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REPORT

Project Name	Transducer-Aided-Crossfloat Calibration
Description	Use of a precise transducer as an alternative transfer standard method for cross float calibrations
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Motivation & Introduction

Pressure balances are critical devices in the realization and dissemination of the SI unit of pressure, the Pascal (Pa). Pressure is a measured property that is equal to the amount of force applied per unit area. Pressure balances are accurate on the order of several parts per million, and available over a broad pressure range from tens of kilopascals (pressures below an atmosphere) to several hundred megapascals. Tubitak UME has pneumatic primary standard piston gauges that were characterized by careful cross-float experiments and modeling of fluid forces on the piston and compared for agreement within stated uncertainties. These were used to calibrate working standard piston gauges that are in turn used for calibrations of test or customer gauges using the cross-float method spanning the range of 10 kPa to 20 MPa. The cross-float method involves using the reference piston gauge to generate a known pressure and adjusting the forces on the test piston gauge (by adding or removing masses) to achieve a balance condition. With the forces balanced and knowing the pressure generated by the reference , the effective area of the test can then be calculated. The effective area is the quantity of interest in a piston gauge; it is the quantity that when combined with the loaded forces on the gauge produces the pressure. Ideally, this is a simple process, but it requires many hours of attention from an experienced metrologist who must assess the state of the gauges during a cross-float (either using a differential pressure cell or by measuring the fall rate of the piston in the cylinder) and add or remove tiny trim masses by hand to achieve the balance condition. I propose a modification to the cross-float calibration method where a pressure transducer is used as a very short-term transfer standard between the two piston gauges. It allows for a much less stringent balance condition and lends itself to automation. If combined with a robotic means of loading masses onto the gauge, automated pressure generation, and piston float, this will enable full automation of piston gauge calibrations. In this experiment, I compare such a calibration with a traditional cross-float. The findings indicate that we will be able to achieve results comparable to those from the traditional cross-float method.

1. Method

The reference standard and test piston gauges are placed on a calibration bench, leveled and plumbed into a manifold with nitrogen supply, pressure controller(CPC pressure controller) for fine gas pressure adjustment, and shut-off valves to isolate the various components as necessary. Valves are adjusted manually to connect either of the two piston gauges to a transducer (Paroscientific, model 745).
Based on the effective area of the reference gauge (known from precise cross-float analysis), well-characterized known masses are added to the reference gauge to generate a desired pressure. Masses are added to the test gauge to nominally achieve the same pressure. In a traditional cross-float, a pressure metrologist adds or removes trim masses until balance is achieved between the two piston gauges to within the resolution of the differential pressure cell. In the transducer aided crossfloat (TAC) method this is unnecessary. Instead, the pressure of the reference piston gauge is sampled by the transducer. The transducer is then closed to the reference gauge and opened to the test gauge. If the transducer reading is sufficiently reproducible and linear, it can be employed as an immediate, short-lived transfer standard.
The standard reference gauge calibrates the transducer and that calibration is immediately transferred to the test gauge. If the transducer reading is a linear function of the actual pressure therefore, $P_{transducer} = lP_{standard} + b$, where

the slope, l and zero-offset b, are properties of the transducer that are ideally but not necessarily independent of pressure. In Eq. (1), the offset between the transducer reading and the standard reference gauge is adjusted for linearity and added to the reading of the test gauge to find the actual pressure on the test gauge:

$$P_{balance,test} = \frac{\Delta P}{l} + P_{balance,std} \;, \qquad \Delta P = \frac{P_{transducer,test} - P_{transducer,std}}{l} \qquad (1)$$

Applied force on the cross floated gauges is given by:

$$F = PA_{eff} = \frac{\sum_i m_i g\left(1-\frac{\rho_a}{\rho_b}\right)+\gamma C}{1+(\alpha_p+\beta_c)\,(T-T_r)} \qquad (2)$$

Where ρ_a, is the air density, ρ_b, is the density of the pressurizing medium, T_{ref}, is the reference temperature (typically 20°C), α_c and α_p are the thermal expansion coefficients of the cylinder and piston, respectively. Note that the surface tension term, γC, is zero for gas pressurizing media, the term $(1- \rho_a/\rho_b)$, is to correct for buoyancy, and the divisor terms are correction for deviation of the actual calibration temperature from the reference temperature. The measurement equation pressure P_T, of the test gauge using the TAC method is the relation given by;

$$P_T = \frac{\Delta P}{l} + \left(\frac{1}{A_{eff}}\right)\frac{\sum_i m_i g\left(1-\frac{\rho_a}{\rho_b}\right)}{1+(\alpha_p+\beta_c)\,(T-T_r)} \qquad (3)$$

The effective area of a general piston gauge is related to the force by Eq. (4) and [2]:

$$A_{eff} = A_0(1 + b_1P + b_2P^2) - \frac{t}{P} \qquad (4)$$

The terms A_0, b_1, b_2, and t are determined by calibration, equations (2) and (4) are combined to calculate the actual pressure generated by the standard reference gauge, and the actual pressure on the test gauge is calculated using Eq. (1).

2.0 Characterization of Transducer

We characterized the stability, repeatability, and linearity of the transducer as follows. To assess repeatability, masses were added to both gauges and the air-actuated valves were switched several times to connect either gauge to the transducer in turn. Transducer readings were captured at about 1Hz. The transducer was sampled approximately twenty times on one gauge before switching to the other gauge. A point is considered an average of these readings during a single sampling of the transducer at either gauge. At a given pressure, six points were taken for each gauge. The initial set of points were taken with the gauges balanced to within 5Pa. Masses were added to the test gauge and this process was repeated a total of five times, covering a pressure range (1-7MPa). In all cases, each time the transducer was switched between gauges at a given pressure, the point returned to the same value within statistical uncertainty, that is, the effect of switching has undetectable influence in the overall result because it is below the noise. A similar repeatability test was performed at a nominal pressure of 7MPa, in which the pressure difference was allowed to be as large as ΔP = 30Pa. Again, we observed the pressure returning to the same value after switching between the standard and test gauges where error bars were found to be one standard deviation. In addition, we verified the stability of the transducer at a representative pressure. After waiting 10 minutes for stability, data was collected for 30 minutes at a single pressure near 1.4MPa generated by reference gauge, in this case a Ruska standard PG, and the overall drift was found to be less than 7mPa/s, well below the resolution of the Paroscientific transducer. Given that readings are taken at 1 Hz, and that calibration at a single pressure will take very short time, when drift is below 1 Pa/MPa level at a single pressure, it can be ignored. From this we can conclude that the transducer readings are sufficiently repeatable. No evidence of hysteresis associated with increasing/ decreasing pressure was found on this mass and time scale. We characterized the linearity of the transducer by generating a known pressure on the standard, and increasing it in small increments. The transducer readings were graphed vs. pressure and a linear fit was performed to find the best value for the slope l, with associated uncertainty σ_l, found by linear regression analysis.

3.0 Experiment Details

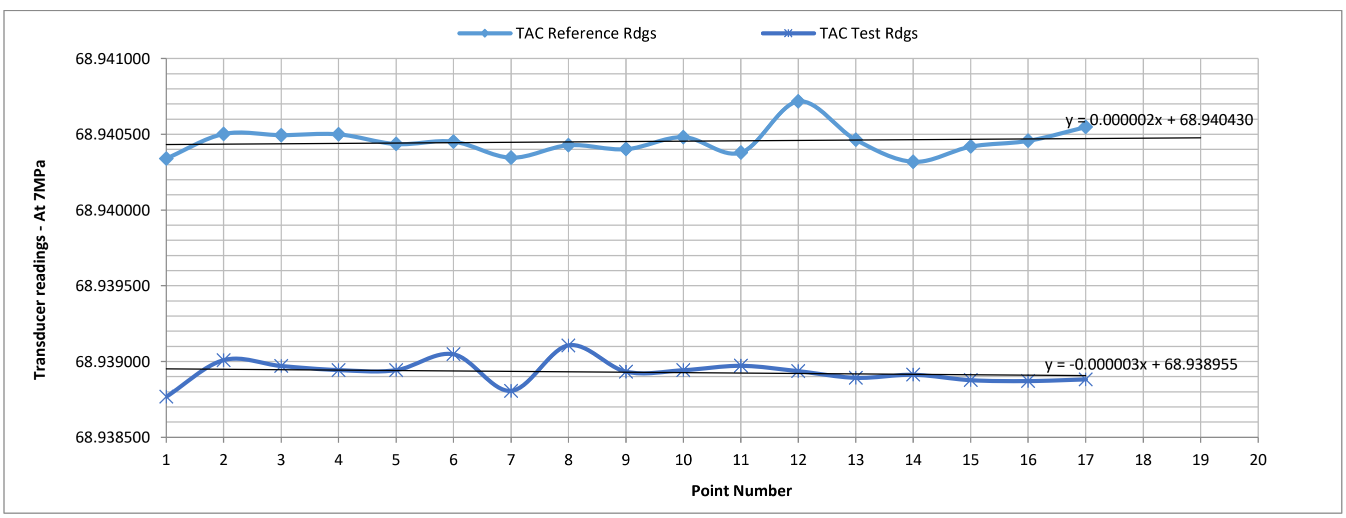
We tested this method using two well-characterized Tubitak UME piston gauges, one was used as a standard (Ruska: 46112) and one was used as a test gauge (DHI PG 7601). The gauges were set up and plumbed in with the transducer (Paroscientific 745) via air-actuated valves. A laser distance meter was plumbed into the same manifold to allow real-time cross checking (determining the piston fall rates) of the traditional method against the TAC method. The system was set up, and allowed to thermally equilibrate. At every 6 pressure points, first a point was taken with the traditional method (trim mass) and then a series of about twenty points within about 0.01% of that pressure were taken using the transducer (*TAC* method). We compared the results from these two methods, as well as comparing this traditional cross-float to the previous traceability certificate from calibration against the appropriate primary standard.

3.1 Traditional Cross-Float

Considering first the traditional cross-float, the test gauge was floated against the standard gauge at six pressure points. The temperature-corrected forces were calculated in the usual way using Eq. (2). The effective area of the test gauge could then be calculated from the pressure generated by the standard gauge—using known masses and pre-determined calibration coefficients for the gauge in Eq. (4)—at each pressure point. The data were fitted to a linear function and extrapolated to zero to get a final value for the effective area of ***A*eff, crossfloat** = **4.90130850E-05 m^2**

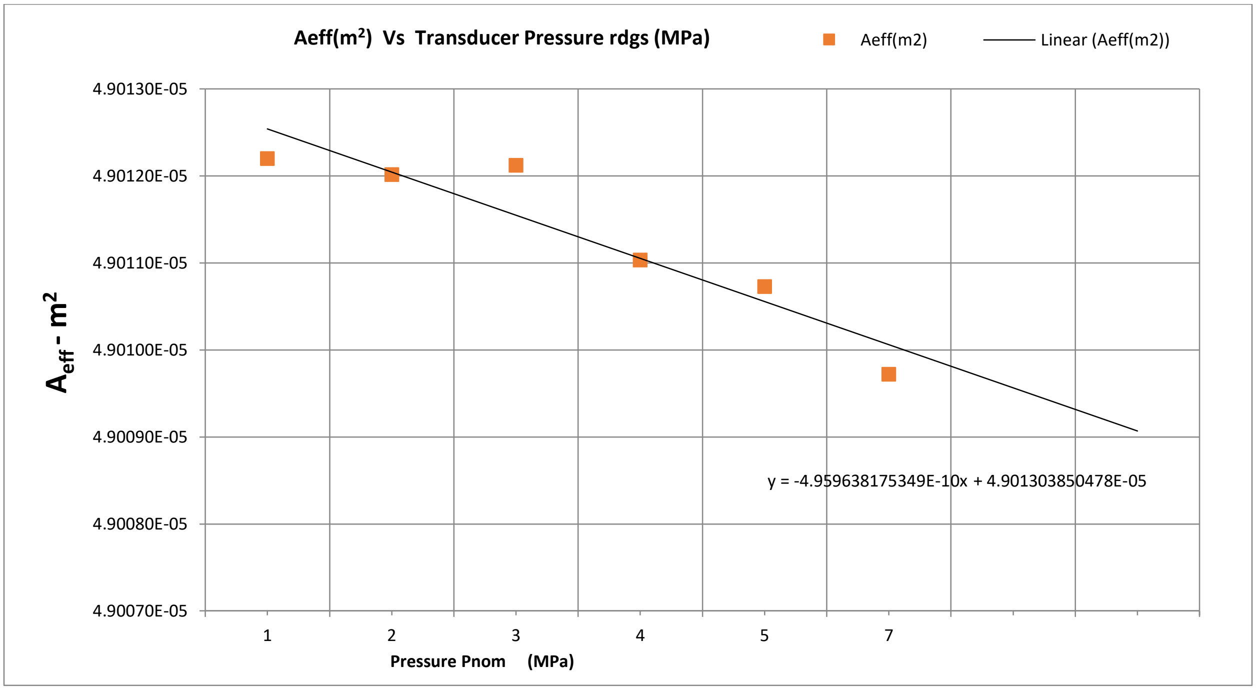
3.2 Transducer-Aided Cross-Float

The test gauge was calibrated at six pressure points spanning the range (1, 2, 3, 4, 5, 7MPa). At each of these pressures, seventeen (17) points were taken without varying pressure between the standard and test gauges (ΔP) and repeated in five cycles of measurements. Typical data are plotted below at a pressure around 7MPa.



Equations (2) and (4) are used to calculate the pressure generated by the standard as usual, and Eq. (1) in combination with the transducer readings is used to calculate the pressure and effective area of the test gauge (using force values calculated for the test gauge from Eq. (2)). The effective area was calculated with the correct slope *l* and compared to a similar calculation in which the slope was assumed to be unity. The latter represents a much more convenient real-life approach, because the act of determining the slope requires tedious loading of trim masses. Both of these *TAC* method results were compared to results obtained by a traditional cross-float, discussed in the results section below. As ΔP gets larger, it becomes more difficult to keep both gauges floating and spinning while switching back and forth between them with the transducer. The allowed size of pressure change depends on system particulars and will need to be determined by the metrologist at the time of calibration, but the main objective is to eliminate the need for trim masses. If the regular (not trim) masses in a set differ by Δm, then so long as the ΔPmax >Δmg/Aeff, this goal has been achieved. The manifold should be constructed in such a way as to minimize changes in volume at cross-floating because such changes are liable to disrupt the balance condition.

4.0 Experimental Results



The results for the effective area at zero pressure of Tubitak UME piston gauge, Ruska: 46112, from the two methods under comparison are
$A_{eff,0}$;cross float = 4.90130850E-05m^2 for the traditional cross float, **$A_{eff,0\ TAC}$;real slope = 4.90113026E-05m^2** and **$A_{eff,\ 0\ TAC}$; ideal slope = 4.9013039E-05m^2** for the transducer-aided calibration.
These can also be compared to a previous cross-float calibration of this piston gauge in which the effective area was found to be
$A_{eff,\ historic}$= 4.90156700E-05m$^{2.}$ The traditional cross-float agrees with this historical value to less than 1mm^2/m^2. It is shown that the results from the three different methods are in very good agreement.

5.0 Conclusions and Future Work

Calibrations by the TAC method can be made that are in sufficient agreement with traditional cross-float calibrations. The transducer chosen should have sufficiently good resolution, linearity, and stability characteristics in the pressure range of interest. Adoption of the TAC method will reduce metrologist time and necessary expertise without introducing any significant error or uncertainty, and is an important step in total calibration automation. It is important to note that transducer behavior has been observed in some cases to change over time, the behavior of the transducer should be monitored for long-term consistency. It is worth pointing out that the value of the slope *l, may* not entirely be an intrinsic property of the transducer, but may relate with distortion or other effects of the piston gauges themselves. Further experiments and studies are required to investigate this parameter. I intend to further this study in pressure laboratory at my institute and implement transducer aided Crossfloat using a commercially acquired known precise transducer.

6.0 Acknowledgements

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