ULTRAHIGH VACUUM IN SUPERCONDUCTING SYNCHROTRONS

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Abstract

The achievement of ultrahigh vacuum conditions in the range of 10^{-10} – 10^{-12} Torr is a very complicate task for charged particle accelerators. For the superconducting accelerators the main rest gas is the hydrogen which does not freeze effectively on the chamber wall even under the liquid helium temperature. A fast ramp of the magnetic field in the superconducting synchrotrons leads to the heating of the vacuum chamber and the additional evaporation of the hydrogen from the vacuum wall. Non-evaporable getters under the liquid nitrogen temperature are planned to the pumping of the hydrogen and achievement of the necessary vacuum conditions in the new accelerator complex of the NICA project at JINR.

VACUUM GAS COMPOSITION

In the atmosphere conditions the main gas components are nitrogen and oxygen. Other gases like water, argon, CO_2 occupy less than 1% of the air volume. The gas composition at vacuum condition is varied depending on many factors: choice of material, cleaning, baking, pumping system design, type of pumps, temperature, photon, electron or ion bombardment of the surface and many others.

Water is the main gas in unbaked metal chambers. The water outgassing does not depend significantly on the nature of metals, on surface treatments and on temperature (for temperatures lower than 110° C). At present no methods, except heating, exist to remove water from unbaked metals.

At the ultrahigh vacuum condition H is the main gas desorbed by baked metals. The outgassing of hydrogen is an intrinsic property of metals and the value of the outgassing rate of hydrogen is stable at room temperature. The diffusion model predicts values for the hydrogen outgassing that are in accord with experimental observations. Firing decreases the hydrogen outgassing rate by more than 2 orders of magnitude.

Gas molecules are dissolved into the bulk of materials during the production processing and during their permanence in air. In vacuum, the lighter molecules diffuse and, after reaching the surface, they are released. Only hydrogen atoms have enough mobility in metals to attain the surface where they recombine to form H_2. The models that take into account all the steps in the outgassing process are quite complicate and, in general, they give only asymptotic solution for limit conditions.

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PUMPING SYSTEMS

Different pumping systems are used for the achievement of ultrahigh vacuum conditions in particle accelerators. Ion sputter pump cannot effectively remove hydrogen from the rest gas and can be used in the combination with other pumping systems. Turbomolecular pumps has a minimum limit about 10^{-11} Torr and can be used as preliminary pumping system only. Titanium sublimation pumps require the periodical activation at high temperature and cannot be used with superconducting accelerators at the cryogenic temperature.

Cryosorption pumps are the most popular pumping systems for the achievement of the ultrahigh vacuum conditions at superconducting accelerators. Cyocondensation is based on the mutual attraction of similar molecules at low temperature. The key property is the saturated vapour pressure, i.e. the pressure of the gas phase in equilibrium with the condensate at a given temperature. It limits the attainable pressure. Only Ne, H_2 and He have saturated vapour pressures higher than 10^{-11} Torr at 20 K (Figure 1). The vapour pressure of H_2 at 4.3 K is in the 10^{-7} Torr range, at 1.9 K lower than 10^{-12} Torr.

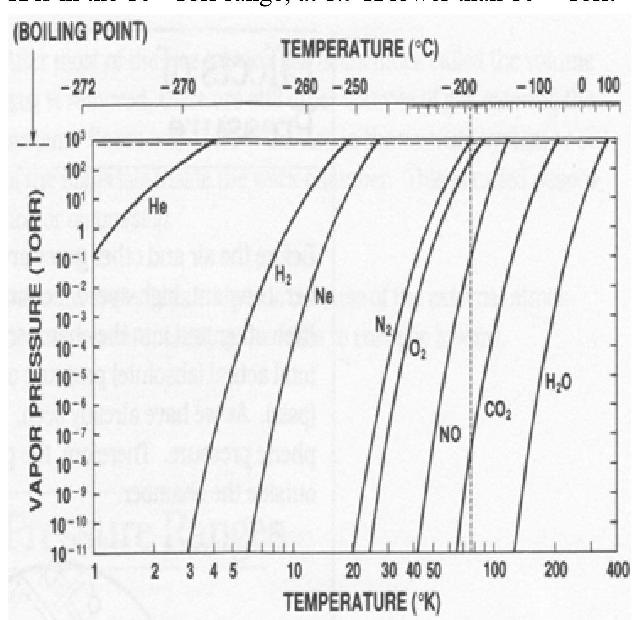

Figure 1: Vapour pressure of common gases.

Cryosorption is based on the attraction between molecules and substrate. This interaction is much stronger than that between similar molecules. Gas molecules are pumped at pressures much lower than the saturated vapour pressure providing the adsorbed quantity is lower than one monolayer. Porous materials in cryosorption

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pumps are used to increase the specific surface area; for charcoal about 1000 m^2 per gram are normally achieved. The important consequence is that significant quantities of H_2 can be pumped at 20 K and He at 4.3 K.

NON EVAPORABLE GETTERS

Non evaporable getters (NEG) are usually used at the room temperature. Gases diffuse into the interior of the getter material. Gases are categorized into four families based on their interactions with NEGs:
- hydrogen and its isotopes - sorbed reversibly;
- CO, CO_2, O_2, and N_2 - sorbed irreversibly;
- H_2O, C_xH_y - sorbed in a combination of two processes;
- rare gases - not sorbed at all.

The dissolution of the oxide layer is possible only in metals having very high oxygen solubility limit, namely the elements of the 4th group: Ti, Zr and Hf. NEG materials are produced industrially by powder technology. Small fragments are sintered to form pellets, discs or plates [SAES]. The powder can also be pressed at room temperature on metallic ribbon. NEG pump can be used in combination with ion pumps.

An activation temperature is a function of the activation time and depends on the NEG material (Figure 2). NEG partially activated during bakeout at T ~ 250°C. Full pumping speed is obtained after heating at 400°C for 45 min or 300°C for 24 hours; activation pressure is $P < 10^{-5}$ Torr. NEG pumps can be activated more than 50 times without significantly losing of its characteristics.

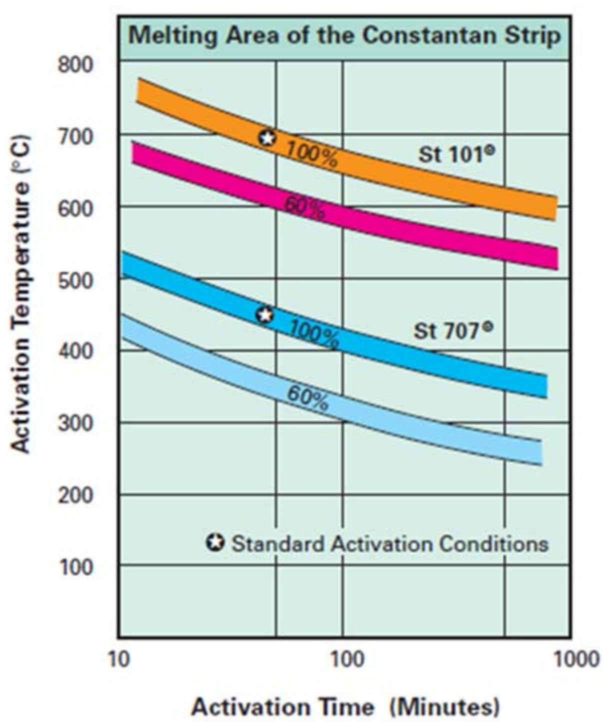

Figure 2: The dependence of the activation temperature on the activation time for different NEG pumps.
St707® [1]: 70% Zr, 24.6% V, 5.4% Fe.

Up to now NEG don't used under cryogenic temperatures. Nevertheless NEG still have good pumping speed for H_2 close to liquid nitrogen temperature (Figure 3).

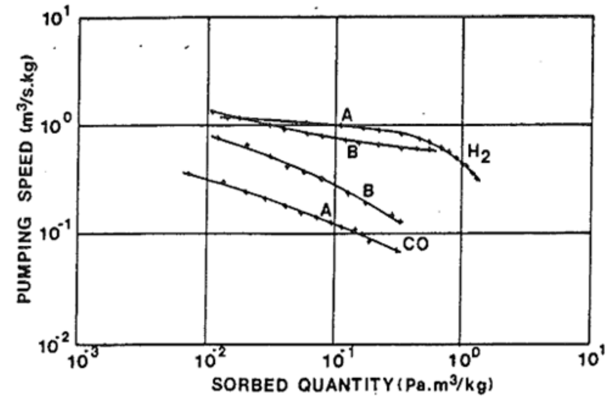

Figure 3: H_2 and CO sorption characteristics for Zr-V-Fe getter alloy at (A) room and (B) LN_2 temperature after activation at 400°C for 300 min [2].

SUPECONDUCTING ACCELERATOR

A few superconducting particle accelerators over the world operate at ultrahigh vacuum conditions. Large Hadron Collider (LHC) at CERN (Switzerland) has 27 km circumference with ultrahigh vacuum conditions about 10^{-12} Torr. Cryogenic chambers have the temperature of the liquid helium at 1.9 K that permits very effectively freeze hydrogen on the chamber wall. A special beam screen is used in the beam pipe to prevent the heating of the outer shell which is kept the helium temperature [3].

All camber walls which are operated under room temperature were coated with NEG pumps. CERN's NEG coating facility was constructed for this purpose. More than 1300 chambers coated with TiZrV NEG for the LHC. Standard chambers are 7 m long, 80 mm diameter [4].

The superconducting synchrotron SIS100 will be constructed in frame of the new FAIR project (Germany) [5]. Total length of SIS100 is 1083.6 m (82% cold, 18% warm), basic structure is hexagonal - six straights and six arcs, 25 warm sections (24 x 9.1 m long, 1x 3.3 m), 25 cold sections (6 long arcs: 5x 135m, 1x 122.6m), 19 short straight sections (18 x 4.3m, 1 x 9.2m).

The inner beam pipe wall will be used as expanded cold surface of an efficient cryopump with practically infinite capacity for nearly all condensable gas species. Static vacuum pressure inside the chamber is about 10^{-12} Torr, under dynamic conditions less than 10^{-11} Torr. Due to the fast magnet ramping eddy currents heat up the chamber wall to temperatures > 20 K [6].

10 cryosorption pumps per arc (each 13 m) and one per short quadrupole doublet in the straight sections are planned for vacuum chamber under cryogenic temperature. Cryosorption pump consists of several round cryopanels (copper disks coated with charcoal) which are cooled down to T ~ 4.5K [7].

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NICA PROJECT

General goal of the NICA project [8] is to study of hot and dense strongly interacting QCD matter and search for possible manifestation of signs of the mixed phase and critical endpoint in heavy ion collisions. The Nuclotron-based Ion Collider fAcility (NICA) and the Multi Purpose Detector (MPD) are proposed for these purposes.

In the frame of the project a few superconducting accelerators will be operated as an accelerator chain. Superconducting booster synchrotron will be used for the accumulation and acceleration of the gold ions from the linear accelerator. Next step particles are injected from Booster to the superconducting synchrotron Nuclotron, where particles are bunched and accelerated up to experimental energy. Finally particles are injected bunch per bunch from Nuclotron to superconducting collider rings.

Vacuum conditions in circular accelerators are defined by the beam life during accumulation and acceleration processes. The vacuum condition at Booster and Collider was estimated on the level of 10^{-11} Torr, at Nuclotron the necessary vacuum value is about 10^{-9} Torr. During 2007 – 2011 years the Nuclotron vacuum system was upgraded and at the present time Nuclotron operates with vacuum value about 10^{-9}-10^{-8} Torr [9].

The Booster optics structure permits to install the standard vacuum station each 9 m (Figure 4). The problem is that the cross section of the beam chamber is too small (ellipse 130 x 69 mm) and the vacuum conductance of the such pipe is not enough to reach the necessary vacuum condition.

To resolve this problem NEG pumps which operates under temperature close to the liquid nitrogen were proposed. NEG pumps can be installed in each free space between dipoles and quadrupoles.

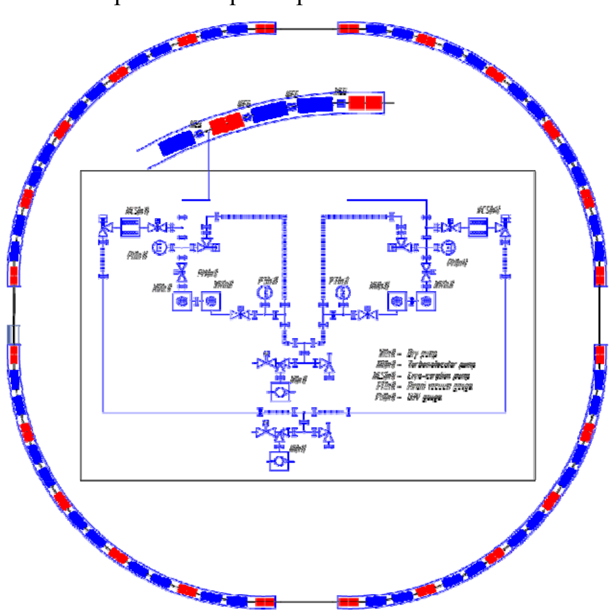

Figure 4: Scheme of Booster optics structure and pumping station: red is quadrupoles, blue – dipoles.

It means that vacuum chambers inside superconducting magnets will operate under temperature close to the liquid helium but vacuum chambers between superconducting magnets can operate under temperature close to the liquid nitrogen. This idea can significantly decrease the cost of the pumping system in the comparison with cryosorption pumps which have more complicate construction and the own cryogenic system.

Next year a special cryogenic test bench will be assembled at JINR for the testing of vacuum chambers and NEG pumps under cryogenic temperatures.

This year in the collaboration with Vakuum Praha company [10] the vacuum test bench was assembled at JINR for the testing of vacuum chambers under the room temperature. After baking procedure during 30 hours with 280°C the vacuum was reached value about 10^{-11} Torr (Figure 5). The ultrahigh vacuum was reached with the combination of the ion pump and titanium sublimation pump with the nitrogen trap.

Figure 5: JINR vacuum test bench under the room temperature.

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