Vacuum Technology Division
Room C120-122 - Session VT-TuM

Particle Accelerators and Large Vacuum Systems

Moderators: Julia Scherschligt, National Institute of Standards and Technology, **Steven Wulfsberg**, SAES Getters USA

8:00am **VT-TuM-1 Study on a Pressure Anomaly Detection Method Applying Machine Learning in SuperKEKB Accelerator Vacuum System***, **Yusuke Suetsugu,*** High Energy Accelerator Research Organization (KEK), Japan

A large-scale vacuum system of the SuperKEKB accelerator has been running well since the first commissioning in 2016. However, owing to the large beam currents and the high frequency of beam loss and re-injection, air leaks from connection flanges due to thermal cycles caused by the intense synchrotron radiation etc., and irregular pressure rises due to discharging etc. have been often observed. Sometimes, they resulted in serious troubles which interrupt the beam operation. If any signs of abnormal pressure are detected before a usual alarm is issued or before machine operators notice the abnormality, quick countermeasures can be taken before the major troubles occurs. We are proposing and studying an anomaly detection method applying machine learning to detect the signs of pressure anomalies and call attention to operators as early as possible. First, a typical beam-filling cycle is defined as the period from the beam (re-)injection, storage, and abort. For each of the approximately 600 vacuum gauges in the main ring, the measured values for three days from eight days before the beam-filling cycle to be checked are defined as the "standard data", which include several beam-filling cycles. Then the regression curve for the behaviors of pressures during a beam-filling cycle is derived using the standard data against beam current (beam injection and storage) or time (just after beam abort). Second, for every beam-filling cycle to be checked, the standard errors are calculated from the measured pressure values during the cycle (“measured data”) using the obtained regression curves. Using the ratio of the standard error of the measured data to that of the standard data and so on as feature quantities, the behavior of pressure is judged to be "normal" and "abnormal" (2 class classification) utilizing a two-layer neural network. The classification criteria are previously learned from actual abnormal behaviors of pressures when vacuum troubles occurred since 2016. A simulation test using the actual beam abort events from May 2022 showed that signs of pressure anomalies can be detected. Here we report on the status of the study on this pressure anomaly detection method.

8:20am **VT-TuM-2 NEG Coating for PETRA IV: Resistivity and Sticking Probability Measurements***, **Ruta Sirvinskaite**, L. Lilje, S. Lederer, R. Boespflug, N. Plambeck, S. Antipov, M. Schroeder, A. Winiarska,* DESY, Germany

Non-Evaporable Getter (NEG) development at DESY has been ongoing to accommodate PETRA IV machine requirements. While most of the PETRA IV beam vacuum chambers will be manufactured from oxygen-free silver-bearing (OFS) copper and coated with NEG, getter film performance on these substrates has not been tested as extensively as on the stainless-steel. In order to investigate pumping and impedance properties of the columnar NEG films, TiZrV and Zr layers with varying thicknesses were sputtered on four Cu-OFS tubes. The 1 µm films were activated at temperatures ranging from 140 to 250 °C to determine how the sticking probability as well as CO pumping capacity develops over time after multiple saturations prior to increasing the activation temperature. By measuring the attenuation of the RF signal along the four tubes, resistivity of both NEG materials was calculated. The results were then compared to previously reported findings for columnar NEG films.

8:40am **VT-TuM-3 Vacuum System for Cornell Brookhaven Energy Recovery Linac Test Accelerator***, **Yulin Li**, D. Burke,* Cornell University

A novel electron accelerator, Cornell Brookhaven Cornell Energy Recovery LINAC Test Accelerator (CBETA) has been successfully designed, constructed, installed and commissioned by collaboration between CLASSE and Brookhaven National Laboratory.Many unique accelerator technologies are implemented in CBETA, including photo-cathode electron injector, 4-turn superconducting RF (SRF) Energy Recover LINAC (ERL), non-scaling Fixed-Field Alternating Gradient (NS-FFAG) optics with 4x energy acceptance.The CBETA layout consists of an existing photo-cathode injector with an SRF cryomodule (ICM) as well as a main LINAC cryomodule (MLC), a NS-FFA return loop (that transports electron beams at four energies, 42, 78, 114 and 150 MeV in a single bore beampipe), and two splitter sections where the four energy beams are separated and combined. The total circumference of the CBETA loop is about 80-m.The basic requirement of the CBETA vacuum system is to achieve an adequate level of vacuum and physical aperture for transporting electron beams at four different energies.Furthermore, by the nature of this test accelerator, the vacuum system engineering must accommodate a very high density of beam diagnostics tools, such as over 150 beam position monitors, and insertable beam profile viewers.Beam path length change of up to 20° RF-phase are achieved in the splitter sections via one set of three RF-shielded sliding joints mounted on a pair of motorized stages in each of the eight-splitter beam lines.Aluminum alloy was chosen as primary beampipe construction material because of its good electric conductivity (resistive-wall), no residual radioactivity (from beam losses), low magnetization (from cold work and welding etc.) as well as its low cost of fabrication (machining, extrusion, etc.).Compact non-evaporable getter (NEG) pumps are used due to the space constraints.To preserve the high performance of the superconducting RF cavities in the MLC, all vacuum beam line components were constructed and assembled in strict particulate-controlled condition, and installed using portable clean rooms.The CBETA vacuum system installation was completed in the summer of 2019 and the entire CBETA accelerator system was commissioned shortly after.All CBTA milestones were successfully achieved, including full beam energy recovery after 8 turns of beam circulations through the SRF cavities and the NS-FFA return loop.We present the CBETA vacuum component construction and installation, and the vacuum system operational experiences.

9:00am **VT-TuM-4 Operational Experiences of NEG Dominated Pumping System at CHESS-U***, **Leila Aboharb**,* Cornell University

Successful operations of the Cornell High Energy Synchrotron Source Upgrade (CHESS-U) have proven the in-service reliability of the compact non-evaporable getter (NEG) pumps in a new experimental vacuum system predominantly pumped with distributed NEG-strips and modular high-capacity NEG pumps. The 80-meter section improvement in the Cornell Electron Storage Ring (CESR) is composed of 6 double-bend achromats operating with a single positron beam up to 200 mA. After a successful commissioning period, a vacuum level of 10^{-9} Torr was achieved with minimal maintenance and NEG re-activations.

The CHESS-U vacuum system experienced a catastrophic failure when a beam steering error created a pinhole leak in an undulator vacuum chamber (0.6-mm wall). The installed NEG-dominated pumping system had demonstrated an adequate pumping performance, which allowed a quick recovery and reconditioning of the affected 20+ meter vacuum section. With the hard work of the technical staff, X-ray user operations were able to resume after 10 days of recovery efforts (chamber fabrication and replacement, vacuum conditioning). The accidental air-exposure to the NexTorr pumps (combination of ion pump and NEGs) resulted in minor Argon instability issues that required mitigation. Corrective actions were developed in areas such as thermal monitoring, chamber construction, and beam steering while also granting the opportunity to test the pumping integrity of the effected NEG pumps after the exposure.

The 3-year operational experiences of the NEG pumping system will be presented.

9:20am **VT-TuM-5 ALS-U Vacuum Systems Production QA/QC Process***, **Sol Omolayo**,* Lawrence Berkeley Lab, University of California, Berkeley

The Advanced Light Source at Lawrence Berkeley National Lab is in the process of being upgraded to a 4th generation light source. The upgrade requires thousands of vacuum components to be procured, fabricated, inspected, assembled and installed. QA/QC is paramount concerned in ensuring the vacuum system meets requirement. A process was developed to manage QA/QC from the design phase to the installation and commissioning

9:40am **VT-TuM-6 Exploring Large Vacuum Systems at LIGO: A Brief Introduction to the Vacuum Challenges of the Cosmic Explorer***, **Melina Fuentes-Garcia**,* LIGO Laboratory, California Institute of Technology*; J. Feicht,* California Institute of Technology

The Laser Interferometer Gravitational-Wave Observatory (LIGO) consists of a set of multi-kilometer-scale gravitational wave detectors able to detect major events in our universe, such as black hole pair collisions. Because of stringent noise requirements, LIGO operates in an ultra-high-vacuum environment to minimize disturbance to the laser, optics, and other equipment inside the chambers. Factors such as material outgassing, contamination control, seal integrity, and pumping must all be optimized for minimal disturbance to the detectors. Cosmic Explorer (CE) aims to increase LIGO's sensitivity tenfold by scaling LIGO's 4 km long vacuum arms to 40 km, which amounts to a 90-million-liter vacuum system nominally sustained at 1E-9 Torr. This next-generation detector will significantly enhance our ability to detect gravitational waves, but will require greater challenges to the design and construction of its large vacuum system. Here we introduce some of the major challenges currently being studied, with an emphasis on the selection of alternate beam tube materials and elimination of high temperature bakeouts to reduce outgassing.

11:00am **VT-TuM-10 Exploring the Gravitational Wave Universe: Vacuum Systems for LIGO A+ and Beyond***, Michael Zucker,* LIGO Laboratory, Caltech and MIT **INVITED**

LIGO, the Laser Interferometer Gravitational-wave Observatory, recently completed the first phase of an upgrade called A+. This has improved sensitivity to gravitational waves from distant colliding black holes, neutron stars and other astrophysical phenomena by effectively circumventing the Heisenberg uncertainty principle, using a new quantum engineering technique called *Frequency-Dependent Squeezing* (FDS). An extension of both LIGO vacuum systems was required to enable this new technique. FDS is also an important step toward realizing vastly improved next-generation gravitational wave instruments, such as the *Einstein Telescope* and *Cosmic Explorer,* planned for the next two decades. These instruments will extend the realm of gravitational wave observations to the edge of the observable universe. Such new facilities will rely on ultrahigh vacuum at unprecedented scale, up to an order of magnitude larger than present instruments, presenting novel design and engineering challenges.

11:40am **VT-TuM-12 A Cryogenically Cooled Water Trap for ITER's Vacuum System***, **Jared Tippens**, C. Smith III,* Oak Ridge National Laboratory

The ITER project has the goal to demonstrate the feasibility of fusion and to advance the scientific and engineering understanding of fusion for future commercial reactors. The vacuum systems that are under development for the tokamak and supporting systems are expected to be dominated by one-of-a-kind devices due to their scale and varying operating environments.One specific challenge for these devices is the ability to process and recycle tritium, a radioactive hydrogen isotope in the fuel that is necessary for the fusion reaction to occur but is rare on Earth. Additionally, several of the vacuum systems are sensitive to water vapor which has the capability to inhibit pump performance if not removed from the gas stream. A custom designed water trap can enable both requirements to be met, and four of them are planned for the ITER vacuum system.

Due to vacuum operating pressures (as low as 1 Pa), a desiccant such as Zeolite cannot be efficiently used to adsorb and retain water vapor, so an alternative approach was chosen to utilize a cryogenically cooled water trap to desublimate water vapor from the process gas. The temperature must be lowered enough to remove the water vapor from the stream, but not so low as to remove the helium and gaseous hydrogen isotopes. With helium at a temperature of 80K available in ITER's vacuum pumping room, this cooling load was selected as source for the water trap cooling.

To comply with the nuclear requirements, the tritium content inside the trap must be continuously monitored and removed to exhaust processing. The water trap must also be a double contained vacuum vessel with safety switches to mitigate the risk of tritium exposure to the vacuum pumping room. The tritiated water stored within must be removed batchwise to exhaust processing using heaters and inert purge gas. The capacity of the trap must be large (up to 5 kg of water) to account for the unlikely event of gross system water leaks, but in practice will accumulate water vapor at a low and steady rate of 1 Pa.m^3/s. Each trap must fit within a 1 meter diameter by 1 meter tall space reservation and include embedded tubes that enable heat transfer between the cryogenic helium and the process gas.

In summary, a cryogenically cooled water trap has been designed to meet the unique requirements of ITER and its vacuum systems. Four of these traps will protect sensitive vacuum equipment from water vapor as well as enable the recycling of tritium back into the fuel.

12:00pm **VT-TuM-13 Photon Stimulated Desorption Beamline at NSLSII***, M. Ferreira,* ESS, Sweden*; S. Hulbert, P. Palecek, I. Saleh, M. Seegitz, T. Shaftan, O. Tchoubar, **Robert Todd**,* Brookhaven National Laboratory

Understanding the expected gas desorption of an accelerator is critical in the proper design of accelerator vacuum systems and can have a major impact on the machine design and cost. From some of the earliest work on the subject for the Cambridge Electron Accelerator up through and including LHC, desorption measurements have played an important role in predicting vacuum behavior of large accelerators susceptible to synchrotron radiation. Much of this early work served well the machines they applied to and other machines with similar parameters and material choices. But as machines continue to be developed with higher energy, beam current, stability and susceptibility to e-cloud, novel materials need to be investigated to improve vacuum, and in some cases reduce SEY (Secondary Electron Yield). Part of these investigations require careful study of their desorption yields. This would benefit future upgrades to the existing NSLS-II facility as well as other synchrotrons facilities with stringent design specifications. Additionally, such a beamline could have a major impact on the selection and validation of proposed materials and components for EIC, including possible coatings for the electron storage ring, IRs (Interaction Regions) and the beam screen of the Hadron/Ion ring. Desorption rates of these newly proposed materials would be used as inputs to advanced modeling tools such as Molflow and SynRad for accurate predictions of vacuum behavior. A beamline at NSLS-II, dedicated to the PSD/ESD study of novel and proposed vacuum materials has been constructed and commissioned to advance further research into desorption behavior. The PSD of stainless steel and OFHC copper to be used for the Rapid Cycling Synchrotron of EIC have been measured and compared to prior work to baseline the system, with plans to evaluate the NEG coated chambers for the EIC electron storage ring. The layout of the experimental line and the commissioning measurements will be presented.

Author Index

Bold page numbers indicate presenter