Vacuum Technology Division
Room On Demand - Session VT-Invited On Demand
Vacuum Technology Invited On Demand Session

VT-Invited On Demand-1 Small Diameter NEG Coated Vacuum Chambers by Copper Electroforming, ***Lucia Lain Amador,*** CERN, Switzerland **INVITED**

Non-evaporable getter (TiZrV) thin film coatings provide ultra-high vacuum conditions in particle accelerators. They are deposited on the internal walls of the vacuum chambers, transforming them from a gas source into a chemical pump. The trend in electron accelerators design consists in approaching the poles of the steering magnets close to the electron beam. This implies reducing the magnet aperture and using very small diameter vacuum pipes [1]. The application of physical vapor deposition (PVD) in such small diameter chambers becomes then very difficult. The aim of this work is to develop a novel procedure of coating/assembly, using a sacrificial aluminium mandrel as substrate of the thin film together with the creation of a surrounding copper chamber by electroforming [2]. As low as 3 mm diameter coated vacuum chambers were successfully produced using this method. After process optimization, TiZrV getter coating showed a good H_2 pumping performance with slightly delayed activation temperature compared to reference NEG coating values.

[1] C. Steier et al., Proceedings of IPAC, Richmond, USA p. 1840 (2015)

[2] L. Lain Amador, P. Chiggiato, L. M.A Ferreira, V. Nistor, A. T. Perez Fontenla, M. Taborelli, W. Vollenberg, M-L Doche, J-Y Hihn, J. Vac. Sci. Technol. A, 36, 021601 (2018)

VT-Invited On Demand-7 Vacuum Technology for Fusion Research, ***Christian Day,*** Karlsruhe Institute of Technology (KIT), Germany **INVITED**

Vacuum technology is of paramount importance for the design and operation of nuclear fusion devices. Since the start of the first tokamak and stellarator machines in the 60s, vacuum requirements in the harsh fusion environment turned out be design driving. One has to know that, contrary to the accelerator community, where there is a quest for lowest pressures, the pressure requirements in fusion (during the plasma pulse) are relatively moderate (1 Pa range). The pumping speed challenge in fusion, in particular for the larger devices, is not driven by low pressures but comes from the high throughput needed to compensate for the low burn-up of the injected deuterium-tritium fuel.

The first lab-scale machines triggered the development of high throughput turbomolecular pumps. With increasing size, pumping speed requirements became larger and larger. Nowadays, most medium-size fusion devices are equipped with cryogenic pumps. A highlight of this technology is ITER, where the use of tritium poses additional requirements on the vacuum system design.

The next step after ITER, then producing its own tritium and providing electricity to the grid, will be a demonstration fusion power plant (DEMO), the pre-conceptual design of which is under elaboration in different places on the world. On DEMO scale, accumulation pumps would build up excessive tritium inventories which imply regulatory issues. This is why a R&D programme has been launched in Europe to develop alternative pump technology.

The paper will introduce in how the requirements and challenges have evolved over the last five decades of nuclear fusion vacuum technology. Examples will be given for turbomolecular and cryogenic pumps. The DEMO development programme which looks into tritium-compatible mercury driven diffusion and liquid ring pumps as well as high capacity getter pumps will be reviewed and recent highlights be presented.

VT-Invited On Demand-13 Innovations in Gauges and Gas Analysis, *U. Bergner,* VACOM, Vakuum Komponenten & Messtechnik GmbH, Germany; ***Klaus Bergner,*** VACOM Vakuum Komponenten & Messtechnik GmbH, Germany **INVITED**

Due to the rapidly advancing digitalization, many B2B and B2C products are experiencing increasing miniaturization to make them more robust, more powerful and require less energy. At the same time, these products are expected to have increased functionality and flexibility. Typical examples are computer chips, OLEDs or smartphones. These products are manufactured by complex equipment. Key function is in first step to make grown complexity visible and in second step to become proficient with it. This is the only way to reach high yield and first time right rates as well as high reproducibility. Hereby many components, which are usually out of focus, are very important; vacuum measurement sensors. In our contribution we describe the current development of partial- and total pressure measurement technology including innovative solutions.

VT-Invited On Demand-19 Quality and Regulatory Issues for Vacuum Technology in Nuclear Power Plants, ***Charles Smith,*** US ITER / ORNL; *A. Buckley,* US ITER **INVITED**

The ITER Project is a collaboration between China, the European Union, India, Japan, Korea, Russia, and the United States to build the world's largest tokamak, a magnetic fusion device that will prove the feasibility of fusion energy on a large scale. The device incorporates a large, multi-function vacuum system as part of its primary systems. This will be the first such vacuum system which must be designed to meet the requirements of a nuclear regulatory body. US ITER Project Office (USIPO), which is managed by UT-Battelle on behalf of Oak Ridge National Laboratory for the US Department of Energy, is responsible for the design, fabrication, and delivery of major subsystems, including the Roughing Pump System (RPS) and the Vacuum Auxiliary System (VAS) to the ITER site in Cadarache, France.

Quality and regulatory compliance are of paramount importance to ensure the safe and reliable operation of ITER. As such, the vacuum system is subjected to the requirements of ASME B31.3 and must also undergo review in accordance with the European Pressure Equipment Directive (PED). All fabrication of bespoke components must undergo enhanced surveillance and monitoring to ensure it will perform as required in this challenging regulatory environment. As US ITER supplies equipment to the ITER Project construction site in Cadarache, France for integration, contracts are awarded across the globe. Ensuring compliance is an added challenge when working with a variety of 'equivalent' codes which vary based on the version year cited, differing ways to define qualified personnel, use of different unit systems, and adapting commercially available vacuum technology to meet the rigorous regulatory requirements for an operating nuclear power plant.

This presentation will discuss the quality assurance and regulatory challenges associated with a first of its kind system, the challenge of ensuring the implementation of an ITER approved quality program using a variety of standards and codes, and methods by which the USIPO has adapted its on-site surveillance program to ensure the production of quality hardware during the Covid-19 pandemic.

VT-Invited On Demand-25 Progress in the Construction of the ITER Vacuum System and Advancement in Vacuum Technologies for Fusion, ***Robert J.H. Pearce,*** *I. Banerjee,* ITER Organization, France; *J. Benet,* Fusion for Energy, Spain; *B. Boussier, J. Buckerfield,* ITER Organization, France; *F. Canadell,* Fusion for Energy, Spain; *F. Chitu, A. Cobalt, M. Dremel, S. Giors, G. Godia, S. Hughes, E. Quinn,* ITER Organization, France; *C. Smith,* US ITER Project; *A. Teissier,* Fusion for Energy, Spain; *D. Williamson,* US ITER Project; *L. Worth,* ITER Organization, France **INVITED**

ITER is under construction in the south of France in order to demonstrate the feasibility of fusion as a clean power source. It is one of the world's largest scientific and engineering collaborations. The civil structures have progressed, allowing the start of installation of very large vacuum vessels, in-vacuum components and vacuum piping networks.

The ITER vacuum system will consist of a number of large volume vessel systems including: the Cryostat (~ 8500 m3), the Torus (~1330 m3), the Neutral Beam injectors (~180 m3 each) and a large number of lower volume systems. The Vacuum System forms an integral part of the Fusion Fuel Cycle, streaming all gas originating or injected into the tokamak, through the Roughing Pumping System, to the other Tritium Plant processing systems.

The technology of the Vacuum Systems is particularly driven by ITER's fusion power operational phases, where gas streams dominated by hydrogen isotopes will be pumped in a magnetic and ionizing radiation environment. More than 90% of the vacuum system will however be installed and operational for the First Plasma phase.

An overview of the ITER construction is given with details of the challenges and solutions for assembling the UHV systems whilst completing civil works.

New technological developments, to facilitate the demanding vacuum and pumping duties coupled with safe confinement of radioactive/tritium inventories, are highlighted with results from the qualification programs for: in-vacuum nuclear dust filtration, large demountable rectangular UHV metallic sealing, tritium compatible mechanical vacuum pumps, cryogenic pumps, vacuum/cryogenic valves, vacuum instrumentation and vacuum leak localization techniques.

The paper will show spectacular progress in the construction of ITER and in the advancement of vacuum fusion technologies. Confidence in the vacuum system design and operability for both the ITER first plasma and fusion power phases will be demonstrated.

VT-Invited On Demand-31 Overview of the Outgassing Behavior of Metals, Polymers and Ceramics*, **Katharina Battes**, C. Day, V. Hauer,* Karlsruhe Institute of Technology (KIT), Germany **INVITED**

For every vacuum system the outgassing behavior of the applied materials has an impact on the pump down time and the minimum achievable pressure. Especially, at large systems or if low pressures are required, outgassing rates play a major role.

To systematically study their outgassing rates, different metals, polymers and ceramics were investigated at the Outgassing Measurement Apparatus (OMA) at KIT. OMA uses the so-called difference method, a modified throughput method, to determine specific outgassing rates related to the geometrical surface area of the sample. The advantage of the difference method is that a second vacuum chamber, which is identical to the sample chamber, is used as a reference in order to directly subtract the background outgassing rate of the chamber.

The investigated materials include stainless steel 316L, tungsten and copper alloys, Viton® and Vespel® as well as alumina, titanium nitride and silicon carbide, for example.

This paper compares the results of the performed outgassing rate measurements of the different materials as a function of time and temperature, ranging from 10^{-2} to 10^{-9} $Pa\cdot m^3/(s\cdot m^2)$. Information about the outgassing species are furthermore determined with a quadrupole mass spectrometer. Finally, the influence of manufacturing and pre-treatments of the samples will be discussed and a recommendation regarding the use of the material in vacuum is given.

VT-Invited On Demand-37 SynRad and MolFlow for Vacuum Analysis of CERN*, **Marton Ady**, R. Kersevan, P. Baehr,* CERN, Switzerland **INVITED**

SynRad+ and MolFlow+ are Monte Carlo simulators for synchrotron radiation (SR) and ultra-high vacuum (UHV), currently developed at CERN.

SynRad+ allows to trace photons - emitted by common magnetic accelerator elements - in a geometry describing the vacuum chamber by polygons. The calculated SR flux can be converted to dynamic gas load, and imported to MolFlow+ for an independent UHV simulation, predicting the pressure profile.

This talk presents recent developments, such as the transition to open-source and cross-platform, the support for geometry editing within the graphical user interface, and an external tool to convert large accelerator sequences to optics and geometry files readable by the codes.

The future development roadmap is outlined, including scripting and iterative simulations. Of particluar importance, the effort to run the codes on latest-generation Nvidia GPUs is presented, with early results showing 300x speedup on entry-level consumer cards. Finally, the feasibility of running the codes on high-performance clusters is discussed.

VT-Invited On Demand-43 Next Generation Synchrotron Light Source: Vacuum System of the 3 GeV Electron Storage Ring at MAX IV Laboratory*, **Marek Grabski**,* Max IV Laboratory, Sweden **INVITED**

The 3 GeV electron storage ring at MAX IV laboratory is the first synchrotron light source that implemented compact multi-bend achromat (MBA) magnet lattice to lower the beam emittance, and fully coated with non-evaporable getter (NEG) vacuum system to ensure low gas density. The storage ring started commissioning in August 2015 and currently delivers photon beams from insertion devices to several beamlines that are in user operation or commissioning.

Several technological challenges had to be tackled in order to achieve ultra-low emittance of the stored electron beam. One of the challenges was the vacuum system, which had to cope with severe space constraints, imposed by the compact MBA lattice, and intense synchrotron radiation from the circulating electron beam. To ensure compact, reliable and cost effective solution the vacuum chambers were constructed out of water cooled, extruded copper pipes. The inner surface of the vacuum system was NEG coated all along the storage ring circumference.

After over 5 years since the start of commissioning, the NEG coated vacuum system proved to be reliable and conditioning well. Average dynamic pressure measured around the storage ring is below 1 picobar and is reducing with the accumulated beam dose. The beam lifetime related to residual gas density is greater than 39 Ah. The total beam lifetime is above the design value of 5 Ah - thus is not limited by the vacuum level. Several successful interventions to install new vacuum components were performed on a few achromats in the storage ring during shutdowns. This was done utilizing venting of the system with purified neon gas, thus avoiding the need of re-activation of the NEG coating and saving intervention time without compromising the storage ring performance.

Design principles, performance and operational issues of the 3 GeV storage ring vacuum system will be presented.

VT-Invited On Demand-49 Vacuum Technology of Hyperloop*, **Tom Kammermeier**,* Leybold GmbH, Germany*; D. Corcoran,* Leybold USA Inc.*; S. Rosenstraeter,* Leybold GmbH, Germany **INVITED**

The anticipated demand of vacuum technology for a large scale Hyperloop track of some hundreds of kilometers is enormous. Even though the requirements of evacuating a huge air-filled chamber and the maintaining of a low pressure environment seems simple at a first glance, the details might be much less trivial. Unlike every other vacuum chamber in the world, in this case, the pumping stations will be scattered over hundreds of kilometers. Pressure variations along the track are only permissible in a small range, otherwise there would be an impact on the pods' aerodynamics. The operation pressure must be a trade-off between aerodynamic friction, energy consumption of the pumping system and a low leak rate of the tube construction. Finally, a short pump down time after e.g. a maintenance interval is desirable but easily impacts the investment into vacuum pumps – and can result in an unnecessary abundance of pumping speed, which could mean a lot of idle machinery during standard operation.

Peak energy consumption for any hyperloop vacuum system will occur during end-to-end pump-down along the track. Pump down times of the order of 12–24 hours can be anticipated. Issues for pump systems can include overheating due to gas compression; overloading of the motors; or exceeding temperature limits due to low heat dissipation at low gas pressures. Total pumping speed requirement can easily add up to millions of m^3/h for a 1000 km track. In view of this, calculations of power requirements or energy consumption, respectively, have become as important as vacuum performance.

By using the Leybold-Simulation Software, we have calculated different scenarios. The software accounts for all relevant parameters like pumping speed curves, conductance effects of piping, energy consumption, variable rotation speeds depending on gas load etc. Results are discussed in particular with regard to energy efficiency.

VT-Invited On Demand-55 Latest Developments and Uses of Neg Technology in Fusion Energy Applications*, **Enrico Maccallini**, P. Manini, M. Urbano, F. Siviero, L. Caruso, A. Ferrara, M. Mura,* SAES Getters SpA, Italy*; M. Siragusa, E. Sartori, P. Sonato,* CONSORZIO RFX, Italy*; G. Motojima, T. Murase, S. Masuzaki, T. Morisaki,* NIFS, Japan*; C. Day, S. Hanke,* KIT, Germany **INVITED**

ZAO® is a new sintered getter material allowing the use of the Non-Evaporable Getter (NEG) technology in fusion energy applications where large fluxes of hydrogen and its isotopes have to be adsorbed/desorbed with unchanged pumping properties over multiple cycles. In this presentation, we report the experimental characterization of ZAO®sintered getters, in pressure regimes and sorption amounts relevant for fusion applications. Experimental results will be presented on the integration of ZAO®based pumping system in final applications such as NBI and divertor devices.

Author Index

Bold page numbers indicate presenter