Vacuum System for the RIKEN Superconducting Ring Cyclotron

Kazuo SUGII, Kumio IKEGAMI, Shigeru YOKOUCHI, Akira GOTO, and Yasushige YANO
RIKEN (The Institute of Physical and Chemical Research)
2-1, Hirosawa, Wako-shi, Saitama 351-0198, Japan

Abstract

In order to achieve the goal of 99% beam transmission in the SRC, the beam-chamber pressure is necessary to be of the order of 10^{-6} Pa. Cryopumps with a total pumping speed of 170 m^3/s as a main pumping system are planned to be used in order to achieve the required range of pressure as quickly as possible. The pumping-down time to the order of 10^{-6} Pa is estimated to be a few hundred hours.

1 Introduction

Beam transmissions are aimed to be above 99% for all ion beams available in the RIKEN Superconducting Ring Cyclotron (SRC). In a heavy-ion accelerator, beam losses are mainly caused by a change of charge state due to collisions of the beam against residual gas. Therefore, the pressure of the beam chamber is required to be as low as possible in order to reduce beam losses. We have estimated the required pressure from the relationship between the pressure and the beam loss, and have designed the vacuum system for the SRC.

2 Pressure required for the SRC

A beam transmission η is given by

$$\eta = \exp(-N_0\, \sigma_T\, \beta\, c\, t\, P), \tag{1}$$

where N_0 is the number of residual gas molecules per unit volume at 1 Pa and is 2.5×10^{14} molecules/cm^3/Pa at 293K, σ_T the charge-exchange cross section, β the ratio of ion velocity to velocity of light (c), t the accelerating time, and P the pressure of the beam chamber. For a given cross section and an accelerating time, the beam transmission can be obtained as a function of pressure from Eq.(1). We have considered the beam transmission of $^{238}U^{58+}$ ions for example, since the charge-exchange cross section of heavy ions such as $^{238}U^{58+}$ is very large.

Firstly, the accelerating time of ion in a ring accelerator is approximately given by the following equation:

$$t = \{(\Delta E\cdot A)/(\Delta V\cdot q)\}\cdot(h/f), \tag{2}$$

where ΔE is the difference between the beam energies at injection and extraction, A the mass number, ΔV the average of effective accelerating voltages per turn at injection and extraction, q the charge number, h the harmonic number, and f the RF frequency. Table 1 shows the typical parameters of RF resonators for the acceleration of $^{238}U^{58+}$ ions. The accelerating time estimated from Eq.(2) using these parameters is 5.8×10^{-5} sec.

Secondly, it is necessary to estimate the electron-stripping cross section of the fast heavy ions in collision with the residual gas molecules. For heavy ions accelerated to a very high energy range, there are few published data on the charge-exchange cross section. At NSCL, the Betz-Schmelzer approximation with a correction factor of 5 has been adopted in the high energy range of the K1200 cyclotron [1]. We also applied the above approximation to the SRC, and obtained the electron-stripping cross section of 4×10^{-18} cm^2 for $^{238}U^{58+}$ ions at the injection energy of 58.0 MeV/nucleon.

Table 1
Typical parameters of RF resonators for the acceleration of $^{238}U^{58+}$ ions.

Frequency (MHz)	27.2
Harmonic number	6
$T_{inj.}$ (MeV/nucleon)	58.0
$T_{ext.}$ (MeV/nucleon)	150
$V_{inj.}$ (MV/turn)	1.24
$V_{ext.}$ (MV/turn)	1.64

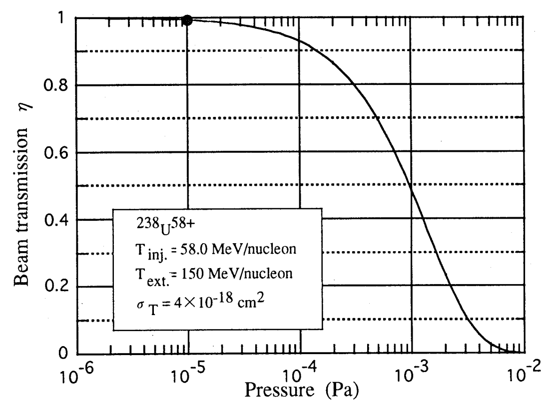


Fig. 1 Beam transmission of $^{238}U^{58+}$ ions at the injection energy of 58.0 MeV/nucleon as a function of pressure of the beam chamber.

The beam transmission of $^{238}U^{58+}$ ions in the SRC thus obtained is shown in Fig. 1 as a function of pressure of the beam chamber. As can be seen from this figure, the pressure is required to be below 1×10^{-5} Pa in order to achieve the goal of 99% beam transmission.

3 Vacuum system for the SRC

The vacuum chamber of the SRC consists of six beam chambers each being in the sector magnet, four RF resonators, a flattop resonator, two valley chambers, and the beam pipes for injection and extraction (see Fig. 2). Table 2 shows the total volume of the vacuum chamber and the surface areas of main materials. We plan to use eighteen cryopumps with a total pumping speed of 170 m^3/s as a

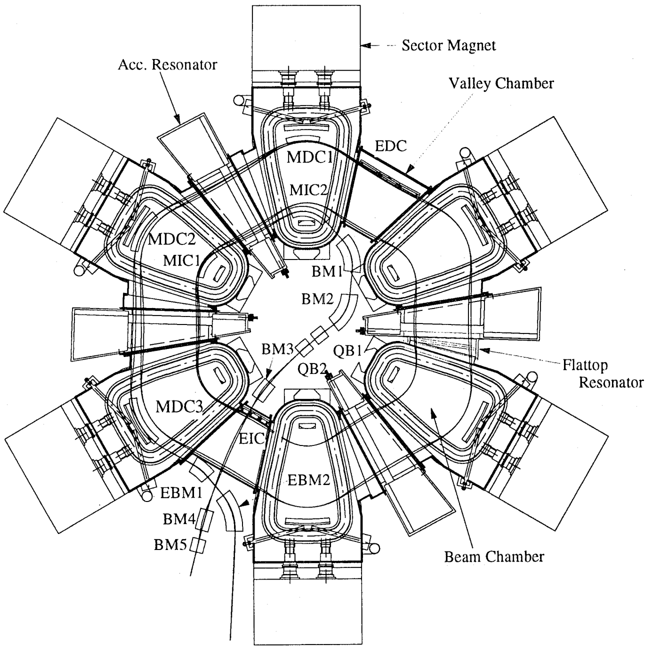


Fig. 2 Plan view of the SRC.

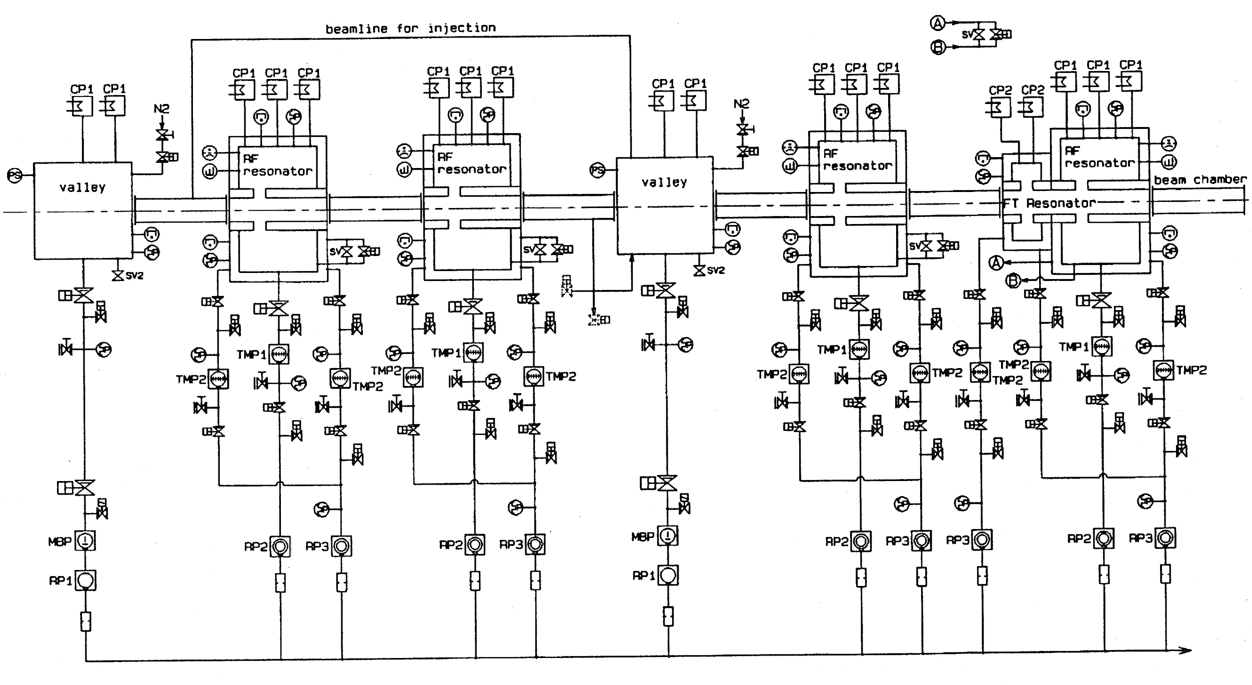
main pumping system in order to achieve the required range of pressure as quickly as possible.

Figure 3 shows the designed pumping system for the vacuum chamber of the SRC. The pumping system consists of a roughing system, a high-vacuum system, an ultra-high-vacuum system and a differential pumping system.

Table 2
Total volume of the vacuum chamber and the surface areas of main materials exposed to high vacuum. The values including the whole extent of sub-vacuum are shown in parentheses ( ).

Area	Stainless steel	197	(442)	m^2
	Copper	356	(605)	m^2
	FPM (O-ring)	3.4	(5)	m^2
Volume		85	(90)	m^3

The surface areas of the RF resonators and the flattop resonator are very large, since the resonators have a structure of duplicated wall as the IRC resonators do [2]; copper plates are supported on the stainless steel vacuum walls of them. We plan to evacuate the gas in the sub-vacuum space between the vacuum walls and the copper plates by a differential pumping system in order to reduce gas load for cryopumps. Therefore, it is necessary to minimise the leak rate from the sub-vacuum space to the high-vacuum space. The roughing system is composed of a roots pump of 2600 m^3/h and a rotary pump of 290 m^3/h, and is installed at each valley chamber. The high-vacuum system is composed of a turbo-molecular pump of 5.5 m^3/sec and a rotary pump of 155 m^3/h. This high-vacuum system is installed at each RF resonator. The turbo-molecular pump of high-throughput type is to be used. The reasons for it are as follows: (1) to shorten the pumping time prior to the ultra-high-vacuum system by switching from the roughing system to the high-vacuum system at a high pressure (about 70 Pa), and (2) to prevent the contamination in the RF resonator caused by backflow of



CP1: cryopump of 10 m3/s. CP2: cryopump of 5 m3/s
RP1~3: rotary pump, MBP: roots pump
cold cathode gauge hot cathode gauge (B-A)
pirani gauge mass spectromater
pressure switch

TMP1: turbo-molecular pump of 5.5 m3/s, TMP2: turbo-molecular pump
SV, SV2: safety valve

Fig. 3 Pumping system for the vacuum chamber of the SRC.

oil vapor from a rotary pump by the same switch. If the ultra-high-vacuum system starts to operate at a pressure of 1×10^{-3} Pa, the total pumping time during the operation of both the roughing and high-vacuum systems (from the atmosphere to 1×10^{-3} Pa) is calculated to be about 22 hours. The ultra-high-vacuum system deploys eighteen cryopumps: sixteen of 10 m^3/sec and two of 5 m^3/sec. The cryopumps of 5 m^3/sec are installed at the flattop resonator and those of 10 m^3/sec are distributed to the two valley chambers and all of the RF resonators. We chose cryopumps as the main pump of ultra-high-vacuum system, because they have large pumping speeds against the water vapor and hydrogen gas, both of which are predominant residual gas components in an unbaked vacuum system. Furthermore, they can be operated even in a large environmental magnetic field. Total effective pumping speed of the cryopumps is about 75 m^3/sec at the beam passage. By using this pumping speed and the published data for outgassing rate of materials, the pumping-down time to achieve the order of 10^{-6} Pa is estimated to be more than a few hundred hours.

The pressure of the vacuum chamber of the SRC will be measured with a nude type of hot ion gauge during a non-operation period of the SRC. During the SRC operation, a cold cathode gauge will be used, since a hot ion gauge is of no practical use due to a large leakage flux from the sector magnet. Being constructed with a permanent magnet, it is expected to be usable even in an external magnetic field. Measurement of pressure using a cold cathode gauge under an external magnetic field is reported [3]. However, we also measured the influence of an external magnetic field on cold cathode gauges, because the pressure measurement is limited by a large leakage flux from the SRC magnet [4].

4 Summary

Beam transmissions are aimed to be above 99% for all ion beams available in the SRC. In order to achieve such a goal, the pressure of the beam chamber is necessary to be below 1×10^{-5} Pa for $^{238}U^{58+}$ ions for example. We plan to adopt eighteen cryopumps as the main pump. Total effective pumping speed of the cryopumps is about 75 m^3/sec at the beam passage, and the pumping-down time to achieve the order of 10^{-6} Pa is estimated to be more than a few hundred hours.

References

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