This paper describes the development and preliminary testing of a newly constructed temperature controlled transfer standard package for high accuracy CDGs with improved temperature stability. This is achieved by providing the accurate and precise temperature control of the CDG placed inside of miniature environmental box and kept at the fixed temperature with stability better than ± 2 mK. The mentioned transfer standard package minimizes the ambient temperature effects upon the sensor, denies the need to apply a correction for thermal transpiration effect and thereby increases accuracy of the transducer.

2. Transfer standard package

The proposed temperature controlled transfer standard package consists of a high accuracy CDG placed inside a thermal enclosure with a temperature control assembly and external temperature controller (see figure 1).

![Figure 1](image.png)

**Figure 1.** General view of temperature controlled transfer standard package with CDG

To reach better temperature stability of the CDG’s sensor the plate surface of the temperature control assembly directly contacts the upper surface of the aluminum housing of the sensor where before that the upper part of the CDG’s cover body has been removed. The CDG’s own heater is not used in this case and it is switched off. The commercially-available external temperature controller is used to
control the electrical current to the thermoelectric (TE) modules. This arrangement enables the interior temperature of the enclosure and the CDG’s sensor to be controlled to better than ±2 mK for room temperature changes of up to several degrees.

The mentioned temperature controlled transfer standard package allows perform measurements by using CDGs at any fixed temperature in the range from 15 °C to 30 °C with stability better than ±2 mK.

To determine the real temperatures of the CDG’s sensor inside of aluminum housing in the temperature range from 15 °C to 30 °C some preliminary measurements were performed. Initially, sensor temperature of the temperature control assembly has been checked with previously calibrated thermistor type temperature sensor at room temperature and corrected value has been set to the temperature controller. After that CDG’s sensor temperatures were measured in the temperature range from 15 °C to 30 °C using same calibrated temperature sensor, which was inserted through the vacuum connection port after venting the CDG (see figure 2).

![Figure 2](image)

**Figure 2.** Principal scheme of the CDG’s head with temperature sensor inserted through the vacuum connection port.

The CDG’s own heater was not used in this case and it was switched off. The temperature control of the CDG’s sensor was provided by transfer standard package at different fixed temperatures in the temperature range from 15 °C to 30 °C. When CDG’s sensor temperature was stabilized within ±2 mK (generally after about 6 hours), temperature controller setting temperature and CDG’s sensor real temperature data were taken. Finally, when all the data of two temperature sensors in the temperature range from 15 °C to 30 °C have been taken and behavior of dependence of two temperature sensors was determined, temperature controller can easily set to provide room temperature conditions.

3. Results and discussion

Two CDGs (A and B) considered belong to the same manufacturer with their own transfer standard packages (Package 1 and 2) were evaluated at UME for zero instability, zero drift and zero temperature coefficients. To determine CDG’s zero instability absolute CDG A (130 Pa full scale) and CDG B (1.3 kPa full scale) were placed into the package 1 and 2 respectively. Both CDGs were operated with their own control and measuring unit where own heaters were switched off. The temperature controls of both CDGs were provided by their own temperature controlled transfer standard packages at room temperature 20 °C. Figure 3 (a) and (b) show the results for zero instabilities and room temperature changes during measurements. The data were monitored via digital data ports (RS-232) of the devices over the 93 hours (CDG A) and 70 hours (CDG B).
As shown in figure 3, even smallest changes in room temperature within ± 0.1 K influence on the CDG’s zero stabilities. The CDG A showed a maximum drift rate of 0.01 mPa h⁻¹ and ± 1.1 mPa maximum zero instability over 93 hours while CDG B demonstrated a maximum drift rate of 0.03 mPa h⁻¹ and ± 5 mPa maximum zero instability over 70 hours.

To determine the influence of room temperature on CDG’s zero, the room temperature was increased from 20 °C to 23 °C and then has been returned back to 20°C, while CDGs were controlled by their own temperature controlled transfer standard packages at room temperature 20 °C. While CDG A showed a maximum change of 1 mPa per degree Celsius or 0.001% of full scale, CDG B demonstrated a maximum change of 0.9 mPa (0.0009% of full scale). As is clearly demonstrated in figure 3, CDG A and CDG B have opposite signed temperature coefficients.

4. Conclusions
UME has developed and tested portable temperature controlled transfer standard packages suitable for intercomparisons of pressure standards operating in the range of 13 Pa to 130 kPa. A principally new method for temperature control of CDG’s sensor is proposed, which allows control temperature of the sensor at any fixed temperature in the range from 15 °C to 30 °C with stability better than ± 2 mK. The transfer standard packages have demonstrated excellent short-term zero stability which not exceed ± 5 mPa and a maximum drift rate of 0.03 mPa h⁻¹. The mentioned transfer standard package minimizes the ambient temperature effects upon the sensor, denies the need to apply a correction for thermal transpiration effect and thereby increases accuracy of the transducer.

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6. References
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