Vacuum Technology
Room: 230B - Session VT-TuA

Gas Dynamics and Modeling, Pumping and Outgassing
Moderator: Marcy Stutzman, Jefferson Lab, Jacob Ricker, NIST

2:20pm **VT-TuA1 The Evolution of Cryopumps**, ***Sergei Syssoev***, Brooks Automation **INVITED**

Cryopumping is a widely used technique to produce vacuum in an enclosed space via removal of residual gases by cooling them to the point that they are condensed or adsorbed on an appropriate cryogenic surface. Depending upon the application and the gas species, cryopumps operate at different temperatures between 4K and 150K. To attain these temperatures, different thermodynamic cycles are employed ranging from helium liquefaction to mixed gas auto-cascaded systems. Of these various thermodynamic cycles the Gifford-McMahon (GM) cycle has emerged as the dominant cycle for economically delivering the appropriate cooling power at the appropriate temperatures required for cryopumping. Cryopumps based on GM cryocoolers have been commercially adapted to a variety of vacuum processes; notably semiconductor substrate processing equipment, flat panel display fabrication, thin film coatings, analytical instruments and space simulation systems. Built around a dual stage cryocooler, GM cryopumps consists of two internal cryocondensation regions (arrays) that operate at different temperatures. The warmer (first) stage is generally operated at temperatures between 65K and 100K, condensing mainly residual water vapor and other type I gases such as hydrocarbons, carbon dioxide etc. The colder (second) stage is kept at 8K to 20K, which allows condensing of type II gases (such as nitrogen, argon, oxygen) and adsorbing type III gases (hydrogen, helium, neon). To adapt a cryogenic pump to a specific application the geometry and temperatures of the condensing arrays can be modified or tuned to suit the user's application.

By far the dominant application of cryopumping is for the semiconductor fabrication processes of physical vapor deposition (PVD) and ion implantation. There are significant differences in the vacuum environments, namely the gas species and gas densities in which these two processes are conducted. Over time, the vacuum requirements of these processes have become more stringent as line widths decreased in keeping with Moore's Law. In response to the changing vacuum requirements for these processes, the designs of closed cycle cryopumps have evolved. The evolutionary performance improvements of GM cryopump that has taken place in the past few decades will be discussed in this work. Extensive developments have led to significant increase of storage capacity (up to factor 5), pumping speed, pressure dynamics, functionality and energy efficiency. The safety aspects of cryopumping of explosive gases such as oxygen (ozone) and hydrogen will also be discussed.

3:00pm **VT-TuA3 Simulation of a Large Linear Jet Mercury Diffusion Pump with the Test Particle Monte Carlo Method**, ***Xueli Luo***, *T. Giegerich, C. Day*, Karlsruhe Institute of Technology (KIT), Germany

In current nuclear fusion research, the cryopump in various designs has become the standard solution for pumping the plasma chamber. However, considerable amounts of accumulated tritium have been found the issues towards a fusion demonstration power plant (DEMO). A recent study has shown that the mercury diffusion pump has the potential to replace the cryopump, and KIT has been charged to develop a new linear mercury diffusion pump [1]. Obviously, a reliable simulation tool is essential in such a development.

The first mercury diffusion pump was invented by W. Gaede 100 years ago. In the fifties of last century, a large, linear mercury diffusion pump was built and tested in Livermore Research Laboratory [2]. In this paper, we will present the simulation of this pump by ProVac3D, which is a versatile Test Particle Monte Carlo simulation code developed by KIT [3-4]. Based on the fact that the profiles of the mercury jets are hardly changed by the gas load, the simulation was carried out in two steps. First, the background density of the mercury molecules established by the mercury jets was calculated. Secondly, the collision between the molecules of the gas load (N_2 at 15°C) and the mercury molecules had been considered. In order to achieve high simulation precision, ProVac3D had been parallelized, and 10^{12} test molecules were simulated at a supercomputer. The calculated pumping probability, which is the ratio of the number of particles absorbed at the pump bottom to the number of the total simulated particles, was compared with the ratio without collisions between the gas load and the mercury jets. In this way, the pumping effect of the mercury gas jet had been clearly revealed and compared with the experimental data. The agreement is good and this novel simulation approach with ProVac3D will be employed in the development of such a pump for DEMO. Further investigation to combine the Monte Carlo simulation of the gas load with the CFD calculation of the mercury jet is in plan.

References

[1] Chr. Day, Th. Giegerich, Development of advanced exhaust pumping technology for a DT fusion power plant, IEEE Transactions on Plasma Science 42 (2014) 1058-1071.

[2] E. Lind, F. Steinhaus, Development of a large linear jet mercury diffusion pump, Report MTA-14, Livermore Research Laboratory, Livermore, CA, US, Jan. 1953.

[3] X. Luo, Chr. Day, H. Haas, St. Varoutis, Experimental results and numerical modelling of a high-performance large-scale cryopump I, Journal Vac. Sci. Technol. A 29 (2011) 041601/1-7.

[4] X. Luo, V. Hauer, Chr. Day, Monte-Carlo calculation of the radiation heat load of the ITER pre-production cryopump, Fusion Engineering and Design 87 (2012) 603-607.

3:20pm **VT-TuA4 Monte-Carlo and Angular Coefficients Simulations of Complex Vacuum Systems Equipped with NEG Pumps**, ***Fabrizio Siviero***, *T. Porcelli, G. Bongiorno, M. Urbano, E. Maccallini, P. Manini*, SAES Getters, Italy

The use of analytical and numerical tools for the simulation of several physical quantities in complex vacuum systems is becoming a well-established practice. Applications range from large machines like particle accelerators to smaller systems, for example analytical instrumentation or special processing chambers. The computational approach is essential whenever an accurate estimation of pressure profiles or effective pumping speeds is needed for vacuum systems that do not present a very simple geometry. This is very often the case of real UHV systems, where NEG pumps are increasingly employed to improve the performances of the pumping system in terms of base pressure, size, weight or power consumption.

Two main approaches are currently used in the field, i.e. the test-particle Monte Carlo (TPMC) and the Angular Coefficients (AC) methods. At SAES labs both these methods are being used, the former by means of the MOLFLOW+ code, the latter with an interface developed internally in MATLAB and ANSYS environment. The simulation work has two main aims: first as a tool to support the development of NEG products, then more and more frequently to help customers in taking full advantage of the use of getter technology in their systems. Indeed, the use of NEG pumps in the vacuum layout may allow redesigning the complete system, for example enabling the improvement of other important parts in the design of the machine.

The case of NEG pumps simulation presents some peculiar features, since it is not always possible to model the pump as a simple absorbing surface, i.e. the flange inlet, but the complete device must be modelled. Thus it becomes important to properly set the characteristics of the pumping surface in terms of geometry and sticking probability. Some examples will be presented about:

i) the NEG characterization in terms of pumping speed for different gases;

ii) the design of new systems and the upgrade of existing facilities, where NEG pumps, including combination pumps (NEXTorr®) and custom solutions, are used to improve the vacuum level or solve practical issues related to the size and weight of the conventional pumping system.

Results show that vacuum modeling of NEG pumps is an helpful tool to system design and optimization.

4:20pm **VT-TuA7 Simulation of Steady-State and Impulse Pressure Profiles in Front-End of A1-Beamline at Cornell High Energy Synchrotron Source**, ***Yulin Li***, Cornell University

During summer 2014 accelerator shutdown, a pair of Cornell Compact Undulators (CCUs) was installed at Cornell Electron Storage Ring (CESR), together with a 3.5-long vacuum chamber with 5-mm vertical aperture. In a canted arrangement, these CCUs provide much brighter X-ray beams to 5 (out of 12) user stations at Cornell High Energy Synchrotron Source (CHESS). To take full advantage of the brighter sources, one of CHESS beamline, namely A1 beamline, was re-designed entirely and constructed with new vacuum chambers along ~25-m length. Similar to most 3rd generation light sources, the new CHESS A1 beamline deployed a windowless design without any vacuum barrier between CESR and A1 user station. However, the windowless design poses potential risks to CESR ultra-high vacuum (UHV) systems from potential vacuum excursions at the user station. Differential pumping and various protection interlocks are

incorporated in the A1 beamline to mitigate the risks. In this paper, vacuum responses to large gas loads in A1 beamline front-end section were simulated using a test-particle Monte-Carlo program, MolFlow+ [1]. The front-end sector of the A1 beamline is constructed of UHV-compatible components with all-metal seals, including an X-ray optics box, beam shutters, two collimators, and all-metal gate valves etc. Vacuum pumping consists of a large turbo-molecular pump (1300 l/s) at the mirror box, and 6 additional sputtering-ion pumps (SIPs) and non-evaporable getters (NEGs) with pumping speed ranging from 45 to 200 l/s. To simulate vacuum incidents, a very large gas load (0.1 torr×liter/sec) is introduced at the X-ray optics box. The vacuum pressure profiles are simulated along the front-end sector to assess the impact of the large gas load to CESR UHV system, for various pumping conditions. To evaluate the A1 front-end sector as a vacuum delay-line, time-dependent pressure profiles are also simulated with MolFlow+. The simulation results indicate that CESR UHV system is immune from vacuum incidents at CHESS user stations and the A1 front-end sector acts as effective delay line.

This work is supported by the National Science Foundation, under Grant# DMR-1332208 and 0936384. Mr. Aaron Lyndaker of CHESS provided a 3D model of A1 front-end used in the simulations.

[1] MolFlow+ is available from CERN's web-site: http://test-molflow.web.cern.ch/

4:40pm **VT-TuA8 APS-Upgrade Storage Ring Vacuum System Design using SynRad/MolFlow+ with Photon Scattering**, ***Jason Carter***, Argonne National Laboratory

The SynRad/MolFlow+ vacuum simulation package from CERN has been used to evaluate a conceptual design of a storage ring vacuum system for the APS-Upgrade project. The design requirements call for a system that can reach sufficiently low pressures within a reasonable commissioning time in order to achieve required beam lifetimes. A SynRad/MolFlow+ simulation of the storage ring vacuum system pressures has been computed which includes photon scattering and predicts photon stimulated desorption outgassing rates from the irradiated vacuum surfaces. The vacuum system design incorporates two important analyses. Synchrotron radiation absorbers are located at critical lattice sites in order to both mitigate high heat loads and to localize the high predicted gas loads so that they can be efficiently removed with discrete pumps. In addition, the residual gas species are calculated to identify regions with high molecular gas concentrations. Vacuum pumping is then designed to mitigate the high mass gas loads and increase beam lifetimes.

5:00pm **VT-TuA9 Simulation and Measurement of Radioactive Radon in the KATRIN Main Spectrometer**, ***Joachim Wolf***, Karlsruhe Institut for Technology (KIT), Germany

The objective of the **Ka**rlsruhe **Tri**tium **N**eutrino experiment (KATRIN) at the Karlsruhe Institute of Technology (KIT) is the measurement of the electron neutrino mass. A central component is the Main Spectrometer (MS), where the energy of the β-electrons from tritium decay (18.6 keV) will be measured with high precision. It consists of a large ultra-high-vacuum vessel with a volume of 1240 m^3. The pumping system of the MS consists of turbo-molecular pumps, a large-scale getter pump (3000 m NEG strips, St707) and three cryo-baffles at LN_2 temperature, designed to maintain an ultimate pressure in the range of 10^{-11} mbar.

The NEG strips, as well as the stainless steel walls are known to emanate small amounts of radon atoms, increasing the intrinsic background rate, which would limit the sensitivity for the neutrino mass. The cryogenic copper baffles are expected to capture most of the radon, before it decays in the main volume. However, radon does no not stick to the cold surface indefinitely. There are two possibilities, it either desorbs after a limited residence time (depends on desorption enthalpy and baffle temperature), or it decays into polonium. In the first case, it can contribute again to the background rate.

This work reports on radon measurements with cold baffles at various temperatures and compares the results with Test-Particle Monte-Carlo (TPMC) simulations. The simulation was performed with a modified MOLFLOW+ code, where we added two new, time-dependent features, (i) a finite residence time for all adsorbing surfaces, and (ii) the half-life of the test particles. For the measurements we used two different radon isotopes with a half-life of 4 s and 56 s, respectively. By comparing measured rates with TPMC simulations for different residence times, we want to learn more about the surface conditions of the baffles (Cu, Cu_2O, H_2O) and the corresponding desorption enthalpies.

This work has been supported by the German BMBF (05A14VK2).

5:20pm **VT-TuA10 Degassing of the Kicker Magnet in J-PARC RCS via New *In Situ* Baking Method**, ***Junichiro Kamiya***, *N. Ogiwara, M. Kinsho*, Japan Atomic Energy Agency

The usual way to reduce outgassing from a device in vacuum is to heat up a whole vacuum chamber containing the device. However, the situation, where this method can be applied, is limited due to the heat expansion of the chamber. Especially in accelerators, where the vacuum chambers are connected with nearby beam pipes, this normal bake-out method may not be applied. If a heat source and heat shields are appropriately installed inside the chamber, heat flux is directed to the device. Therefore the device can be baked out without raising the temperature of the vacuum chamber.

One candidate for such bake-out method to be applied is kicker magnets in J-PARC 3GeV synchrotron (RCS), which are installed in large vacuum chambers. The kicker magnets are installed in vacuum to prevent the discharge by high voltage. The kicker magnet mainly consists of Ni-Zn ferrite cores, aluminium electrode plates. The total outgassing rate of the materials is large due to the large surface area. Therefore it is very important to develop a degassing method for the kicker magnets in the beam line because the vacuum quality may become poor after repeated exposures to air for the maintenances. The main outgassing component of those kicker magnet components is water vapour. Therefore the bake-out temperature should be above 100 °C, which is the typical desorption temperature of water vapour from the general surface. In the RCS beam line, 3 and 5 kicker magnets are located in vacuum chambers, whose length is 3 and 5 m, respectively. It is undesirable to use a normal baking method like baking the vacuum chamber of the kicker magnets because the large heat expansion of the vacuum chamber will break nearby equipment such as alumina ceramics pipes. By applying the bake-out method, which is mentioned at the beginning, only the kicker magnet is heated without raising the temperature of the vacuum chamber. In the first stage, we performed the operability assessment of the new degassing method by the calculation with a simple model and the principal experiments using the kicker magnet, which have the same structure as the production kicker magnets in RCS. As a result, the kicker components were heated up above 100 °C by a wide margin, while keeping the temperature rise of the vacuum chamber less than 20 °C. Next, we developed the design of the heater, which has a good maintainability. The small heater of graphite, which is installed through a maintenance port of the vacuum chamber, is designed. The ideal temperature distribution was obtained with this graphite heater. Furthermore, the outgassing of the graphite was suppressed by the heating process.

5:40pm **VT-TuA11 Uncertainty of UHV Flowmeter Standard Related to the Gas-Surface Interaction**, ***Felix Sharipov***, *Y.B. Barreto*, Universidade Federal do Parana, Brazil

Gas flows through orifices of various shapes are used in the primary metrology of vacuum in order to develop a primary standard of conductance [1]. Since the orifices are usually very think and the most part of gaseous molecules passes through the orifice without a collision with its surface, it is assumed the diffuse scattering for those particles which undergo collisions with the surface. However, many experiments, see e.g. [2], pointed out a significant deviation from the diffuse scattering especially for light gases like helium so that the conductance calculated on the basis of the diffuse scattering can be different from the real one and that leads to an additional uncertainty that is not included in the total uncertainty [1]. As was pointed out in Ref.[3], the diffuse-specular model of the gas surface interaction having just one adjustable parameter contradicts to some experimental data on the so-called thermomolecular pressure difference. At the same time, the Cercignani-Lampis (CL) model containing two adjustable parameters describes more physically the gas-surface interaction. The aim of the present work is to calculate the conductance of orifices used in the primary metrology based on the CL model using the accommodation coefficient extracted from various experimental data. A comparison of these data with those obtained for the diffuse scattering will give us the uncertainty related to the gas-surface interaction. Preliminary results show that the uncertainty is within 1%. Basing on these data, some recommendations to reduce the uncertainty will be given.

[1] L. Peksa et al., Vacuum. Vol.101, P.377 (2014)

[2] B.T. Porodnov et al., J. Fluid Mech. Vol.64, P.417 (1974)

[3] F. Sharipov and V. Seleznev, J. Phys. Chem. Ref. Data. Vol.27, P.657 (1998).

6:00pm **VT-TuA12 Investigation of the use of Viton as Certified Reference Material for Outgassing**, ***Janez Setina***, Institute of Metals and Technology(IMT), Slovenia

Goal of this study was to make samples with well known outgassing rate which can be used as a reference for calibration and validation of different outgassing measurement facilities.

Main criteria for selection of suitable material were (i) sufficient solubility of different gases in the material (ii) diffusion constant for different gasses in the range from 10^{-8} cm^2/s to 10^{-6} cm^2/s, and (iii) material shall be "clean" and compatible with high vacuum, which means it shall not release volatile organic compounds. Only materials which have sufficient repeatability and reversibility of gas absorption could be used as reference samples. Materials with desired properties can be found among polymers and we selected Viton (FPM-fluoropolymer) as a good candidate for outgassing reference samples. Use of Viton in high vacuum systems down to 10^{-7} Pa is well established.

We have prepared outgassing reference samples in the following way: pieces of Viton were placed in a gas loading cell and were evacuated on an ultrahigh vacuum system for sufficiently long period to get fully degassed state. Then the loading cell was filled with a pure gas or gas mixture at a pressure up to several 100 kPa and the samples were kept in the gas for several days to penetrate into material to a fully saturated state. Samples were removed out of the loading cell just before they were placed into the outgassing rate measurement apparatus.

A reference sample can be first loaded with a certain gas or gas mixture and measured by a "primary" outgassing measurement system (like the system in PTB-Germany which was developed in the frame of EMRP-IND12 project), yielding a certified reference value of the outgasing rate as a function of time. Then the same sample can be re-loaded with the same gas and under the same conditions and sent in the loading cell to a user in industry or another laboratory for the measurement in their system.

Certified reference samples can be used in round robin tests for the proficiency testing of systems in different laboratories. Distinctive feature of newly developed reference samples based on Viton material is that they can be reloaded many times and with many gases, and also with mixtures of gases at arbitrary concentration ratios. Gases which do not react chemically with Viton are expected to produce reproducible outgassing rates. This was confirmed in our tests with gases H_2, He, Ar, Kr, CH_4, N_2, O_2 and CO.

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