

Vacuum Technology

Room 321 - Session VT2-ThM

Engineering for Big Vacuum Systems

11:00am VT2-ThM-13 Recent Results and Paths Forward Towards the Development of a Continuous Cryogenic Pumping and Impurity Removal System for Fusion Devices, *Trey Gebhart, Nirajan Adhikari, Oak Ridge National Laboratory*

Future deuterium-tritium fueled fusion power plants must breed tritium and sustain a burning plasma using a semi-closed loop fuel cycle. The DT fusion fuel cycle is an important aspect of any fusion energy configuration whose purpose is to provide fuel to the plasma, pump and separate machine exhaust products, and recover fuel from breeding and plasma exhaust products. The current method of separation requires a large building for palladium membranes and cryogenic distillation columns. The concept of directly recirculating the exhaust gas, bypassing the tritium plant, to make fuel pellets was proposed in the 1990s and later termed Direct Internal Recycling (DIR). The residual fusion fuel in the machine exhaust stream is separated locally and diverted directly to the fueling systems, bypassing isotopic separation and other processing equipment, and therefore significantly reducing the required size of the tritium plant, reducing plant tritium inventory, and thus increasing the economic viability of fusion as an energy source.

One concept for DIR consists of a series of cryogenic pumps to separate the impurities from the machine exhaust gas by utilizing the different triple point temperatures of exhaust constituents. Pumps for this concept are being developed at Oak Ridge National Laboratory. In this concept, the plasma exhaust gases are initially passed through an impurity trap operating at ~25-30 K to desublimates impurities such as hydrocarbons, argon, oxygen, and nitrogen. The resulting process stream will consist of deuterium, tritium, and helium. The process stream is then pumped by a continuous cryopump known as a "snail pump". This pump is a steady state continuous cryopump that desublimates all remaining exhaust gas constituents while allowing helium, a byproduct of the fusion reaction, to pass through. The helium is pumped to the tritium plant for processing while the desublimated material is continuously scraped off, heated until sublimation, and transported to the fueling system. The resulting clean DT stream is then sent directly to the fueling systems. This contribution outlines the overall design of the system, along with the most recent modeling and experimental results from this potential fusion pumping system. The R&D paths forward required for deployment in the fusion environment will also be presented.

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11:15am VT2-ThM-14 SPARC Tokamak Vacuum Pumping System Commissioning and Status, *Matt Fillion, Oliver Mulvany, Evelyn Richards, Alana Guilbault, Carl Avola, Emily Marget, Chris O'Connor, Commonwealth Fusion Systems; Shaun Hughes, Commonwealth Fusion Systems, UK; Chris Tesluk, Eric Dombrowski, Cory Crowley, Heena Mutha, Commonwealth Fusion Systems*

The SPARC tokamak is a compact, high-field, deuterium-tritium fueled magnetic confinement device, aimed at demonstrating net energy gain. The SPARC vacuum pumping systems (VACP) comprises three subsystems: the cryostat pumping system provides vacuum insulation of cryogenic components, the leak detection system provides interspace pumping of vulnerable double-walled vacuum components, and the torus pumping system is an integral part of the D-T fuel cycle to enable plasma operations.

Each VACP subsystem is being commissioned to demonstrate plant readiness for plasma operations. This talk will provide an update on SPARC vacuum pumping systems assembly and commissioning activities, and coming steps. We will discuss the plant-side integrated commissioning and characterization of the vacuum pumping systems; e.g., system base pressures and vacuum quality. Additionally, we will demonstrate the system's ability to receive hydrogen isotope gas loads via a temporary test stand, verify its exhaust paths, and validate fault responses.

11:30am VT2-ThM-15 Scalable Strategies for Large Ultra-High-Vacuum Systems, *Melina Fuentes-Garcia, California Institute of Technology*

The Laser Interferometer Gravitational-Wave Observatory (LIGO) detects gravitational waves by measuring distortions in spacetime as they pass

through a set of 4km-long interferometer arms. To achieve the required sensitivity, the interferometer must operate under ultra-high-vacuum (UHV) to minimize phase noise associated with scattering from residual gas species in the beamtube arms. Water vapor, a dominant gas species, has a strong binding energy to stainless steel, and when a beamtube is exposed to atmospheric air during venting, a bakeout is typically required to accelerate desorption and restore UHV conditions. For LIGO, and other large-scale systems, bakeout is not feasible due to the significant cost. Presented here are two complementary studies motivated by this challenge. The first examines backfilling of a UHV chamber, made of a section of initial LIGO beamtube, with ultra-high-purity dry air to suppress re-adsorption of water vapor, with the potential of avoiding a bakeout entirely. The second investigates an alternative bakeout method and alternate beamtube material for third generation gravitational wave detectors, such as Cosmic Explorer. It utilizes a movable induction heater to drive off water vapor from a mild steel beamtube. While this effort is intended to inform design on future detectors, in particular beamtube material selection and bakeout technique, it draws on experimentation and modeling closely related to that of the first study. Together, these investigations point toward practical strategies that can be applied to large scale UHV systems.

11:45am VT2-ThM-16 Engineering Aspects of a-C Coating Systems Targeting Low Secondary Electron Yield, *Abhilash S Reghu, Byron Golden, Jessica Brown, Sumanta Nayak, Susheng Xin, Kenneth Decker, Charles Hetzel, Brookhaven National Laboratory*

The amorphous carbon (a-C) coating campaign for the Electron-Ion Collider (EIC) beamline at Brookhaven National Laboratory is advancing rapidly. A prototype system successfully established the coating process, paving the way for the design and construction of a 12-meter full-scale production coating machine, which is currently undergoing testing. Once validated, more coating machines will be deployed to expand the facility and complete the campaign on schedule. This paper presents the essential features and engineering considerations of the coating systems and discusses key lessons learned during commissioning, testing, and operation, with a focus on strategies for achieving low secondary electron yield.

12:00pm VT2-ThM-17 Programmable Resonance Tracking of a Quartz Crystal Microbalance in High Vacuum Using Moku:Go, *Sehrish Akhtar, Clemson University*

A programmable method was developed to track the resonance of a nominal 6 MHz AT-cut quartz crystal microbalance (QCM) in high vacuum and compare its response with a commercial INFICON crystal monitor. The QCM was operated at approximately 1×10^{-7} hPa and exposed to a 405 nm laser over settings corresponding to externally measured average powers of approximately 4 to 65 mW. Moku, a software-configurable instrument combining waveform generation and spectrum analysis, was used to excite the crystal, measure its frequency response, and implement the tracking routine. Initial frequency sweeps located the response minimum near 5.982850 MHz. The minimum was then followed using a three-point quadratic estimate and a hybrid routine that alternated full three-point calibration with faster two-point updates. During a laser-off stability test, the tracked frequency had a standard deviation of 0.428 Hz and a total peak-to-peak variation of 4.139 Hz. Separate sweeps at 0.1, 3, and 5 Vpp located the same response minimum, indicating that the excitation amplitude did not measurably shift the resonance. In separate measurements using the same crystal and corresponding laser protocol, the Moku and INFICON systems reproduced the same stepwise increase in frequency with increasing average laser power. However, their reported absolute frequencies differed by approximately 107 Hz at the lowest tested power and 187 Hz at the highest tested powers. The INFICON monitor provided a higher sampling rate and lower baseline variation, while the Moku-based system allowed the excitation and tracking procedure to be programmed within a single instrument. These results show that programmable spectrum-based tracking can resolve transient QCM responses in high vacuum and that the tracking method must be considered when comparing absolute frequencies and laser-induced frequency shifts between QCM controllers. The platform is being developed for future studies of ice-coated QCMs under localized laser irradiation and possible ion bombardment in high vacuum.

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