O 66: Vacuum Science Technology: Theory and Applications

Time: Wednesday 15:00–18:00 Location: H8

Invited Talk O 66.1 Wed 15:00 H8

Unveiling the crucial role of kinetic modeling of gas flows in vacuum and fusion technologies — •Christos Tantos and Thomas Giegerich — Institute for Technical Physics, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, 76344, Germany

Accurate and reliable modeling of non-equilibrium flows is not only of academic interest within the scientific community, including the field of vacuum gas dynamics, but is also crucial for the design and enhancement of engineering processes, such as those in vacuum and fusion technologies. In these applications, the flow is characterized by molecular mean free paths that are comparable to the reference characteristic length, making a particle-based description of the flow field essential. This requires the use of the Boltzmann equation and widely accepted numerical methods for solving it, such as the stochastic Direct Simulation Monte Carlo (DSMC) and the deterministic Discrete Velocity Method (DVM).

This talk discusses key aspects of rarefied gas dynamics in vacuum and fusion technologies, emphasizing the link between theory and practice. It is divided into two parts. The first covers recent advances in modeling multicomponent transport phenomena in vacuum technology using DSMC and DVM methods, with a focus on gas separation in multicomponent flows. The second part analyzes vacuum gas dynamics in fusion systems, presenting numerical simulations (2D and 3D) of pumping systems in fusion machines and highlighting their design impact.

Invited Talk O 66.2 Wed 15:30 H8

Advances in traceable vacuum and outgassing rate measurements — •Matthias Bernien[1], Annas Bin Ali[1], Thomas Bock[1], Tom Rubin[1], Janez Setina[2], Perrin Waldock[3], Kirk Madison[3], and Karl Jousten[1] — [1]PTB, Abbestr. 2-12, 10587 Berlin — [2]IMT, Lepi pot 11, 1000 Ljubljana, Slovenia — [3]University of British Columbia, 6224 Agricultural Road, Vancouver, B.C. V6T 1Z1, Canada

For the pressure range from 10 mPa to 130 Pa, a fully automated static expansion system made of aluminum has been set up and validated. Its principle involves transferring a fixed amount of gas from a smaller volume to a larger one, creating a well-defined lower pressure, provided that the initial pressure and the volume ratio are accurately known. Relative standard measurement uncertainties between 0.08% and 0.012% are achieved. Primary standards utilizing cold atom traps offer a promising new approach for realizing the pascal in the UHV range by measuring the loss rate caused by collisions with gas molecules. To establish these standards, the University of British Columbia and PTB have carried out a comparison between a mobile standard based on cold atoms and a continuous expansion system for N_2, Ar and H_2. In the semiconductor industry, outgassing from components in vacuum must be well controlled. Contaminants are monitored using QMSs which lack stability. This is particularly problematic when maximum levels of contaminants must be agreed between manufacturers and suppliers. To improve the comparability of outgassing rate measurements, reference samples for dodecane and water have been developed suitable for in-situ calibration of QMSs.

O 66.3 Wed 16:00 H8

BeamPipes4ET: Innovative On-Site Production and Welding of the Einstein Telescope Vacuum Tubes — Charlotte Benning, •Robert Joppe, Oliver Pooth, and Achim Stahl — III. Physikalisches Institut B, RWTH Aachen

The Einstein Telescope will be the first gravitational wave detector of the third generation. It requires about 120 km of vacuum tubes with a diameter of 1 m to achieve the design sensitivity and reduce scattered light. BeamPipes4ET introduces an innovative production concept for vacuum pipes, incorporating a new welding technology and adapting existing flange and T-section production methods. This approach enhances reliability, significantly reduces labor, welding, and finishing efforts. By manufacturing pipes on-site from coils of sheet metal in a continuous process, transportation needs are minimized, and pipe connections are eliminated. Additionally, the project pioneers laser beam welding under mobile vacuum and transfers advanced pipe feature integration technologies to further streamline production.

This talk presents the current status and ongoing activities in the BeamPipes4ET project.

O 66.4 Wed 16:15 H8

Aluminum fiber optical vacuum feedthroughs for challenging environments — •Christoph Bartlitz, Kristian Kirsch, Marco John, Marcel Hannemann, Andreas Trützschler, and Klaus Bergner — VACOM Vakuum Komponenten & Messtechnik GmbH, In den Brückenäckern 3, 07751 Großlöbichau, Germany

Fiber optical components are used in a wide variety of places, both in scientific experiments and in production processes in vacuum systems. In principle, these components enable interference-free transmission of the finest measurement signals over long distances, robust sensor technology and maximum transmission speed. Hermetic optical fiber feedthroughs based on stainless steel, ceramics and quartz glass have become established for coupling light signals to vacuum- and process chambers.

We designed and tested a novel optical fiber feedthrough whose metallic components are made entirely of aluminum.

These technologies enable the application of optical fibers as in-vacuum diagnostic within challenging environments. Thereby, the diagnostic is driven by fiber Bragg gratings (FBGs) in the optical fiber itself. The application of FBGs as an in-vacuum temperature sensor is demonstrated, where an optical fiber containing a bunch of several FBGs becomes a compact, stable, robust, and flexible network of local sensors at different positions in vacuum with up to km-length signal path.

O 66.5 Wed 16:30 H8

Comparative Measurements of Ion Pump pumping speed according to ISO/DIS 3556 and DIN 28429 — •Marcel Herrmann, Kristian Kirsch, Marco John, Christoph Bartlitz, Andreas Trützschler, and Klaus Bergner — VACOM Vakuum Komponenten & Messtechnik GmbH, In den Brückenäckern 3, 07751 Großlöbichau

Sputter Ion Pumps (SIP) offer an appealing strategy to efficiently maintain ultra-high and extremely-high vacuum conditions in a vacuum chamber. The pumping speed, i.e. the volume flow of gas extracted from the vacuum in a specific period of time, can be determined according to various standards. However, recorded pumping speeds may vary severely, depending on the standard chosen and the detailed procedure applied. This talk compares experimentally obtained pumping speeds of several SIPs, acquired according to the most commonly applied standards, DIN 28429:2014 05 and ISO/DIS 3556 1.2(1992).

O 66.6 Wed 16:45 H8

Performance and future of the KATRIN experiment after 6 years of tritium operation — •Joachim Wolf — Karlsruher Institut für Technologie (for the KATRIN Collaboration)

The Karlsruhe Tritium Neutrino experiment (KATRIN) searches for the effective electron neutrino mass with electrons from the β-decay of tritium with an unprecedented sensitivity of <0.3 eV/c2. The β-electrons are guided magnetically through the 70-m long setup, moving from the gaseous tritium source through a differential pumping section (DPS) and a cryogenic pumping section (CPS) to the high-resolution spectrometer. In the spectrometer, the kinetic energies of the decay electrons are analysed in an electrostatic high-pass filter (MAC-E-filter). Background considerations require a very good vacuum in the order of 10-11 mbar in the large spectrometer vessel (volume 1240 m^3, surface: 1222 m^2). A combination of NEG pumps and turbo-molecular pumps reliably provides the necessary pumping speed since more than 10 years. In addition, a very clean surface and low outgassing rates are mandatory.

After several years of engineering runs, the experiment started full tritium operation in March 2019, searching for the effective mass of electron-anti-neutrinos. These measurements will finally end in December 2025, followed by hardware upgrades and a new physics program. This talk reports on the performance of the components, after almost 20 years of R&D and 6 years of tritium operation with special emphasis on vacuum-related issues, followed by a description of future plans for the KATRIN setup.

O 66.7 Wed 17:00 H8

Miniaturized Pirani vacuum sensor with active heat-loss

compensation — •Julian Eiler[1], Stefan Weber[2], Peter Gerlesberger[2], Heinz Plöchinger[2], and Rupert Schreiner[1] — [1]Faculty of Applied Natural Sciences and Cultural Studies, OTH Regensburg, D-93053 Regensburg, Germany — [2]Thyracont Vacuum Instruments GmbH, D-94036 Passau, Germany

Pirani sensors measure the thermal conductivity of the residual gas in a vacuum by creating a thermal gradient between a heated sensor element and a heat sink. The heat flux from the sensor element to the heat sink over the residual gas is a measure of the vacuum and can be determined by the electrical power applied.

In addition to the heat flux over the gas, there are further energy losses from the heating structure due to radiation and parasitic heat fluxes via the suspensions of the sensor element. These losses reduce the sensitivity of the sensor.

For this reason, a Micro-Pirani sensor in the shape of a microhotplate was developed that actively compensates the heat flux via the suspensions. This was achieved by placing additional heating structures on the suspensions, which interrupt the heat flow from the sensor element via the suspensions during operation. This active compensation improves the sensitivity at low pressures, enabling vacuum measurements from atmospheric pressure down to 10e-6 mbar.

O 66.8 Wed 17:15 H8

Feasibility Study on Laser-Based Real-Time Monitoring of Hydrogen Atom Beams — •Tobias Geier, Alexander Marsteller, and Robin Grössle — Karlsruher Institute for Technology, IAP-TLK, for the KAMATE Collaboration

Through the observation of neutrino oscillations, it has been shown that there are three different neutrino mass eigenstates. Current measurements of the oscillation length of the flavor states yield a lower limit for the effective electron neutrino mass of ~ 0.05 eV (inverted ordering) or ~ 0.01 eV (normal ordering). The sensitivity of the KATRIN experiment is limited to ~ 0.3 eV. Therefore, future experiments which aspire to achieve inverted ordering or better need new technologies. For the next generation of experiments aiming at the direct determination of the neutrino mass using high-resolution beta spectroscopy on tritium, atomic tritium is to be used. The advantage over the currently used molecular tritium (T_2) lies in the avoidance of molecular excitations in the $^3HeT^+$ daughter molecule, which lead to a smearing of the beta spectrum, thus limiting the maximum achievable resolution. In order to employ atomic tritium for beta spectroscopy, it is essential to cool it to a few mK and trap it magnetically. A method for contactless real-time analysis of the beam is required to monitor and control the operation of the atomic source. This talk presents a method for characterizing the beam profile based on Rayleigh scattering of a laser beam. By measuring the intensity with a sensitive camera, the particle density can be mapped. In this contribution, the results of a first experimental feasibility study are presented.

O 66.9 Wed 17:30 H8

Challenging tasks in modern vacuum technology applications — •Kristian Kirsch, Andreas Trützschler, Christoph Bartlitz, Marcel Herrmann, Marco John, and Klaus Bergner — VACOM Vakuum Komponenten & Messtechnik GmbH In den Brückenäckern 3 07751 Großlöbichau / Germany

Cutting-edge technology from the field of particle accelerators, quantum technology applications and lithography is pushing the limits of vacuum technology. In general, off-the-self" products are not sufficient for that. In this context, product developers and scientists need to find a joint language to deal with this task. The focus of this talk is to explain needs and challenges of today's cutting edge technology applications related to vacuum requirements. Therefore, we address different state-of-the-art applications. One focus is the fundamental difficulty to fulfill demanding vacuum conditions in one compact system. On the other hand, we address the complex and demanding task of isolating quantum objects within a quantum application like quantum computing, quantum gravimetry, and quantum metrology. Based on this, benefits and drawbacks of different vacuum technology solutions to all of these requirements are shown within the transition from customized single components to standardized and industrial ready serial components.

O 66.10 Wed 17:45 H8

Different Approaches to Vacuum System Performance Improvement for the Einstein Telescope — •Charlotte Benning, Robert Joppe, Maike Kühler, Stefan Krischer, Oliver Pooth, and Achim Stahl — III. Physikalisches Insitut B, RWTH Aachen

The Einstein Telescope will be the next European gravitational wave detector. It requires about 120 km of vacuum tubes in tunnels with a diameter of 1 m for a laser beam to achieve the design sensitivity. The required pressure of less than 10^{-11} mbar introduces the need for innovations that help with performance improvement and cost reduction. The current baseline concept of the vacuum system includes passive sections of stainless steel welded inside the tunnels and connected to pumping stations. Achieving ultra-high vacuum (UHV) in these tubes requires high pumping capacities and long bake-out times of the tubes, which are associated with high energy and equipment costs.

This talk discusses two possible improvements over the baseline design: Integrating non-evaporable getter (NEG) surfaces into the inside of the tubes to reduce costs and aiming for a more homogeneous distribution of pumping power (distributed pumping). Furthermore, forming seamless flanges from the pipe material eliminating the need for welding is presented, which is especially relevant for the underground environment of the Einstein Telescope.