

## ***Application Note – Model 745***

### ***Quasi-spherical Resonators for State-of-the-Art Temperature and Pressure Metrology***

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There are two international research efforts underway that aim to redefine two quantities vital to both science and industry: pressure and temperature. Since 1998, an atomic standard of pressure – namely, a pressure standard based on the atomic properties of helium rather than one based on masses and pistons, has been under development [1]. In 2005, the Comité Consultatif de Thermométrie (CCT) recommended to the Comité International des Poids et Mesures (CIPM) that the Boltzmann constant,  $k_B$ , should be remeasured in preparation for the redefinition of the Kelvin [2]. Quasi-spherical cavity resonators are specialised instruments that are central to both international research programs. Accurate, high-resolution and real-time knowledge of the gas pressure in and around these resonators is essential to both research efforts. Paroscientific's Digiquartz Model 745 laboratory standard is the transducer of choice for these demanding applications.

Quasi-spherical resonators are cavities that have been intentionally perturbed from a perfect sphere: e.g. a triaxial ellipsoid with axes of length  $a$ ,  $1.001a$  and  $1.002a$ , where  $a \approx 5$  cm. These unequal axes separate each of the triply degenerate microwave resonance frequencies of a sphere into three, non-overlapping, easily measured frequencies, which can then be measured with part-per-billion precision (ppb) [3]. To compete with piston gauges, the atomic pressure standard aims to measure helium's dielectric permittivity,  $\epsilon_{He}$ , in the 1 to 5 MPa range with a relative uncertainty approaching  $10^{-9}$ .

Quasi-spherical resonators are also used for primary thermometry; Pitre *et al.* [4] recently measured both the acoustic and microwave modes in a helium-filled quasi-spherical resonator over the temperature range 7 to 273 K and proved that ITS-90 contains errors as large as 0.01 K within this range. In acoustic thermometry, the microwave modes of a quasi-spherical resonator allow the cavity's thermal expansion to be determined with part-per-million (ppm) uncertainty. Alternatively, at 273.16 K (where the temperature uncertainty is lowest), the microwave modes of the quasi-spherical resonator can be used to determine the cavity's volume, potentially with part-per-million uncertainty. Knowledge of the resonator's volume is required to convert measured acoustic resonance frequencies and an accurate knowledge of the gas sample's molar mass into a determination of  $k_B$  [5]. Another measurement of  $k_B$  with an uncertainty of about 1 ppm is required before its value can be *defined* as exact, and the SI unit of temperature, the Kelvin, can be redefined in terms of  $k_B$  rather than in terms of the triple point of water.

At the University of Western Australia, we are contributing to the international programs aimed at measuring  $k_B$  by investigating whether the microwaves modes of quasi-spherical resonators do

in fact allow the cavity's volume to be determined with ppm uncertainty. There are two phases to this research. First, reference 3D coordinate measurements of the internal and external surfaces of a quasi-spherical resonator were made at NMI Australia [6]. These coordinates allow us to calculate the shape and volume of the resonator from an experimental technique with entirely different systematic errors. The second phase involves measuring the microwave modes of the resonator isothermally as a function of pressure. We use a Digiquartz Model 745-45 laboratory standard to measure the pressure sufficiently well that we can calculate the value of  $\epsilon_{\text{He}}$  within the resonator to parts in  $10^9$ . This then allows us to calculate the resonator's volume from the measured microwave resonance frequencies, as a function of the helium pressure. The aim of this research is to test whether the microwave-derived cavity volume is consistent at the ppm level with the volume derived from the 3D coordinate measurements. If this test is successful it would greatly accelerate the program to re-define the Kelvin from a unit linked to a material-based artefact to a unit linked to a fixed fundamental constant of nature.

## REFERENCES

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1. M R Moldover, *J. Res. NIST* **103** (1998) 167-175.
2. Consultative Committee for Thermometry, Recommendation T2 (2005) to the CIPM, *New determinations of thermodynamic temperature and the Boltzmann constant*, CCT/05-31. See also <http://www1.bipm.org/en/committees/cipm/> and <http://www.bipm.fr/en/committees/cc/cct/>
3. E F May, L Pitre, J B Mehl, M R Moldover, J W Schmidt, *Rev. Sci. Instrum.* **75** (2004) 3307-3317.
4. L Pitre, M R Moldover and W L Tew, *Metrologia* **43** (2006) 142-162.
5. M R Moldover, J P M Trusler, T J Edwards, J B Mehl and R S Davis, *Phys. Rev. Lett.* **60** (1988) 249-252.
6. <http://www.measurement.gov.au/>

Photograph of an assembled quasi-sphere including microwave cables.



Schematic of a quasi-spherical resonator: a 'race-track' cavity.

