Progress Toward Realizing Pressure with Dimensionally-Characterized Piston Gauges

NIST provides world-class standards for pressure measurements through development of innovative approaches to realization of standards. The purpose of the work described here is to determine the performance levels of large-diameter, piston/cylinder assemblies (i.e., piston gauges) with dimensionally determined areas, and thereby establish their utility as primary pressure standards. The ultimate goal is to realize the unit of pressure, the pascal, in the atmospheric to high-pressure regime, and transfer the unit of pressure to our customers.

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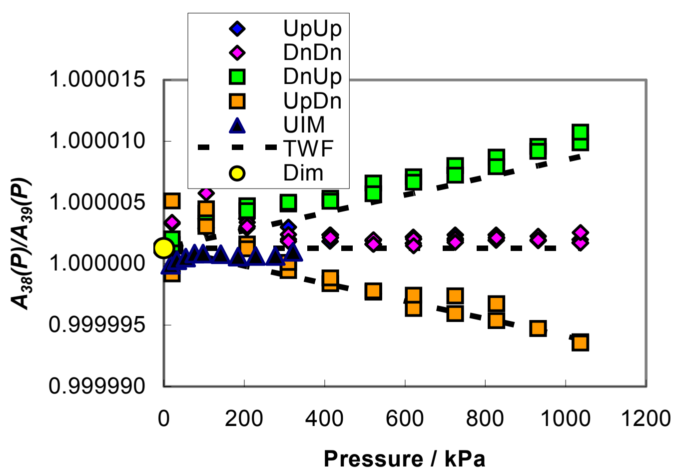
Accurate determinations of pressure are required for determining the altitude of aircraft, measuring barometric pressure, and monitoring and process control in manufacturing. The pressure standard for NIST in the atmospheric range is a mercury manometer. Piston/cylinder assemblies (*i.e*, piston gauges) are an alternative means for establishing pressure; they can operate from the atmospheric range to several hundred MPa (tens of thousands of psi) by using a variety of piston diameters and mass loads. Dimensional measurements allow a direct determination of the effective area of a piston gauge, and therefore the pressure it can generate, without calibration by another pressure artifact. The ability to measure the dimensions of the piston/cylinder assemblies that are extremely round and straight has allowed us to contemplate piston gauge pressure standards whose uncertainties approach the best manometers. Realizing pressure by two independent systems (manometers and dimensioned piston gauges) provides more credence to the uncertainties claimed for each. At NIST an additional independent realization of the pressure unit provides a means to check the operation of our primary mercury manometers and a primary pressure standard having considerably greater operating range.

For the last few years, NIST has been studying two 35 mm diameter piston gauges as potential primary standards, designated as PG38 and PG39. Both artifacts have been accurately dimensioned by Physikalisch Technische Bundesanstalt (PTB) and analyzed using a model of normal and shear forces on the base and flanks of the piston. The artifacts have also been compared directly to the NIST Ultrasonic Interferometer Manometer (UIM) for the last decade. The effective area of both artifacts as determined by the dimensional method agrees to the values as determined by the comparison to the UIM less than 1.5 x 10^{-6} (relative difference). This is better than the relative standard uncertainty from the dimensional measurements, estimated as 3.0x10^{-6}. Based on this result and long-term stability of the artifacts with respect to the UIM, we are now propagating the characterization into the NIST gas pressure scale up to 17 MPa. This effort involves direct cross-float comparisons between PG38 and PG39 and other NIST piston gauges, together with estimates of the elastic distortion due to pressure based on capacitance measurements and, independently, on numerical models. 35 such comparisons were completed in FY2005. An example of a cross-float comparison for PG38 and PG39 is shown in the figure below, in which the ratio of effective area for PG38 to that of PG39 is calculated. The diamond and square symbols indicate ratios from cross-floats of the gauges for different combinations of piston orientation (Up, Dn, etc.). The triangles indicate ratios from comparisons to the UIM (which is always upright). The dashed lines indicate ratios based on thick-wall formulae (TWF) from elasticity theory. The circle represents the ratio based on the dimensional measurements (DIM). The artifacts have the unique feature that the piston can be oriented either upright or downward in the cylinder, and the distortion depends on the orientation. The direct comparisons provide ratios of areas between various gauges; this figure provides confirmation that our distortion estimation is correct.



NIST's characterization of pressure standards enhances our ability to provide state-of-the-art measurement capabilities to its customers at levels that exceed the capabilities of many NMIs. These capabilities provide US instrument manufacturers with competitive advantage in global markets.

References:
J.W. Schmidt, ***"Primary pressure standards based on dimensionally characterized piston/cylinder assemblies",*** *Metrologia* **43** 53-59 (2006).

Future Plans: In the coming year, we will complete the analysis of data collected for 35 piston gauge comparisons and revise uncertainty statements for NIST piston gauge standards operating up to 17 MPa.