12. Atomic Standard of Pressure

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Objective: To develop a primary standard for pressure in the range 0.3 MPa – 5 MPa. This will be accomplished by measuring and calculating the dielectric constant $\varepsilon(p,T)$ of helium with sufficient accuracy to make the pressure uncertainty obtained from existing standards (piston gages) significantly larger than the pressure uncertainty from in $\varepsilon(p,T)$.

Problem: Below 300 kPa, the primary pressure standard at NIST is a mercury manometer. Above 300 kPa, commercially manufactured piston-cylinder sets are used as pressure standards. These sets are complicated artifacts. In operation, the piston must rotate to insure gas lubrication and both the cylinder and piston deform significantly. Thus, piston-cylinder sets must be calibrated against the primary-standard mercury manometer at low pressures and their performance is extrapolated to higher pressures using numerical models of the coupled gas flow and elastic distortions. Piston-cylinder sets exhibit a gas-dependence that is not well understood. Thus, the extrapolation is not fully trusted and it cannot be checked by independent methods above 300 kPa. If the dielectric constant of helium were known accurately enough to serve as a primary pressure standard from 300 kPa to 5 MPa, an independent test of the models used to interpret piston-cylinder sets would be possible.

Approach: Dielectric constant measurements are being improved by drawing on NIST's expertise in electrical metrology. Using that expertise, we developed a novel, doughnut-shaped, four-electrode cross capacitor. We measured C_{TB} and C_{IO} and computed the average: $C_x = (C_{TB} + C_{IO})/2$, which is the cross capacitance. (See Fig. 1.) The average compensates for relative motion of the electrodes (changes in s) and for dielectric layers on the electrodes, *e.g.* oxides, adsorbed water, or films of oil. In use, the cross capacitor is enclosed by a pressure vessel that is filled with the test gas.

The calculation of $\varepsilon(p,T)$ of helium from quantum mechanics is being improved by Szalewicz (Univ. of Delaware) and collaborators. Ultimately, the uncertainty of the calculated values of $\varepsilon(p,T)$-1 will be approximately 10^{-6}. This would be the uncertainty of the pressure standard if the relative uncertainty of the measurements of C_x were 10^{-9}.

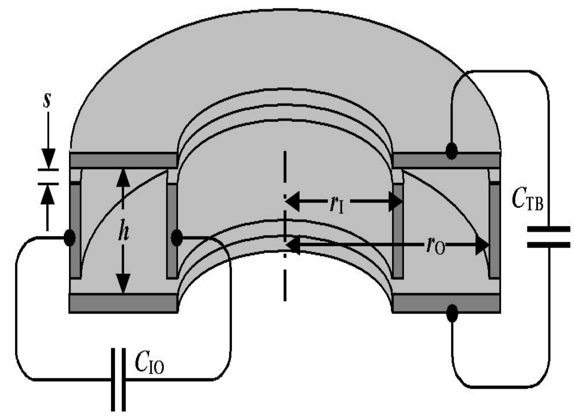

Figure 1. Cut-away sketch of a toroidal cross capacitor.

Results and Future Plans: Two cross capacitors were constructed out of superinvar and tested using commercially available capacitance bridges. For helium pressures up to 7 MPa, the cross capacitor concept was experimentally proven at the level of approximately $0.3\times10^{-6}\times\varepsilon(p)$. However, heat treating the superinvar electrodes caused them to become became mechanically lossy. This prevented us from determining their elastic constants with the necessary accuracy via resonant ultrasonic spectroscopy (RUS). We made reference-quality measurements of $\varepsilon(p)$ for methane, nitrogen, carbon dioxide, argon, and helium at 50°C. (See Report 12.)

We will build a new cross capacitor using a maraging steel. This should be compatible with RUS; however, it will require a better thermostat than superinvar requires. To further improve the capacitance measurements, we will build a special-purpose capacitance bridge.

Publications:

Buckley, T. J. Hamelin, J. O., and Moldover, M. R. ***"Toroidal Cross-Capacitor for Measuring the Dielectric Constant of Gases"*** Review of Scientific Instruments, 71, 2914-2921 (2000).