VACUUM SYSTEM FOR THE NIJI-III COMPACT STORAGE RING

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ABSTRACT

The NIJI-III is a compact storage ring measuring about 15 m in circumference with four superconducting bending magnets. It is under development as a synchrotron light source for X-ray lithography with a stored beam current of 200 mA at a stored energy level of 615 MeV. The vacuum system is designed to attain a pressure of less than $1x10^{-9}$ Torr at beam storage. The compact ring design makes it difficult to install a large number of pumps able to satisfy the required pumping speed.
For the purpose of realizing a high pumping speed, a cryopump as a result of cooling the superconducting magnet duct wall to the liquid helium (LHe) temperature is adopted, as a result the total pumping speed of $2.8x10^{4}$ l/s is obtained.

INTRODUCTION

Fig. 1 is a plan view of the NIJI-III compact ring, which consists of four superconducting bending magnets and two long and two short straight sections.[1] This ring is about 15 m in circumference with two beam ports per bending magnet. Two all-metal valves dividing the ring into two sections are provided. Reducing the overall ring dimensions as shown in Fig. 1 without sacrificing the desired level of performance as the light source for x-ray lithography means more severe requirements to the vacuum system because of the limited space on pump installation.

The vacuum system design and several test results are reported in this paper.

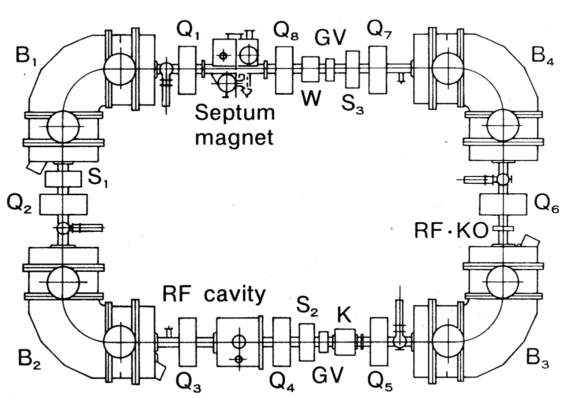

Fig.1 Plan view of NIJI-III

B1-B4 : Bending magnet
Q1-Q8 : Quadrupole magnet
S1-S3 : Sextupole, octupole magnet
W : Wobbling magnet
K : Kicker magnt
GV : Gate valve

VACUUM SYSTEM

Vacuum chamber

Fig. 2 shows the cross section of the superconducting bending magnet and beam duct.[2] The bending duct was made by bending an SUS 304L pipe to a radius of 0.5 m by high frequency induction heating. On the outside of this duct (ø170 x 10t) superconducting coils are mounted. The flange seal is indium coated, helicoflex of superior air tight characteristics in the very low temperature region of 4.2° K.
Inside the duct an absorber is used to deal with heat load by synchrotron radiation (SR). As the power per one magnet by SR is about 1.25 kW at 615 MeV and 200 mA, liquid nitrogen (LN_2) is used to cool the absorber. The absorber surface is held at 77° K by recycling the LN_2 at the flow rate of 35 l/h. The absorber is made of SUS 304L stainless steel and its surface is finished by buffing. The duct cross section for the straight section is show in Fig. 3. They are flat, hexagonal in shape, measuring 130 mm width, and 60 mm height, and are made of SUS 304L sheet formed by press work. The flanges are conflat type throughout. There are eight straight ducts in total and six of them have pumping ports, gauge ports and side-welded bellows. Furthermore, four of the six have screen monitoring ports whereby to observe the beam trajectory during the trial run of this ring. The opening of the pumping ports is covered by a slit plate as not to induce instability in the stored beam. Another point of note is that each duct has a beam position monitor of four button type and ion clearing electrode. The bellow is made by welding 316L stainless steel, having the same shape as that of the beam duct. The baking heaters (ø3.2 microheaters) are installed to attain an electric power density of 0.5 w/cm^2. The vacuum vessel is made of stainless steel except for the rf cavity and the kicker chamber. Inner surface of the rf cavity is copper. The kicker chamber is made of ceramic and the inner surface is coated with 100Å TiN.

Chamber conditioning and baking

The model ducts were tested to determine the surface treatment and to evaluate the effect of baking. The results obtained are show in Table 1. The model ducts were made of 304L stainless steel and an outgassing rate of $q=5x10^{-12}$ $Torr.l/s.cm^2$ or less was required. For the measurement of outgassing rate a throughput method was adopted and a turbo molecular pump (TMP) was used there. The buffing and electropolishing satisfied the target in the test. In the NIJI-III ring electropolishing is adopted for complicated construction of the straight duct having some ports and buffing for the bending duct of large and simple construction. The prototype ducts were also tested and attained the same degassing rate as model duct for evaluation.

However, since the superconducting coils are mounted on the outside of the bending duct, a certain limit is imposed on baking temperature. Furthermore, baking is difficult when it is assembled to a cryostat. Therefore, the problem is what is to be done, and how to retain the effect of baking of the duct before assembly. As measures against this problem, the exposure of the duct to atmosphere is minimized up to the final stage of assembly to the cryostat. In addition baking was performed at 80°C to avoid the failure to the cryostat after every exposure of the duct to atmosphere. And the N_2 gas was filled in the duct at an atmosphere. These treatments are effective to reduce outgassing rate because the high temperature baking effect before assembly is retained by the memory effect if the duct is exposed short enough to atmosphere.
Therefore, the outgassing rate can be reduced by the order of one, in comparison with the case where only low temperature baking is applied or no baking applied at all.

Table.1 Outgassing rat of stainless steel SUS 304L

	Surface treatment	Outgassing rate (Torr·l/s·cm²)
Model type	Buffing	2.6×10^{-12}
	Glass beads blasting	1.2×10^{-11}
	Chemical polishing	6.0×10^{-12}
	Electro polishing	4.1×10^{-12}
Proto type	Buffing	2.0×10^{-12}
	Electro polishing	5.0×10^{-12}

After baking at 200°C for 10 hours

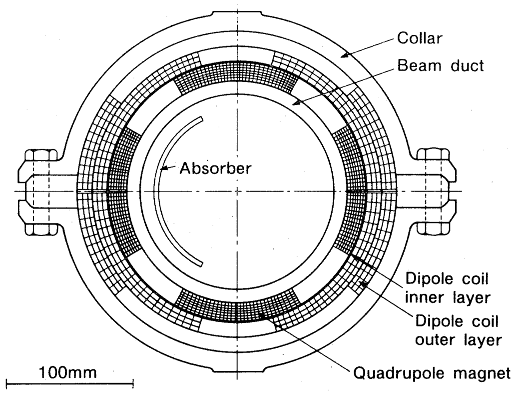

Fig.2 Cross section of superconducting bending magnet and beam duct

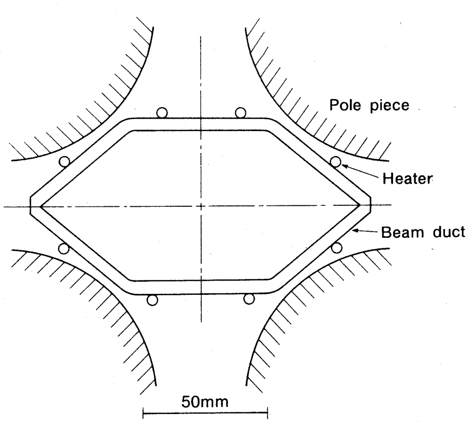

Fig.3 Cross section of the quadrupole and beam duct

Pumping speed

The vacuum system must be designed to maintain a beam loading vacuum pressure of 1×10^{-9} Torr in order to realize a beam life of more than 24 hours. The outgas in the vacuum chambers mostly caused from the beam duct wall surface exposed to SR. The photon stimulated gas desorption coefficient η is said to be broadly affected by the history of the beam duct. In case of the NIJI-III the outgassing rate is $Q_{SR}\sim7\times10^{-6}$ Torr.l/s at the stored beam current of 200 mA for 615 MeV using $\eta=2.5\times10^{-6}$ molecules/photon for sufficiently exhanced stainless steel.[3)]
Adding to the thermal desorption, the overall ring outgassing rate is $Q\sim9\times10^{-6}$ Torr.l/s, and a pumping speed of 9×10^{3} l/s is required to achieve the pressure of 1×10^{-9} Torr. The η will be a larger value, however, at early stage of the ring operation. Therefore, a large enough margin of pumping speed is required.

Cryopump test

A model test was made in order to estimate the pumping speed attainable with the cryochamber. The cooling surface area of 6×10^{3} cm^2 was almost the same as that of the prototype. First, the chamber was roughed by a TMP with baking at 200°C for 10 hours. After roughing, a sputter ion pump (SIP) was operated to obtain ultra-high vacuum. When the pressure of 1.8×10^{-9} Torr was achieved, the cooldown of the chamber started with LN_2. After this cooling, the chamber and the absorber were further cooled using LHe and LN_2, respectively. Fig. 4 shows the pumping curve of the cryochamber.
For measurement, a through-put method was adopted and a dry N_2 gas was released as the measuring gas. The pressure was measured by using two ionization gauges. Flow rate is estimated by the orifice conductance and the measured pressure drop.
The pumping speed attained in the model test is approximately 5×10^{3} l/s. This result demonstrated that the cryochamber is very effective for a compact ring in realizing a much higher pumping speed.

Vacuum system

Fig. 5 is a plan view of the vacuum system for the NIJI-III compact ring. As a result of the adoption of the cryochamber for evacuation, the vacuum pressure inside the ring is held much lower than the level of minimum requirement. Acting as a cryopump as described above realizes the pumping speed of $\sim 2 \times 10^4$ l/s in total for the four bending ducts. In addition, 230 l/s SIP and 800 l/s titanium getter pumps (TGP) with NEG are installed in six places in the straight sections and inflector. Furthermore 500 l/s SIP and 800 l/s TGP are installed in the rf cavity. The total pumping speed of $\sim 2.8 \times 10^4$ l/s is comfortably greater than the pumping speed required of 9×10^3 l/s. For vacuum pressure measurement, five ionization gauges and a quadrupole mass spectrometer for leak and residual gas composition measurement are installed. Two 200 l/s TMP in the inflector and rf cavity are used for roughing.

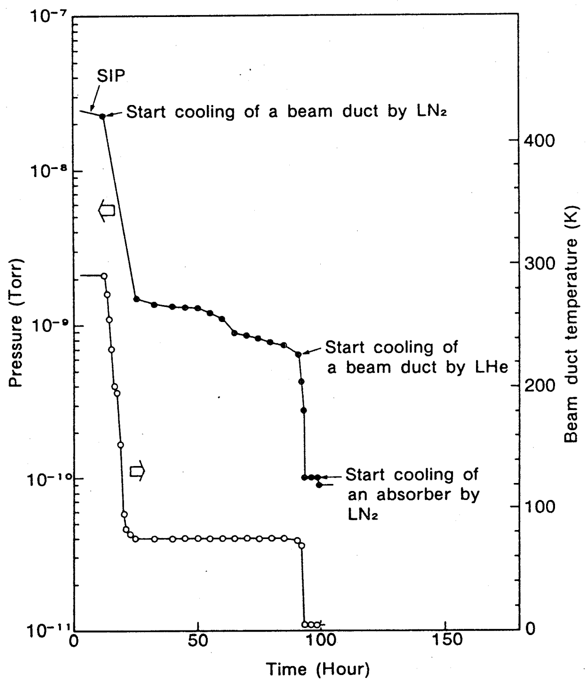

Fig.4 Pumping curve of cryochamber

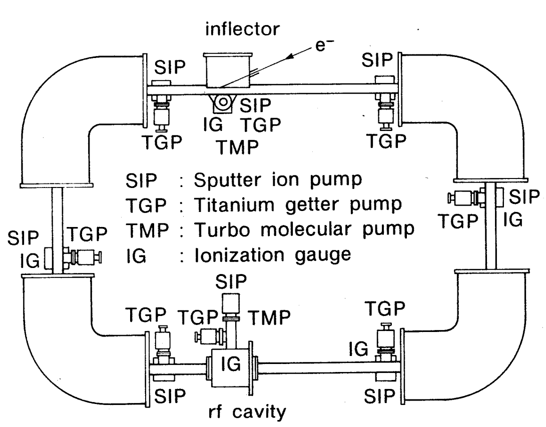

Fig.5 Vacuum system NIJI-III

STATUS

The NIJI-III was first constructed with four normal conducting bending magnets in order to insure the injection parameters. On the 21st June, the first beam was accumulated. After that the stored beam current of approximately 10 mA was achieved. Then the pressure in the bending section without distributed ion pump was 9×10^{-10} Torr. When one of four conventional bending magnets was replaced with a superconducting bending magnet, the pressure near the superconducting magnet was improved to 3×10^{-10} Torr at no beam load, while other bending section was $\sim 6 \times 10^{-10}$ Torr. These results have confirmed the effect of the cryochamber of the NIJI-III ring.

ACKNOWLEDGEMENT

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REFERENCE

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