Vacuum Technology
Room 205 ABCD W - Session VT2-TuM

Measurement, Simulations and Accelerator Vacuum Systems

Moderators: Freek Molkenboer, TNO Science and Industry, the Netherlands, **Sol Omolayo**, Lawrence Berkeley National Laboratory

11:00am **VT2-TuM-13 Enabling Vacuum Process Monitoring with Time-of-Flight Spectroscopy***, **Marco John**, Klaus Bergner, Sebastian Hüttl, Kristian Kirsch, Andreas Trützschler,* VACOM Vakuum Komponenten & Messtechnik GmbH, Germany

The increasing complexity of industrial vacuum processes requires broader and deeper knowledge of the vacuum itself. A crucial aspect for increasing quality demands is the necessity of in-situ monitoring and control of pressure and residual gas composition within vacuum processes. A consequence of advanced process control is the reduction of production errors, prevention of failures or major damage in combination with increased operating time. Traditional monitoring devices like hot cathodes or quadrupole mass spectrometers are both only able to measure either pressure or residual gas composition. Therefore, these devices are only conditionally suited for complete process control of vacuum processes. With our novel wide-range vacuum monitor NOVION®, which combines the well-known technology of time-of-flight spectroscopy with our patented ion trap, industrially available pressure and gas analyzation is possible at the same time.

In this talk we present the fundamental principles of the novel vacuum monitor and explain the compact combination of well-known time-of-flight spectroscopy with our own patented ion trap. Within different application cases we discuss advantages and limits of this technology and demonstrate with one single device wide range gas analysis, simultaneous measurement of total and partial pressures, leak detection for Helium and detection of air leaks. With these combined capabilities the novel vacuum monitor is able to quickly capture the complete pressure and gas composition measurement at various stages of the vacuum process chain. In addition, we demonstrate a special signal enhancement method to improve the resolution in the near signal-to-noise range.

11:15am **VT2-TuM-14 Update on Fixed Length Optical Cavity (FLOC) Pressure Calibration Standard for Calibration of Military and Commercial Aircraft***, **Jacob Ricker**, Kevin Douglass, Thinh Bui, Jay Hendricks, Jay H. (Fed) <jay.hendricks@nist.gov>,* NIST

NIST has constructed several Fixed Length Optical Cavity (FLOC) pressure standards based on gas refractivity and shown that they are effective at measuring absolute pressure [1]. The US Air Force has recently funded development of these standards for the support of their Air Data Calibration Systems. These Air Data Systems provide calibration for altimeters and air speed indicators and traceability of these sensors is crucial for all operational military and commercial aircraft. NIST has been constructing a new portable FLOC constructed of an Invar material. This presentation will describe the assembly and testing of a new lower cost/robust/portable calibration system capable of calibrating gas pressure sensors over the entire range of 1 Pa to 10 MPa. The testing includes pressure performance and system stability.

References:

[1] https://doi.org/10.1016/j.measen.2021.100286.

11:30am **VT2-TuM-15 Single-Laser Optical Pressure Measurements to Support Air Data Calibration***, **Kevin Douglass**, Thinh Bui, Jacob Ricker, Jay Hendricks,* National Institute of Standards & Technology

NIST is currently constructing a portable robust Fixed Length Optical Cavity (FLOC) pressure standard to be optimized for the calibration of aircraft altimeters, rate of climb indicators, and air speed indicators while also extending the operating pressure range close to 10 MPa.To reduce cost and help simplify the operation of the system we have tested an optical approach that only uses a single laser locked to the reference cavity with a portion of that light being modulated to generate a sideband which is locked to the sample cavity.The tradeoffs and advantages of this technique will be discussed.

11:45am **VT2-TuM-16 Radiometric Force Due to Accommodation Coefficient of Gas-Surface Interaction***, **Felix Sharipov**,* Universidade Federal do Paraná, Physics Department, Brazil*; Benjamin Schafer,* Harvard University

The radiometric force arises when a body heated non-uniformly by some radiation is immersed in a gas at a low pressure. This phenomenon results from gas-surface interactions, which are characterized by the accommodation coefficients. In turn, these coefficients depend on the gas species and surface properties such as roughness and chemical composition. When the accommodation coefficients are not constant over the body surface, the radiometric phenomenon arises when the body is a different temperature than the surrounding gas, even if the body temperature is uniform. In the present study, we calculate the force exerted on a thin membrane with different accommodation coefficients on its top and bottom surfaces. The membrane temperature is assumed to be higher than that of the surrounding gas. The direct simulation Monte Carlo method is used to span a wide range of the Knudsen number including the free-molecular, transitional, and viscous flow regimes. The force reaches its maximum value when the mean-free-path is close to the membrane diameter. Thus, if the membrane diameter is about 1 cm, then the force is maximum at the pressure about 1 Pa. We show that perforations in the membrane increase the radiometric force for higher pressures. The obtained results allow to optimize the membrane geometrical parameters to reach significant radiometric force. Analysis shows that the radiometric force caused by the accommodation coefficient difference can levitate a lightweight membrane that is a few centimeters wide in near-space conditions.

12:00pm **VT2-TuM-17 Thermal Transpiration: Beyond Takaishi and Sensuiλ***, **Robert Berg**,* National Institute of Standards and Technology (NIST)

Thermal transpiration, also known as the thermomolecular effect, applies when a pressure gauge at temperature T_2 is used to measure the pressure of a gas held at temperature T_1. Examples include gas thermometry (say T_1 = 10 K) and temperature-controlled gauges (say T_2 = 318 K). When the temperature difference is large and the gas mean free path is comparable to the diameter of the tube connecting the two volumes, thermal transpiration can make the pressure ratio P_1/P_2 much less than 1.

Thermal transpiration has been described by physically motivated empirical functions, physics-based numerical models, and a physics-based analytical model. The most common empirical function is that of Takaishi and Sensui (T-S) [1]. Numerical models are rarely used because they rely on details of geometry and surface accommodation that restrict the model's use to a specific scenario.

There is only one physics-based analytical model, the "dusty gas" model [2], which employs the concept of a gas composed of infinitely heavy "dust" molecules. The dust molecules scatter the ordinary gas molecules, so that the flow in the connecting tube has a viscous component and an opposing rarified-gas component. The dusty gas model was used during the 1960s and 1970s to describe experimental measurements, most notably by Malinauskas and co-workers. Despite that success, it has not been widely used because the model's core equation requires a numerical solution.

The dusty gas model is superior to the T-S empirical function. The T-S function assumes perfect surface accommodation, while the dusty-gas model does not. Also, the T-S function has three free parameters of obscure meaning, and fitting those parameters to experimental data can hide an error in the data. In contrast, the dusty gas model has only two free parameters with clear physical meaning. The first parameter accounts for imperfect accommodation, and the second accounts for an error in the ratio λ/d, where λ is the mean free path and d is the tube diameter. A re-analysis of literature data found good agreement with the dusty gas model.

1. T. Takaishi, Y. Sensui, *Trans. Faraday Soc.* **59**, 2503-2514 (1963).
2. A.P. Malinauskas, J.W. Gooch, B.K. Annis, R.E. Fuson, *J. Chem. Phys.* **53**, 1317-1324 (1970).

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