Vacuum Technology Division
Room: 7 & 8 - Session VT-TuM

Large Vacuum Systems
Moderators: Jason Carter, Argonne National Laboratory, Gerardo Brucker, MKS Instruments, Inc., Pressure and Vacuum Measurement Group

8:00am **VT-TuM1 The Role of Vacuum Technology in Discovering the Gravitational Waves from Merging Black Holes**, *R.F.M. Weiss*, ***Michael Zucker***, LIGO Project Caltech and MIT **INVITED**

The observation of the gravitational waves from the merger of two black holes involved measuring the motion of mirrors to a precision of 10^{-18} meters over a distance of 4 km. The measurement was made by optical interferometry between suspended mirrors. Vacuum of 10^{-9} torr was required in 1.2 meter diameter 4km long beam tubes to avoid phase noise of the light and equivalently high vacuum was needed to avoid thermal noise of the mirrors from molecular collisions. The residual hydrocarbon background had to be controlled to avoid contamination of the optics. A significant challenge was to design and construct the vacuum system economically. Some of the fundamental physics and the engineering of the system will be described.

8:40am **VT-TuM3 Vacuum System Engineering for Cornell Brookhaven ERL Test Accelerator**, ***Yulin Li***, *D.C. Burke*, *B. Johnson*, Cornell Laboratory for Accelerator-Based Sciences and Education

A novel electron accelerator, Cornell Brookhaven ERL Test Accelerator (CBETA), is under development by a collaboration between Cornell Laoratory of Accelerator-based Sciences and Education (CLASSE) and Brookhaven National Laboratory. As a prototype accelerator for eRHIC, many unique accelerator technologies will be tested 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 SRF cryomodule (ICM) and a main LINAC cryomodule (MLC), a NS-FFAG return loop that transports electron beams at four energies, 42, 78, 114 and 150 MeV in single bore beampipe, and two splitter sections where the four energy beams are separated. The total circumference of CBETA loop is about 80-m. The basic requirement of CBETA vacuum system is to achieve adequate level of vacuum and physical aperture for transporting electron beams at four different energies. Furthermore, by the nature of test accelerator, the vacuum system engineering must accommodate a very high density of beam diagnostics tools, such as 100+ beam position monitors, beam profile viewers, etc. Beam path length up to 20° RF-phase is required in the splitter sections. Aluminum alloy is chosen for beampipe construction material for its good electric conductivity (resistive-wall), no residual radioactivity (from beam losses), low magnetization (from cold work and welding etc.) as well as lower cost of fabrication (machining, extrusion, etc.). Compact non-evaporable getter (NEG) pumps are used due to the space constraints. As in situ beampipe bakeout is practically impossible, a program was carried out to measure aluminum alloy outgassing rates at various controlled processing (bakeout, purified dry nitrogen venting, etc.). As a measure of vacuum system cost reduction, metal knife-edge seal flanges made of non-coated aluminum alloy (type 6013-T6) were developed as the beam diagnostics ports. The results of the outgassing study were used to validate vacuum pumping system design via 3D simulation. In this presentation, we report the status of CBETA vacuum system design and fabrication. Measurements of aluminum alloy outgassing rate and tests of aluminum knife-edge flanges will also be discussed.

9:00am **VT-TuM4 Vacuum System for CHESS-U Upgrade at CESR**, ***Xianghong Liu***, *S. Barret, D.C. Burke, J.V. Conway, A.T. Holic, Y. Li, A. Lyndaker*, Cornell Laboratory for Accelerator-Based Sciences and Education

A sextant of Cornell Electron Storage Ring (CESR) will be upgraded with Double Bend Achromat (DBA) lattice and CHESS Compact Undulators (CCUs) to significantly boost the performance of Cornell High Energy Synchrotron Source (CHESS). A lot of efforts are being made in preparation for the final installation in late 2018 for this upgrade project, dubbed CHESS-U. With this upgrade, CESR will be converted from a counter-propagating two-beam ring to a single-beam ring. The beam energy will be increased from 5.3 GeV to 6 GeV, and the beam current for normal operation will be increased from 120 mA to 200 mA. Because of the geometrical constraints from the magnets, the beampipe aperture of this new section is 52mm (horizontal) by 22mm (vertical), which is much smaller than the rest of CESR. The vacuum pumping for this new section will be different too, consisting of a combination of Non-Evaporable Getter (NEG) strips, modular NEG pumps, and ion pumps.

The beam pipes are mainly made of three types of aluminum extrusions, fitting inside quadrupole magnets, dipole magnets, and undulators respectively. All extrusions have cooling water channels to handle the thermal load from synchrotron radiation. The same channels are also used for vacuum hot-water bake-out. Dipole extrusions are formed to the correct bending radius by stretch forming in a softer temper, and heat treated to higher temper after forming. With required space available, the dipole extrusion includes an ante-chamber for NEG strip (SAES St 707) pumping. The NEG strip is activated by resistive heating to about 400°C for half an hour. The electrically insulating support mechanism of the NEG strip is adapted from the design used in APS. Instead of being built from extrusions, the dipole chamber where the X-ray beam exits is made of two machined halves that are welded together; a cylindrical crotch is inserted at the flared end of this chamber to absorb approximately 4 kW of synchrotron radiation.

In this presentation, we will give an overview of the design of the vacuum system, and report the estimated pressure profile based on Molflow^{+} calculations, some design details of major components, results from NEG strip pumping tests, and progress in vacuum chamber productions.

9:20am **VT-TuM5 Newly Designed Alumina Ceramics Beam Pipe with Large Aperture for RCS in J-PARC**, ***Junichiro Kamiya***, *M. Kinsho*, Japan Atomic Energy Agency, *K. Abe*, HIPSD, Japan

The 3 GeV Rapid Cycling Synchrotron (RCS) in J-PARC aims to generate one of the highest power protons in the world. The design extraction beam power is 1 MW, which consists of 8.3×10^{13} protons per bunch with 3 GeV energy at 25 Hz repetition rate. The rapid change of the magnetic field at such repetition rate causes the induced current if the beam pipe was made of metal. Therefore, beam pipes of alumina ceramics were used. The cross-sectional diameters of the pipes range from 250 to 500 mm, as is the case for the titanium beam pipes and bellows. There are several cross-sectional shapes corresponding to the various beam shapes. The beam pipes in the dipole and quadrupole/sextupole magnets have racetrack and circular shapes, respectively. The beam pipes in injection magnets have racetrack and rectangular shapes. Unique cross-sectional shape is adopted for the ceramics beam pipes for the injection quadrupole magnet. Because the injection beam and circulating beam pass through the injection quadrupole magnet, its cross-section has a racket shape fitting into 500 mm diameter. Recently this ceramics pipes for the injection quadrupole magnets were newly designed. In the new design, the bellows are attached to the titanium sleeve of the beam pipe by welding to obtain the better maintainability in the narrow area under high radioactivation level. In the conference, we will report the design concept of the new alumina ceramics beam pipes with unique shape and the several results of the verification tests.

9:40am **VT-TuM6 Vacuum Performance of Taiwan Photon Source Storage Ring**, ***Hsin-Pai Hsueh***, *G.Y. Hsiung*, *J.R. Chen*, National Synchrotron Radiation Research Center, Taiwan, Republic of China

The Taiwan Photon Source storage ring vacuum system has been developed to be pre-baked and installed under vacuum for 14-m arc sections. The straight sections were in-situ baked followed the installation of adjacent arc sections. During first stage commissioning, foreign object was found and the bending vacuum chamber of this particular arc section was replaced without baking (neither pre-baked and installed under vacuum, nor in-situ baking). Subsequently, four more bending chambers in other four different arc sections were replaced without baking either. Since this time saving method is different from our system design philosophy, a detailed pressure and mass spectrum analysis is necessary. From measured data, the photon stimulated desorption is no longer as dominant as we would like it to be as designed. The thermal outgassing is more than 25% of total outgassing at highest current (400mA or above). The total beam dose is almost 1500 Amp-hour. The photon-stimulated-desorption (PSD) pressure over beam current ($\Delta P/I$) is 2.33E-11 Pa/mA. In this presentation, the analysis results will be presented.

11:00am **VT-TuM10 The Vacuum System Design of a New FEL Test Facility (CLARA) at STFC Daresbury Laboratory**, ***Keith Middleman***, STFC, UK

Recent UK government funding has facilitated the construction of Phase 1 of a unique FEL accelerator test facility (CLARA – Compact Linear Accelerator for Reserach Applications). This test facility will allow the UK to reserach a variety of FEL operating modes to establish a roadmap for the UK and its plan to build a UK FEL user facility.

This paper will look specifically at the vacuum system design of this unique accelerator detailing the challenging design of the photoinjector, the FEL section and the possible use of NEG coating and the requirement for implementing a differential pumping scheme to separate two vacuum systems with 3 orders of magnitude pressure difference over 50 cm. Many other aspects of the accelerator design will be described and data showing the 'real' perfromance of the accelerator presented.

11:20am **VT-TuM11 EBL2: Realization and Qualification of an EUV Exposure System**, ***Michel van Putten***, *N.B. Koster, A.F. Deutz, B.A.H. Nijland, P.J. Kerkhof, P.M. Muilwijk, B.W. Oostdijck, J. Westerhout, C.L. Hollemans, E. te Sligte, W.F.W. Mulckhuyse, F.T. Molkenboer, A.M. Hoogstrate, P. van der Walle, J.R.H. Diesveld, A. Abutan*, TNO, Netherlands

In 2014, TNO started the design of a new facility to test samples with EUV light (13.5 nm). This facility is called EUV Beam Line 2 (EBL2) and enables study of the interaction of lithographic photomasks, optics and other samples with EUV light by irradiation, *real-time* imaging ellipsometry and *in vacuo* XPS surface analysis.

The integration of EBL2 started in Q2 of 2016 and at the end of 2016 the major milestone – *first light* – was reached. Currently, the building phase of EBL2 being completed. During Q3 of 2017 we anticipate to complete the qualification. Once qualified, the EBL2 facility will be accessible for external customers and research groups.

The realization of such a facility is the translation from a design to a manufactured, integrated and tested system. During AVS63 the realization of some of the modules was presented, this presentation will discuss the integration of the complete system. Challenges in this are: motion in vacuum, use of UHV compatible materials, alignment of EUV optics.

The qualification of the EBL2 facility was done in three steps: module verification, system verification, and system validation. During the verification steps, EBL2 and its constituent modules were assessed against specifications. Next was system validation where the ability to satisfy user needs was verified.

This presentation will focus on the completion of the realization of EBL2 and results of the system verification and validation phases.

EBL2's EUV irradiation performance is discussed in terms of EUV power, vacuum cleanliness, positioning of samples like reticles, and the setup and control of the sample environment in terms of positioning, temperature and gas environment.

11:40am **VT-TuM12 Construction and Commissioning of Tri Alpha Energy C2W machine**, ***Alan Van Drie***, Tri Alpha Energy

Tri Alpha Energy (TAE) is researching a novel fusion concept of energetic ions magnetically trapped as large orbits in a Field Reverse Configuration plasma (FRC). TAE has completed building and commissioning its latest machine, C2W.

The talk will first give a brief overview to TAE's concepts and C2W, followed by a discussion of the physics that drive the vacuum requirements, such as divertor gas loads and how we solved many of the technical vacuum challenges in order to meet our performance goals. Specifically, C2W has four $15m^3$ divertors where H_2 neutral particles from the plasma are pumped at a rate of 2,000 m^3/s. This large pumping is achieved through chemisorption onto titanium films deposited onto LN2 cooled multi-scaled surfaces. Additionally, each divertor has a $200m^3/s$ activated charcoal cryopump optimized for pumping H_2.

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