Tuesday Morning, November 8, 2022

Vacuum Technology Division
Room 301 - Session VT-TuM

Vacuum Technology for Large Vacuum Systems

Moderators: Chandra Romel, Consultant, **Marcy Stutzman**, Jefferson Lab

8:00am **VT-TuM-1 Vacuum Materials for the Next Generation Gravitational Wave Detectors***, **Ivo Wevers**, G. Bregliozzi, P. Chiggiato, M. Rimoldi, C. Scarcia, M. Taborelli,* CERN, Switzerland **INVITED**

Gravitational waves were detected for the first time in 2015 by the LIGO which, since then, has measured several other events in conjunction with VIRGO. These achievements have stimulated studies for next-generation gravitational telescopes to enlarge the discovery potential of such scientific facilities. Two studies are presently considered: the Cosmic Explorer (CE) and the Einstein Telescope (ET) in USA and Europe, respectively. To increase the detection performance a key parameter is the length of the Fabry-Perot cavities in which high power laser beams are stored in an ultrahigh vacuum. For both CE and ET, more than 100 km of ~ Ø 1 m vacuum pipes are required, which would represent up to 50% of the total budget of the new experimental facilities if the LIGO and VIRGO's configurations were adopted. To reduce the cost impact of the vacuum system, unconventional materials, less expensive pipe manufacturing and different surface treatments are scrutinized. In this work, we present measurements performed on low carbon steel (mild steel), having been proposed as an alternative to stainless steel. The outgassing rates of several as-cleaned low carbon steels were measured. Specific hydrogen outgassing rates at room temperature in the 10^{-15} mbar l s^{-1} cm^{-2} were measured for bakeout temperatures as low as 80°C for 48 hours. Water vapour outgassing rates of unbaked samples were similar to or higher than those of stainless steel. To reduce water vapour outgassing, so that a bakeout can be avoided, a silicon coating was proposed. The coating has been produced by chemical vapour deposition with silane as precursor gas; the resulting layer was several hundreds of nanometres thick and resulted in the reduction of the water vapour outgassing rate by a factor 10. Such a value is not low enough to eliminate the need of a bakeout but could open the possibility of temperature treatments below 100°C. Room-temperature specific hydrogen outgassing rates of the Si coated steels in the low 10^{-14} mbar l s^{-1} cm^{-2} were measured after bake-out at 80°C for 48 hours. The hydrogen intake in the studied steels during the coating was investigated by thermal desorption spectroscopy. Optimisation of the mild steel is under study in collaboration with industry to improve vacuum performance and corrosion resistance.

8:40am **VT-TuM-3 Vacuum Design for a Cryogenic Gravitational Wave Detector***, **Rana Adhikari**, C. Wipf,* California Institute of Technology **INVITED**

In 2016, the Laser Interferometer Gravitational-wave Observatory (LIGO) collaboration announced the first detection of gravitational waves (GWs) from the merger of black holes. These ripples in the fabric of spacetime are measured on the earth by laser interferometry. In order for these instruments to work, they must be able to measure mirror motions at the level of 10^{-21} m (100 billion times smaller than a hydrogen atom). The next generation of these instruments will be operated at cryogenic temperatures and use squeezed light to reduce the quantum measurement uncertainty. In this talk I will describe the limits to ultra-precision measurement and how the design of the vacuum system, cryogenic temperature, surface treatments, and laser wavelength affect the measurement. A successful vacuum design would enable the detection of exotic astrophysical phenomena from across the entire universe.

9:20am **VT-TuM-5 CSI; the New Space Calibration Facility at TNO***, **Freek Molkenboer**, R. Jansen,* TNO Science and Industry, the Netherlands*; W. van Werkhoven, T. Luijkx, W. Mulckhuyse,* tno Science and Industry, the Netherlands

In early 2018 TNO started with the conceptual design of a new Space calibration facility, called CSI. The CSI facility will be used for the performance verification and calibration of optical Earth observation instruments on satellites. before the summer of 2022 the facility will be installed and commissioned, and in Q4 2022 ready to receive customers. CSI consists of a few major subsystems, a Thermal Vacuum Chamber (TVC), an instrument manipulation system (consisting of a hexapod and rotation table), a set of optical stimuli and an overall control system.

The TVC will be a vertically positioned stainless steel cylinder with a diameter of 2.75 meters and a height of 2.5 meters. The chamber and thermal shrouds are designed with a diagonal entry, resulting in a wedge-shaped bottom half and top half. This reduces the total height required for opening and operating the chamber as well as facilitating easy loading of the space instrument.

The thermal shroud of the TVC will be able to create an environment between 193K and 353K Two thermal plates will be present to cool areas of the instrument down to 100K if required. The vacuum system consists of two turbomolecular pumps and two cryopumps to reach the ultimate pressure of at least 10e-7 mbar. The vacuum conditions and composition of residual gasses in the TVC will be monitored with an RGA (Residual Gas Analyser) and a QCM (Quarts Crystal Microbalance).

During the calibration of a Space instrument, its orientation relative to the calibration light sources (Optical Ground Support Equipment or OGSE) has to be changed with extremely high accuracy and reproducibility. To achieve this, TNO has selected a vacuum compatible hexapod on a rotation table that meets the stringent accuracy and stability requirements of such an operation. In order to achieve these extreme stability requirements - both in the order of 0.001 degrees - TNO has designed an active thermal system around the hexapod to locally create a thermally stable environment.

During this talk I will discuss the performance of TVC and the instrument manipulation system

9:40am **VT-TuM-6 The Challenges of Heating a Sample in Vacuum***, H. Bekman, **Johannes Velthuis**, F. Molkenboer,* TNO Science and Industry, the Netherlands

Heating a sample up to 400°C in a vacuum system seems not to be complicated, however when this same sample must travel through several vacuum chambers / load locks before arriving at its test location it becomes a greater challenge.

To overcome this stated challenge that is present at EBL2, a large Extreme Ultra-Violet Lithography (EUVL) test facility at TNO that used for EUVL lifetime experiments, we are in the process of designing a special sample holder that can reach, and control the sample temperature between ambient and 400°C.

The sample holder is being developed as part of the EU program, ID2PPAC. The objective of the project is to investigate EUV-material interaction effects at elevated temperatures. This research will contribute applicable knowledge that will result to better material selection in EUVL applications.

It is expected that the last version of the sample holder will require some logic control elements in the sample holder, this because of the limited pinout (number of electrical connections) of the sample holder. The development and testing sub-assemblies of this last version will be time consuming task because a lot of boundary conditions need to be tested.

To ensure that testing of materials can be tested at an earlier phase than before the completion of the last version of the sample holder, two forerunners will be first designed and manufactured.

A complication originates from the EUV power hitting the sample. This EUV power is a heat source that heats up the sample under test. One version will use a low power heater element to control the temperature, this one however is limited in the amount of EUV power the sample can receive, this to prevent overheating the sample.

The second sample holder will be used when the EUV radiation is higher. The sample holder will control the sample temperature by adjusting the backfill pressure between the sample and a colder temperature-controlled element.

By controlling the backfill pressure, the thermal conductance between the sample and the colder temperature-controlled element will change, this method will enable us to cool, and control the temperature of the sample.

During this presentation we will discuss the need for this sample holder, the design, and results of the two first versions of the sample holder. We expect also to be able to present the final design of the last version of the sample holder.

11:00am **VT-TuM-10 Design of ITER Roughing Pump System***, **Charles Smith**, S. Smith,* US ITER **INVITED**

US ITER is charged with supplying mechanical and cryogenic vacuum roughing components to the ITER Organization as part of the United States' commitment to the ITER Project. The Rough Pump system (RPS) as it is known, connects to the Cryostat vacuum vessel (vacuum volume 8500m^3), Torus vacuum vessel (vacuum volume 1400m^3), Neutral beam injector ports, Type 2 Diagnostic instrumentation, and the Service Vacuum System. The RPS provides support for the roughing of these volumes, backing to localized high vacuum pumping stations, and regeneration of the Torus and Cryostat cryopumps. Due to the nature of the ITER machine, traditional gasses (nitrogen, air, helium, etc.) are pumped along with hydrogen isotopes (H_2, D_2, T_2, and combinations thereof). Therefore, the RPS system has specialized roughing trains dedicated to handling each application.

The Non-Active Roughing Systems, defined as systems in which tritium is not expected to be present, employ traditional commercially available pumping technologies. The Non-Active pumping system supports the Cryostat volume roughing, Cryostat Cryopump regeneration, and the Non-Active portion of the service vacuum system. The Active Roughing Systems, defined as systems in which at least some level of tritium is expected to be present, employ all-metal seal roughing pumps coupled with cryogenic systems in the process flow. These all-metal seal pumps are being specifically designed for this application. The cryogenic systems are located in the process stream between the ITER machine vacuum volumes and the active mechanical roughing pumps in order to capture both the hydrogen isotopes and water vapor prior to entering the mechanical pump skids. The cryogenic systems consist of Cryogenic Viscous-Flow Compressors (CVCs) and Condensable Vapor Devices (CVDs). Supercritical and gaseous Helium are supplied from the centralized cryogenic plant and distributed to the RPS systems via Cryogenic Transfer Lines (CTLs) connected to three Cryogenic Distribution Boxes (CDBs) which distribute the cryogens to the CVCs and CVDs using cryogenic jumper connections.

This talk will discuss the unique aspects of the design and requirements of the RPS mechanical and cryogenic pumping elements which allow ITER to engage in the critical science of developing sustainable burning plasma operations to facilitate the design and construction of commercial fusion power plants.

11:40am **VT-TuM-12 Monte Carlo Simulation Studies to Support an Integrated Design for the Cryogenic Vacuum Systems of the Einstein Telescope***, **Xueli Luo**,* Karlsruhe Institute of Technology, Institute for Technical Physics, Germany*; S. Hanke, K. Battes, C. Day,* Karlsruhe Institute of Technology (KIT), Germany

Europe is going to develop a third-generation underground gravitational wave (GW) observatory, known as the Einstein Telescope (ET). It is designed as a novel equilateral triangle with 10 km long arms and the detectors in each corner. Any two adjacent arms compose two independent interferometers. One interferometer will detect low-frequency gravitational wave signals (LF), while the other will be optimized for operation at higher frequencies.

In order to reduce seismic noise, thermal noise and other systematic noise, the whole system will be 200 to 300 m underneath the ground; the beamline pipes, the suspension towers and the cryostat containing the mirror require ultra-high or high vacuum conditions; and the main optics will partly be cooled to cryogenic temperatures below 20 K. In this way, the GW detecting sensitivity of ET will be significantly increased compared to the current advanced detectors (Virgo, LIGO) and the frequency band will be expanded to lower frequencies. The integral ET vacuum system comprises three different parts: (i) the beamline vacuum characterised by outgassing from the pipe walls, (ii) the tower vacuum characterised by outgassing from the suspension arrangement, and (iii) the cryogenic vacuum systems around the LF mirror.

In this paper, a Test Particle Monte Carlo model has been established with the KIT in-house code ProVac3D, to allow for a system analysis of the cryogenic vacuum area. It assesses the impinging rate of residual gas on the cryogenic mirror, depending on the particle sources from the beamline pipes and from the tower, which are systematically varied. With that, the expected speed of frost formation is estimated, which is critical due to degradations of the optical performance, and helpful information on engineering limits are derived. These simulation results are useful to find how far the cryopump section will influence the condition in the warm beamline pipe and the gas flow rate to the optical mirror. As a second major contribution, a shielding concept around the mirror is presented which reduces the gas load to a level fulfilling the requirements.

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