Vacuum Design of RF-resonator for the RIKEN Intermediate-stage Ring Cyclotron

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Abstract

A four-sector ring cyclotron (K=980) has been designed as an accelerator in the RIKEN RI beam factory project. Since heavy and highly-charged ions are mainly accelerated in this cyclotron, the chambers such as an RF-resonator must be kept ultra-high vacuum. From this point of view, the structure of the main resonator has been studied so as to reduce the out-gassing into the beam space. A structure of duplicated walls has been designed; this structure reduces the out-gassing into the beam space less than half of the total out-gassing into the resonator. The displacement of the resonator by the atmospheric pressure has also been confirmed to be tolerable.

1. Introduction

A four-sector ring cyclotron has been designed as an Intermediate-stage Ring Cyclotron (IRC: K=980) [1] which is installed between a four-sector ring cyclotron (RRC: K=540) and a six-sector superconducting ring cyclotron (SRC: K=2500). Heavy ions are accelerated through these three cyclotrons up to high energy (some hundreds MeV/u), and are utilized to produce radioactive ion beams [2]. The IRC is under manufacturing at Niihama works, Sumitomo Heavy Industries, Ltd. (SHI).

Figure 1 shows a plan view of the IRC. The vacuum chambers of the IRC consist of four sector magnet chambers, two main resonator chambers and two valley chambers including a flattop resonator. Ions are accelerated on the median plane in these chambers.

The pressure must be kept ultra-high vacuum in order to reduce the beam loss due to the scattering by residual gas molecules. The ultra-high vacuum allows us to achieve high beam transmission efficiency, and as a result, reduce activation of the cyclotron components.

The pressure required in their path is about 1×10^{-6} Pa. Actual pressure of the RRC, the size of which is similar to that of the IRC, is about 2×10^{-6} Pa [3], twice the required pressure for the IRC. In case of the RRC, the out-gassing of the main resonator is approximately 60 % of total out-gassing. Therefore we made it our main design issue to reduce the out-gassing of the main resonators.

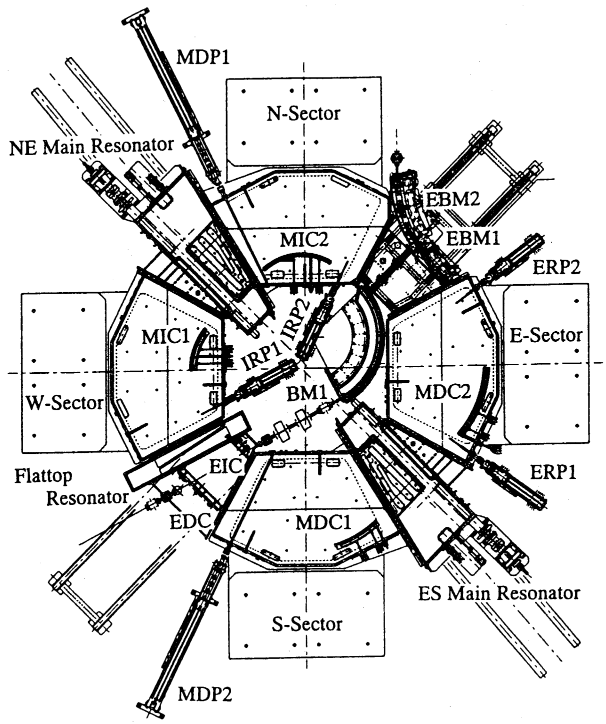

Fig. 1 Plan view of the RIKEN IRC.

2. Structure of Main Resonator

Figure 2 shows a schematic drawing of the IRC main resonator designed. The main resonator is of variable-frequency (18-38.2 MHz) single gap type, similar to that of Osaka University RCNP ring cyclotron [4]. The resonant frequency is varied by rotating a pair of flapping panels. The panels are electrically connected to a copper wall with hinges and flexible copper panels.

We have decided to adopt a structure of duplicated walls for the resonator chamber as shown in Fig. 3, in order to save a total cost for manufacturing compared with the case of the RRC main resonator [5], which uses a copper-clad stainless steel wall. Outer stainless steel wall of 45mm in thickness is a structural material for partition between the vacuum and the atmosphere, so that the outer wall has enough rigidity against the atmospheric pressure. Inner copper wall of 4mm in thickness is used as cavity conductor. Seamless copper tubes are soldered on the outer surface of the copper wall for cooling water flow. In order to achieve an ultra-high vacuum, we have designed the inner volume of the resonator to be separated into two parts with the copper wall from the viewpoint of vacuum. The 25mm gap between the stainless steel and copper walls is called a "sub vacuum part", which has large out-gassing elements like rubber o-rings and is evacuated by two turbo-molecular pumps of 0.5 m^3/s. The inside of the copper wall is called an "ultra-high vacuum part", which is evacuated by three cryogenic pumps of 10 m^3/s. A turbo-molecular pump of 5 m^3/s is installed on the "ultra-high vacuum part" as primary evacuation. The total pumping speed is 30 m^3/s, the same as the case of the RRC. The "ultra-high vacuum part" and the "sub vacuum part" are sealed each other by only metal touching. Therefore a small amount of gas flows from the "sub vacuum part" to the "ultra-high vacuum part".

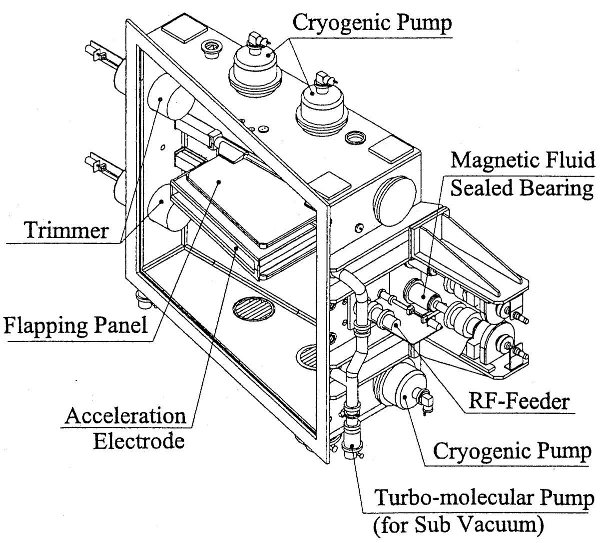

Fig. 2 Schematic drawing of the IRC main resonator.

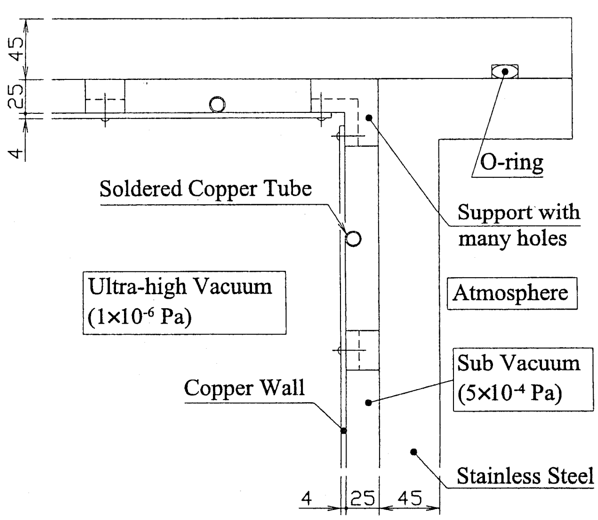

Fig. 3 Schematic drawing of the structure of duplicated walls.

A mechanical safety valve and an electrical safety valve are installed in duplication between the "ultra-high vacuum part" and the "sub vacuum part", so as to avoid mechanical displacement by the pressure difference on the copper wall.

The magnetic fluid sealed bearings are adopted as the rotating bearings for the rod of the flapping panel, in order to reduce the leak rate from the atmosphere. The interface surface between magnet chambers and resonators are sealed by pneumatic expansion seal [6], so that the resonators are able to be withdrawn easily along rails for the maintenance.

The main resonator of Osaka University RCNP ring cyclotron also has duplicated walls. However, it has many holes on the copper walls to get sufficient conductance between the separated parts. In this case, the two separated parts are considered as one vacuum chamber.

3. Out-gassing

As mentioned above, the vacuum chamber of the IRC main resonator can be considered as separated two parts. The two parts are evacuated with a "differential pumping method", the "ultra-high vacuum part" is evacuated by a total pumping speed of 30 m^3/s, while the "sub vacuum part" is evacuated by a total pumping speed of 1 m^3/s. There is a small conductance between two parts. Figure 4 shows a schematic diagram for the calculation of the differential pumping method.

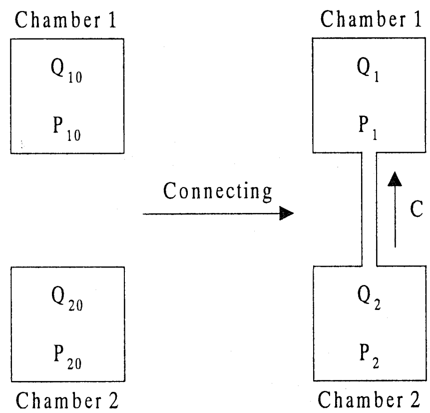

Fig. 4 Schematic diagram for the calculation of the differential pumping method. P_{10} , P_1 and P_{20} , P_2 are the pressure (Pa) in each chamber before and after connecting respectively. Q_{10} , Q_1 and Q_{20} , Q_2 are the out-gassing ($Pa \cdot m^3/s$) in each chamber before and after connecting respectively. C is the conductance (m^3/s) between chamber 1 and 2.

At the equilibrium condition after connecting chamber 1 with 2, the out-gassing in each chamber are expressed by the equation

$$Q_1 = Q_{10} + C \cdot (P_2 - P_1) \tag{1}$$

$$Q_2 = Q_{20} - C \cdot (P_2 - P_1) \tag{2}$$

On the other hand, as the pumping speed is constant, the pressure is proportional to the out-gassing in each chamber. Therefore, ratio of the pressure after to before connecting is expressed as

$$\frac{P_1}{P_{10}} = \frac{Q_{10} \cdot Q_{20} + C \cdot P_{20} \cdot Q_{10} + C \cdot P_{20} \cdot Q_{20}}{Q_{10} \cdot Q_{20} + C \cdot P_{20} \cdot Q_{10} + C \cdot P_{10} \cdot Q_{20}} \tag{3}$$

As the difference of the pressure between "ultra-high vacuum part" and "sub vacuum part" is usually more than two orders, the equation (3) is simplified to

$$\frac{P_1}{P_{10}} \cong 1 + \frac{C \cdot P_{20} \cdot Q_{20}}{Q_{10} \cdot Q_{20} + C \cdot P_{20} \cdot Q_{10}} \qquad (4)$$

One can say that this ratio of P_1 to P_{10} gives an effectiveness of the differential pumping method.

In the case of the IRC main resonator, we estimated that the out-gassing in the "ultra-high vacuum part" $Q_{10} = 2.3\times10^{-5}$ Pa·m³/s, in the "sub vacuum part" $Q_{20} = 6.6\times10^{-5}$ Pa·m³/s and the pressure of the "sub vacuum part" $P_{20} \cong 5\times10^{-4}$ Pa. According to equation (4), the conductance which causes P_1 going up to 150 % of P_{10} can be calculated about 0.03 m³/s, and the gas flow from the "sub vacuum part" to the "ultra-high vacuum part" can be calculated about 1.2×10^{-5} Pa·m³/s in that case. The total out-gassing of the "ultra-high vacuum part" goes up to 3.5×10^{-5} Pa·m³/s as the result. This value is still less than half of the total out-gassing of the resonator (=$Q_{10}+Q_{20}$) and is also about half of the RRC main resonator. The conductance value of 0.03 m³/s is equivalent to a circular hole of 20 mm in diameter.

We have thus decided to adopt such a duplicated structure, controlling the total conductance less than 0.03 m³/s. It is possible to control this value of the conductance by means of only metal touching seal.

4. Structural Analysis

The atmospheric pressure is loaded against the outer walls made of 45 mm-thick stainless steel plates. As the side walls of the resonator is not strong enough to support the atmospheric pressure, it should be supported by the neighboring magnet chamber. Figure 5 shows displacement of the resonator by the atmospheric pressure, calculated using FEM (Finite Element Method) computer code.

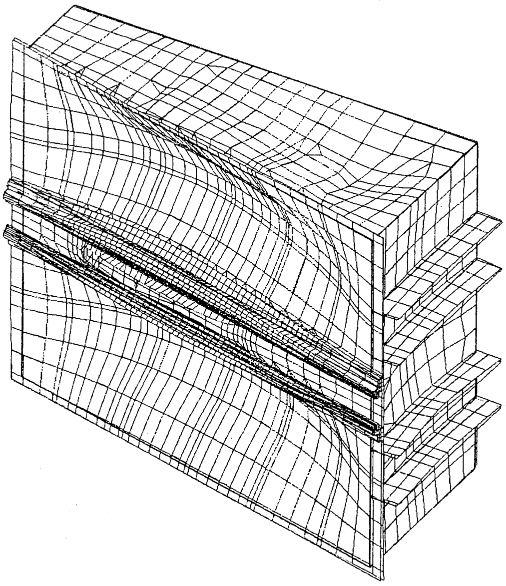

Fig. 5 Displacement of the resonator by the atmospheric pressure, calculated using FEM code.

Four ribs were added on the back-side wall in order to reduce the displacement and the stress. Although the back-side wall at the feeder position moves by 0.3 mm toward the inside, the displacement can be compensated by stroking the feeder. Although the side wall is bent by 1.5 mm at the maximum point, shift of the resonant frequency can be also compensated by the trimmer or flapping panel. The incline of the rotating rod of the flapping panel was estimated about 3 mrad, which is within the allowance of the bearing. It was also confirmed that the stress of the support material between side wall and neighboring magnet chambers was allowable.

5. Conclusion

We have designed a structure of the main resonator for the RIKEN IRC. A duplicated structure, which consists of an "ultra-high vacuum part" and a "sub vacuum part", has been investigated. As each part is sealed by only metal touching, a "differential pumping method" has been adopted. A suitable value of the conductance between the two parts in order to achieve an ultra-high vacuum has been confirmed. The out-gassing in the "ultra-high vacuum part" has been reduced less than half of the total out-gassing in the resonator. Furthermore, we have confirmed that the displacement by the atmospheric pressure is allowable.

References

[1] T. Mitsumoto et al., "Design Study of the IRC RIKEN RI-Beam Factory", RIKEN Accel. Prog. Rep. **32**, (1999) 195.
[2] Y. Yano et al., "Progress of RIKEN RI Beam Factory Project.", RIKEN Accel. Prog. Rep. **30**, (1997) 195.
[3] H. Saito et al., "RIKEN Ring Cyclotron", SHI Tech. Rev. **35**, (1987) 103.
[4] I. Miura et al., "The RF system for the RCNP Ring Cyclotron", Proc. 7th Symp. on Acc. Sci. and Tech., (1989) 89.
[5] T. Fujisawa et al., "Design of Radio Frequency System for the RIKEN Separated Sector Cyclotron", Sci. Papers I.P.C.R., **79**, (1985) 12.
[6] A. Shimizu et al., "Vacuum System of the RCNP Ring Cyclotron", Proc. 7th Symp. on Acc. Sci. and Tech., (1989) 142.