VACUUM SYSTEM FOR THE RIKEN RING CYCLOTRON

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We present main features and status of our vacuum system. To remove the hydrocarbon left on the inner wall surface of chambers from the manufacturing process, we have recently applied two discharge cleaning methods to the chambers. The preliminary experimental results showed that hydrocarbon and H_2O are efficiently removed. Two kinds of cryopumps which are different from the conventional cryopumps, particularly for the cryopanel geometry glued charcoal grains were designed and their performances were experimentally investigated. The results are discussed with special emphasis on the pumping capacity for hydrogen. Our ring cyclotron was completed and the pressure of less than 4 x 10^{-6} Pa was achieved early October.

1. Introduction

Since in our ring cyclotron accelerated ions will travel up to several km, e.g. 3 km for Ar^{+12}, the vacuum chamber has to be evacuated sufficiently well to prevent beams from being lost by repeated collisions of the ions with residual neutral gas molecules. Thus, in our vacuum chamber an operating pressure below the order of 10^{-5} Pa is required, and a total gas load is of the order of 10^{-3} Pa.m^3/s.

The major part of our vacuum system consists of eight chambers and was connected to each other by means of viton o-ring sealed flanges. The pumping system is divided into three stages: First stage is for evacuating from atmosphere to 100 Pa by two mechanical booster pumps of 2600 m^3/hr, second one for evacuating from 100 Pa to 10^{-3} Pa by four turbomolecular pumps of 5000 l/s, third one for pumping from 10^{-3} Pa to a final pressure of 10^{-5} Pa by ten cryopumps of 10^4 l/s and four panel type cryopumps of 6 x 10^3 l/s.

In the first part of this paper we describe a chemical cleaning method applied to our chambers and discharge cleaning methods. As the aim to remove the hydrocarbon left from the manufacturing process we applied electron cyclotron resonance discharge cleaning to the magnet chambers and radio frequency assisted glow discharge cleaning to the valley chamber. These discharge cleaning methods showed a high efficiency in removing hydrocarbon and H_2O from the chambers.

In the second part, the brief descriptions of two kinds of our cryopumps and the results of their performance test are given. Our cryopumps are different from the conventional cryopumps. In the design, special emphasis was given to the high pumping speed for water vapor and the large pumping capacity(or sorption capacity) for hydrogen gas. The experimental results are discussed with special emphasis on the pumping capacity for hydrogen.

2. Vacuum chambers and Sealing

Our high vacuum chamber is divided into eight sections: four magnet chambers, two RF resonator chambers and two valley chambers as shown in Fig. 1. To reduce a total outgassing load, four auxiliary vacuum chambers in which trim coils coated with AL_2O_3 and magnet pole surfaces covered with a kapton super insulation are enclosed, are separated with a memblane of 4-mm thickness from the four magnet chambers as shown in Fig. 2 and the main coils are kept in air. All vacuum chambers except the auxilary vacuum chambers are interconnected via flanges with

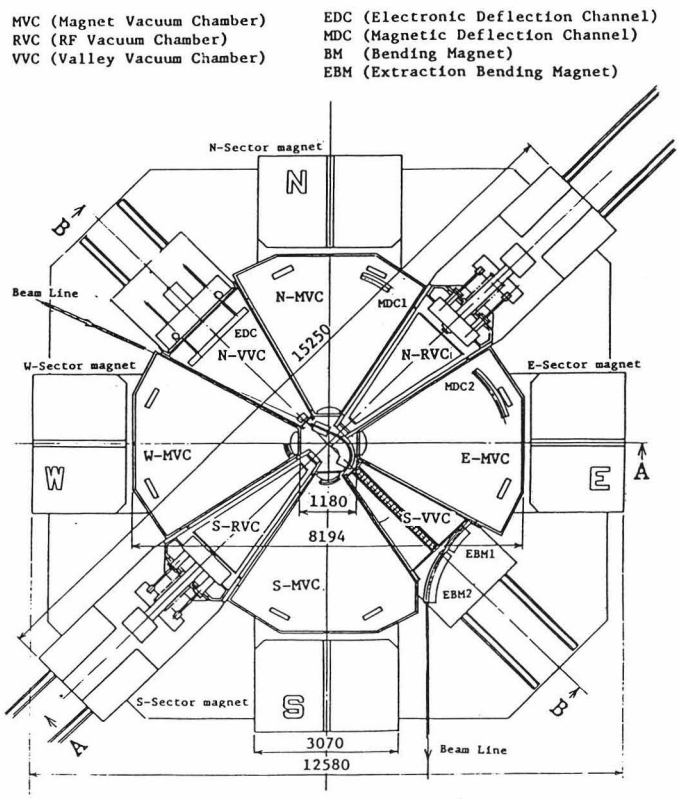

Fig. 1. Plane view of the vacuum chamber.

bellows(see Fig. 2) and to prevent permeation of atmosphere gases through the o-rings, a vacuum tightness between the flanges with bellows and flanges of the eight chambers is done by double viton o-ring seals with guard vacuum in between. The total evacuated volume of our cyclotron is 21 m^3 and the total surface area exposed to the high vacuum, including surface area (170 m^2) of components inserted is 520 m^2 composed as follows:

Materials	Surface area (m^2)
Stainless steel	350
Copper	153
Aluminum	13
BeCup(Beryllium Copper)	6
Viton	1.4
Polyethylene	0.1

The total gas load estimated from respective outgassing rate of these materials after 10 hours pumping is of the order of 10^{-3} Pa.m^3/s and the viton o-ring seals are the major contributors(60 %) to the total gas load.

3. Surface Treatment of Chambers

After the vacuum chamber has been manufactured, the interior is usually strongly contaminated with machine oils, dust particles and oxides. We wiped roughly these contaminations away by acetone and then treated a surface of respective chamber with a chemical cleaning method. The RF resonator chamber was mechanically polished with a scotch scrub brush instead of the chemical cleaning.

3.1 Chemical cleaning

We applied a chemical cleaning to the magnet chambers and the valley chambers and its sequence are as follows: 1) removal of machine oils by a Freon (Daiflon solvent-S_3) jet, 2) removal of animal- and vegetable-oils by an alkali solution (Neos-K) jet, 3) for removal of welding scales and oxided layers, after 1 hour suffusing on the surface with an acid solvent (NEOS CM 305 FA) including surfactant and inhivitor the acid solvent was washed out by a water jet (at room temperature), 4) removal of acid residues by neutralizer (NEOS CM 308), and 5) final spray of the surface with the water jet. After this chemical cleaning, each chamber was independently pumped down and leak checked, and was then installed in the cyclotron vault.

3.2 Discharge cleaning

To reduce the gas load from inner wall surfaces of the chambers, particulary as the aim to remove the hydrocarbon left from the manufacuring process, we are planning to apply electron cyclotron resonance discharge cleaning (ECR-DC) to the magnet chambers and

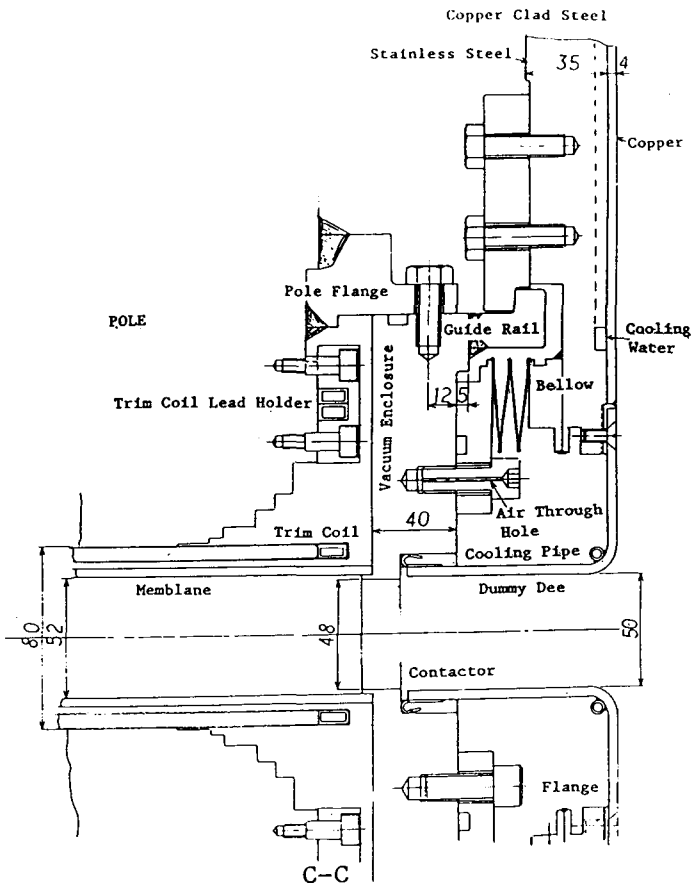

Fig. 2. Cross sectional view between the magnet and RF vacuum chamber.

radio frequency assisted glow discharge cleaning (RFAG-DC) to the valley chambers. We made preliminary experiments for 3/8 sections consisting of one valley chamber and two magnet chambers in order to investigate discharge cleaning effects. The total inner surface area of two magnet chambers and that of the valley chamber including components inserted are 53 m^2 and 29 m^2, respectively, and the volume of the whole system is 3 m^3. The system was pumped by a 5000 l/s turbomolecular pump which is attached to near the center of the valley chamber and a differentially pumped residual gas analyzer (QMA) was attached to a port of the magnet chamber facing the opposition direction of the valley chamber.

A coil anode for the glow discharge consists of a 6 mm hollow stainless-steel tube allowing water cooling and a central tube for introducing gas near the coil. The radiofrequency was supplied by a 13.5 MHz RF generator with a maximum power of 300 W and RF electrode system was coupled through an LC network to a DC power supply (0-1 kv, 5 A maximum).

For ECR-DC we used a 2.45 GHz microwave power source with a maximum power of 1.5 kW. The microwave was injected perpendicular to magnetic fields from the rear of the respective magnet chamber. The results of

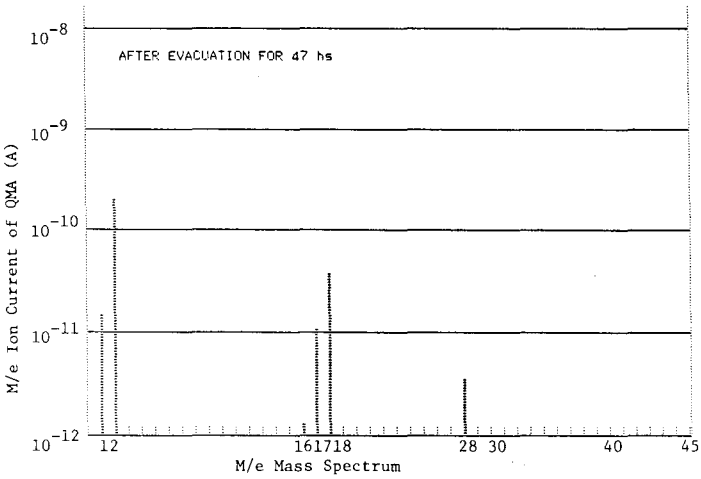

Fig. 3. Mass spectrum of residual gases in the chamber.

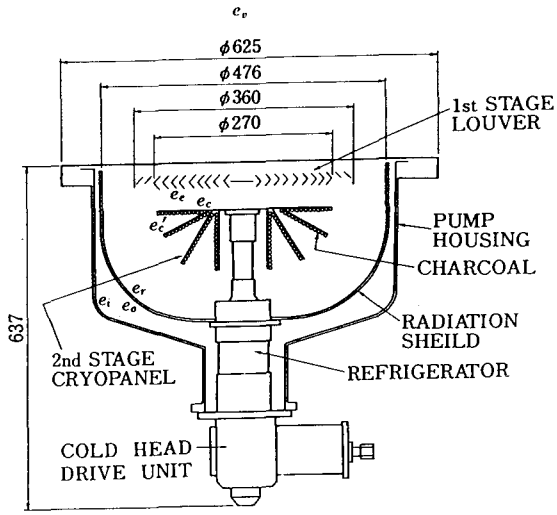

Fig. 4. Cross sectional view of the cryopump.

the mass spectrum by QMA after about 16 hours of discharge conditioning at a low working pressure of 3 x 10^{-2} Pa (H_2) are shown in Fig.3. As can be seen from Fig.3, no the mass peaks above 40 are ever observed. Thus, results of the discharge cleaning show a high efficiency in removing hydrocarbon from the chamber and H_2O.

4. Pumping system

Our pumping system is divided into three stages: 1) the roughing stage for evacuating from atmosphere to 100 Pa by two mechanical booster pumps of 2600 m^3/hr, 2) the intermediate vacuum stage for evacuating from 100 Pa to 10^{-3} Pa by four turbomolecular pumps of 5000 l/s, 3) the high vacuum stage consisting of ten cryopumps (ANELVA model CAP-200) and four panel type cryopumps (ANELVA model CAP-610) pumping from 10^{-3} Pa to a final pressure of 10^{-5} Pa. These cryopumps were newly developed for our device and are different from the conventional cryopumps.

4.1 Cryopumps and their pumping speeds

In the design of these cryopumps, special emphasis was given to the high pumping speed for water vapor and the large pumping capacity (or sorption capacity) for hydrogen gas from the following reasons: Firstly the pumping capacity for hydrogen, namely the amount of hydrogen adsorbable on the charcoal, has to be large because with this kind of pump the interval between regeneration determines the maintanence-free life time of the device, and thus is limited by the pumping capacity. Secondly, baking in our device to remove water vapor sorbed on the surfaces of the chamber and from inserted components is impossible because of the intricated structure as shown in Fig.1. Therefore, a very high pumping speed for water vapor is required. The CAP-200 cryopump is a modified one which is different from the conventional cryopumps, particulary for a cryopanel geometry glued charcoal grains. Its cross sectional view is shown in Fig.4. The pumping speeds were measured and the results are shown in Fig.5. We can see from this figure that the measured average pumping speeds for nitrogen and hydrogen are 1 x 10^4 l/s and 2 x 10^4 l/s, respectively and these experimental results are in good agreement with the design values. The design value of the pumping speed for water vapor is 2.7 x 10^4 l/s. In the Fig.6 a cross sectional view of CAP-610 cryopump is shown. This panel type cryopump has a geometry like a waterwheel and is to be mounted in a stem of the RF resonator. The pumping speed is 6.3 x 10^3 l/s for nitrogen and 8.3 x 10^3 l/s for hydrogen. The design pumping speed for water vapor is 10^5 l/s.

4.2 Pumping capacities of cryopumps for hydrogen

As is well known, the pumping capacity for hydrogen of a cryopump is much smaller than for other gases. Therefore the interval for regeneration of the cryopump, namely maintenance-free lifetime of the

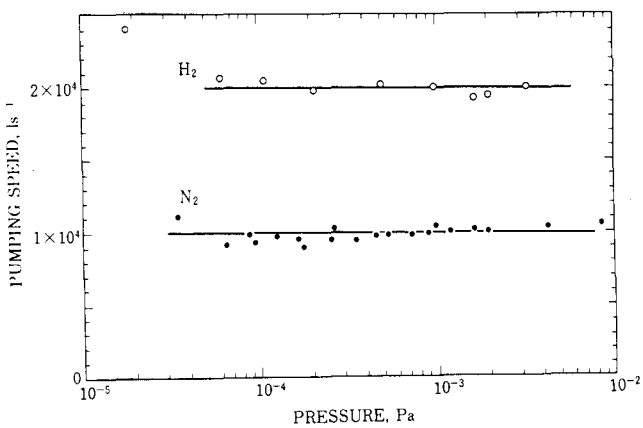

Fig. 5. Pumping speed for gases of the cryopump.

device, is limited by the pumping capacity for hydrogen. The operating pressure required in our device is 10^{-5} Pa at where the partial pressure of hydrogen is considered to be 10^{-6} Pa or below. Even at 10^{-5} Pa, the measurements of the pumping capacity need too much time and it is also difficult to control the small flow rate (0.1 Pa.l/s) of hydrogen gas to keep the pressure of 10^{-5} Pa over a long time. We obtained the pumping capacity by a continuous method which involved measuring the equilibrium pressure at the constant high flow rate of 9.3 Pa.l/s; the result for CAP-200 is shown in Fig. 7.

To measure the pumping capacity in short time even at lower pressure, we employed an discontinuous method. The measuring procedures are as follows: Firstly the amount of hydrogen corresponding to 600 Pa.m^3 was injected and pumped at a constant pressure of 10^{-3} Pa by introducing a flow rate of 15 Pa.l/s. Secondly we stopped the introduction of hydrogen gas and waited to reach an equilibrium pressure at zero flow rate. Thirdly we measured the equilibrim pressure as a function of several flow rates and simultaneously checked the pumping speeds. We repeated these procedures until, for each flow rate, the equilibrium pressure became two times the initial value thus obtaining the pumping capacity for hydrogen gas. The experimental results are shown in Fig.7. It is seen that an increase in a total amount of hydrogen gas adsorbed on charcoal results in an increase of the equilibrium pressure, namely in the range of 10^{-5} Pa, it is 2×10^3 Pa.m^3 and at 1×10^{-2} Pa, it is 7.5×10^3 Pa.m^3.

Since a partial pressure of hydrogen gas in our vacuum chamber is considered to be of the order of 10^{-6} Pa, the pumped quantity is expected to be 1×10^3 Pa.m^3 (see Fig,7). Thus the interval for regeneration of our cryopumps with an effective speeds of 1.6×10^4 l/s is expected to be 700 days. A simular experiment for CAP-610 has been made and the result will be published elsewhere.

5. Conclusions

Our ring cyclotron was completed late September and the pressure less than 4×10^{-6} Pa was achieved early October. The preliminary experimental results of a discharge cleaning showed the high efficiency in removing hydrocarbon and H_2O from the interior of a chamber. The design pumping speeds of our main cryopumps for hydrogen and nitrogen were 2×10^4 l/s and 1.2×10^4 l/s,respectively, and were in good agreement with the experimental results. The design pumping speed for water vapor was 2.7×10^4 l/s. The pumping capacity for hydrogen was dependent on the equilibrium pressure, being reduced with a decrease of the pressure, i.e. throughput: 2×10^3 Pa.m^3 at 1×10^{-5} Pa and 7.5×10^3 Pa.m^3 at 1×10^{-3} Pa.

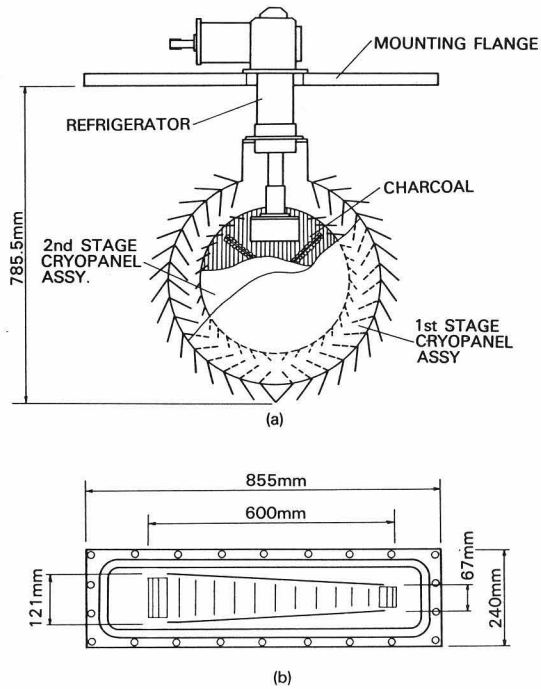

Fig. 6. Cross sectional view of the panel type cryopump.

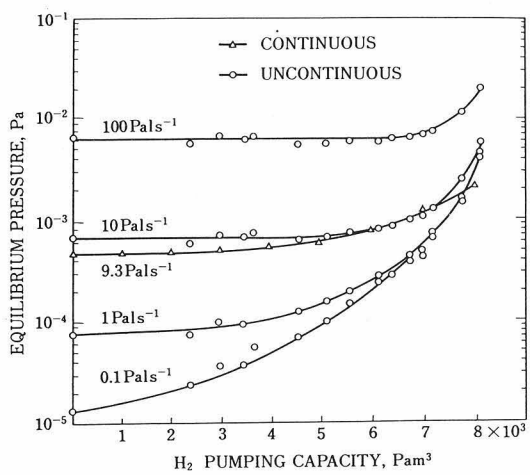

Fig. 7. Pumping capacity for the hydrogen gas of the cryopump.