CHALLENGES OF OBTAINING OF ULTRA-HIGH VACUUM IN NICA PROJECT

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Abstract

NICA is the new accelerator collider complex under construction at the Joint Institute for Nuclear Research in Dubna [1]. Operating pressure in the beam pipes of booster and collider is not more than 2×10^{-9} Pa. Operating temperature of the beam chambers 85% surfaces from 4.2K to 80 K. These parts cannot be baked. Maximum temperature of bake out is 80 C. The beam pipes have a high length and a low conductance. The paper describes problems and paths of decision of achievement ultra-high vacuum in the beam pipes of the NICA complex. For this purpose, in collaboration with Vakuum Praha [2], a test bench for the most effective pumping of the accelerator chamber of the superconducting fast cycling synchrotron has designed and built.

The article provides the simulation results of vacuum distribution in superconducting accelerators with "warm" chamber parts at room temperature. The specialized programming code was developed for this purpose. The simulation has revealed a necessity of installation additional pumping equipment along the booster perimeter. To solve this problem, development of original design of titanium sublimation pump operating at cryogenic temperatures has started in collaboration with the Budker Institute of Nuclear Physics [3].

KEY POINTS TO OBTAINING OF ULTRA-HIGH VACUUM

An achievement of ultra-high vacuum conditions in particle accelerators is very complicate task, which needs to solve different technical tasks during design, production, assembling and service of the vacuum chambers. In the NICA project two accelerators will be operate under ultra-high vacuum conditions: booster synchrotron and collider rings [4].

Vacuum Chamber Design

The typical materials for ultra-high vacuum chambers are stainless steel, cooper, and ceramics. In the NICA project, usually the stainless steel 304 and 316L is used for the vacuum chamber under room temperature and 316LN under cryogenic temperatures.

All composite materials and metal alloys must have certificates for the using in the ultra-high vacuum system. The saturated vapor pressure of all materials must be less than the residual gas pressure. In case of failure to comply with these conditions, the chamber sections shall be provided with additional differential pumping. Some diagnostic systems cannot be baked to a temperature of 280 C and must be separated by gate valves and have its own pumping systems.

The cryogenic vacuum chambers inside superconducting magnets cannot be baked out before the cooling because the material of magnets is not designed for high temperature. In this case, the water cannot be effectively removed from the cryogenic chamber. The main part of the water will be frozen during cooling of the cryogenic chamber but the transitions between “cold” and “warm” parts are not baked and not cooled.

Beam Life Time and Pumping Systems

The pressure for booster and collider rings is estimated on the level of 10^{-9} Pa, which is defined by the beam life due to an interaction with the residual gas. The estimation of the beam dynamics instability shows that this effect is not significant for the design beam intensity. Only for the beam intensity for two order larger the dynamics vacuum instability can play role in the beam lifetime.

The standard solution to reach the vacuum condition up to 10^{-9} Pa is using the combination of the ion pump (IP) with different types of getter: titanium sublimation pump (TSP) and non-evaporated getters (NEG). In the collider and booster for the beam pipes under cryogenic temperature SIP was chosen with IP combination [5].

NEG pump can be used for the cryogenic chamber only when this pump can be separated from the beam pipe with the vacuum valve. During activation procedure, the NEG pump extracts a lot of hydrogen, which absorbs on the wall surface and needs the additional time to pump back to NEG. It means that the vacuum chamber cannot be cool down to the cryogenic temperature immediately after the NEG activation.

The design of the vacuum stand for “cold” chambers in superconducting arcs was elaborated in the collaboration with Vakuum Praha [2]. The vacuum stand includes the oil-free preliminary pumping system with fore vacuum and turbo pimps, ion pump with combination of the TSP pump. The vacuum test under the room temperature show good results. Finally, this vacuum stand will be tested with the real vacuum chamber under the cryogenic temperature.

Pressure Distribution in Booster

The simulation of the pressure distribution in the booster along the vacuum chamber shows that 22^{nd} ion pumps with TSP is not enough to reach the necessary vacuum condition. One of solution is to install an additional TSP between each magnets in the booster [6].

The collaboration between JINR and BINP has started to investigate the possibility of the TSP operation under cryogenic temperatures. First experiments show that TSP can operate under cryogenic temperature and heat inflows during TSP heating up to 1000 C are not a problem for the booster cryogenic system. Next step is to test the full-size

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prototype of the TSP in the accordance with the superconducting magnet design.

The same investigation has stated in collaboration with the SAES company [7]. The aim is to test the NEG pumping efficiency under cryogenic temperature. First experiments show that the efficiency does not drop so much and NEG can effectively pump the hydrogen. The main difference between TSP and NEG is that NEG pump can be activated only once before the cooling down of the vacuum chamber to cryogenic temperature. TSP pump can be activated any time during the superconducting ring operation.

Coating of Wall Surface in Collider

The NEG coating of the vacuum chamber surface for the ultra-high vacuum accelerators is widely used now [8]. This technology is especially important for long beam pipes with small vacuum conductance. Note that the NEG coating is not efficient if the same vacuum chamber has part without the NEG coating. Because the NEG coating does not have a large capacity for the rest gas pumping and will be very fast saturated from the other non-coating surface.

In the NICA project the vacuum chambers, which are in parallel with RF-stations, is planned to coat with NEG. RF-stations will be coated with the titanium nitride which has a good high voltage strength.

The NEG coating is a good material to reduce the secondary electron yield to avoid problem with the electron cloud instability. However, the NEG coating is not used under the cryogenic temperature because the pumping speed drop down near the temperature of the liquid helium 4.2 K.

For the vacuum chamber in the cryogenic part the laser treatment is planned which can very effectively reduce the secondary electron yield [9]. This technology was successfully tested at SPS (CERN) and shows a good result to solve the problem with the electron cloud instability.

STATUS OF ULTRA-HIGH VACUUM CHAMBERS

The NICA accelerators complex has only two storage rings, which are operated under ultra-high vacuum conditions around 10^{-9} Pa: booster and collider. Leaner accelerators, transfer channels and Nuclotron are operated under the pressure larger than 10^{-7} Pa [10].

Booster Chambers

The booster synchrotron has four superconducting arcs under cryogenic temperature and four straight sections under room temperature.

The vacuum chamber of the superconducting arcs have the elliptic cross section and it was bended with the large radius [11]. Vacuum chamber for the superconducting magnets and quadruples was produced under the contract with FRAKOTERM [12]. Finally, vacuum tests was done by FMB Berlin [13], which also produced some other elements for the booster chamber. The most vacuum cambers for superconducting arcs are ready and its mounting in the booster tunnel was started this year.

Almost all straight sections are producing by BINP [3]: RF-sections and electron cooling system are ready and tested at JINR, an extraction system and beam channel to Nuclotron under production. The vacuum stand for RF-stations was produced by PINK [14] in the frame of the contract with MILLAB [15].

The injection septum and kicker are under production at HIVAC (Hastings, England) [16] in the frame of the contract with Cryosystems [17].

Collider Chambers

Collider vacuum chambers for the superconducting magnets under production now in the frame of the contract with FRAKOTERM [18]. All RF-stations and electron cooling system under production at BINP.

Channel from Nuclotron to the collider under production at SigmaPhi [19]. The stochastic cooling system is under design in the collaboration with FZJ [20].

MPD Vacuum Chamber

The most complicate design of the vacuum chamber in the NICA project is the chamber of Multi-Purpose Detector (MPD). The vacuum chamber is about 9 m long and producing from the aluminum alloy AW-2219 with the beryllium insertion 2 m long.

The design of the MPD vacuum chamber is very similar to the vacuum chamber of the ALLICE detector [21]. The CERN vacuum group has large experience in the design and production of same type of chamber. The participation of the CERN vacuum group in the development of the MPD vacuum chamber is under discussion now.

Nevertheless, the Russian company Kompozit [22] last year started the contract with JINR on the production of the prototype of the beryllium insertion for the MPD vacuum chamber. Another Russian company SDB IRE RAS [23] will make the vacuum test of the beryllium insertion next year and start the design of the MPD vacuum chamber.

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