J. Synchrotron Rad. (1998). **5**, 351–353

Operational performance of the NIJI-III superconducting storage ring

Katsuji Emura,* Tsuyoshi Shinzato, Yasumitsu Tsutsui, Hiroshi Takada and Nobuo Noda

Sumitomo Electric Industries Ltd, Harima Research Laboratories, Harima Science Garden City, Kamigori, Hyogo 678-12, Japan. E-mail: emura@okk.sei.co.jp

(*Received 4 August 1997; accepted 23 September 1997*)

The operational performance of the NIJI-III superconducting storage ring has been studied with particular attention focused on the vacuum performance of the cold-bore chamber. Photon-stimulated gas desorption in the cold-bore chamber was examined after commissioning the storage ring. It was confirmed that the photon-stimulated gas desorption due to diffuse reflection of synchrotron radiation at the absorber was not dominant in the gas desorption when the electron beam was accumulated in the storage ring.

Keywords: superconducting storage rings; cold-bore chambers; photon-stimulated gas desorption.

1. Introduction

The compact electron storage ring NIJI-III (Emura *et al.*, 1995) has four superconducting bending magnets. Superconducting coils made of niobium-titan materials were mounted on the outside of vacuum chambers. Both the superconducting coils and the vacuum chambers were cooled by liquid helium at a temperature of 4.2 K. Thus, the inner surface of the vacuum chamber acts as a cryopump, which is called a cold-bore feature.

The cold-bore feature, in general, has the advantage of a high pumping speed compared with conventional vacuum pumps such as sputter-ion pumps (SIPs) and non-evaporable getter pumps (NEGs). The cold-bore feature is suitable for compact storage rings because it is difficult to install a large number of vacuum pumps in storage rings to achieve the required pumping speed.

In contrast, Schuchman (1990) pointed out that one of the disadvantages of the cold-bore feature is the limited knowledge of photon-stimulated gas desorption (PSD) from cold surfaces. When a vacuum chamber is irradiated with synchrotron radiation, photoelectrons are generated at the surface of the vacuum chamber. The photoelectrons are bent by the magnetic field and consequently collide with the vacuum chamber. These photoelectrons desorb a portion of the gas molecules which have been adsorbed in the vacuum chamber. This is the mechanism of PSD (Ishimaru, 1992).

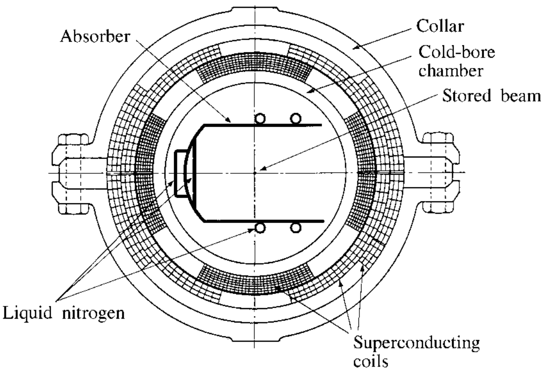

Figure 1
Cross section of the superconducting bending magnet.

Table 1
Main parameters of NIJI-III.

Beam energy	600 MeV
Bending magnetic field	4.0 T
Bending radius	0.5 m
Circumference	18.89 m
RF frequency	158.7 MHz
Harmonic number	10
Peak synchrotron radiation wavelength	5.4 Å

Experiments have been carried out to assess the PSD effect in the cold-bore feature (Jostlein, 1990). The total amount of gas desorption was measured when a cold-bore chamber was irradiated with synchrotron radiation. In storage rings without cold-bore chambers, the gas desorption decreased with the integrated time of synchrotron radiation irradiation, which was effective in obtaining ultra-high vacuum conditions, such as a vacuum pressure of less than 50 nPa. In the cold-bore feature, however, gas desorption did not decrease with the integrated time of synchrotron radiation irradiation (Kanazawa, 1990). This is a problem of the cold-bore feature (Mistry, 1987).

To avoid this problem the cold-bore chamber should not be irradiated with synchrotron radiation. Thus, in NIJI-III, the liquid-nitrogen-cooled absorber was installed in the vacuum chamber of the superconducting magnets so that the cold-bore chamber was not irradiated with synchrotron radiation, as shown in Fig. 1. Moreover, we considered that the cold-bore chamber was irradiated with synchrotron radiation photons reflected on the absorber. Ray tracing of the photons was carried out using numerical simulations which included a specular reflection and did not include a diffuse reflection. The cold-bore chamber was therefore irradiated with photons due to the diffuse reflection in the case of this design of the absorber. It was difficult to avoid this irradiation. Thus, this problem has remained. It is, therefore, important to examine PSD due to the diffuse reflection after commissioning the storage ring. We carried out experiments to examine the above effect and concluded that PSD due to the diffuse reflection was not dominant in the gas desorption at the beam loading in this ring.

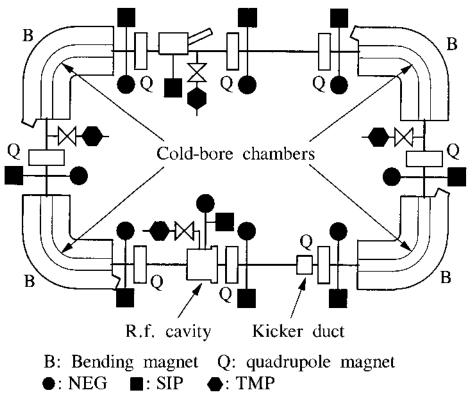

Figure 2
Vacuum system of NIJI-III. SIP: sputter-ion pump; NEG: non-evaporable getter pump; TMP: turbo-molecular pump for rough pumping.

2. Vacuum system

The main parameters of the storage ring are summarized in Table 1. A schematic configuration of the vacuum system of the storage ring is shown in Fig. 2. Nine SIPs with pumping speeds of 0.23 $m^3 s^{-1}$ and eight NEGs with pumping speeds of 0.55 $m^3 s^{-1}$ were installed in the straight sections of the storage ring. In addition, one SIP with a pumping speed of 0.50 $m^3 s^{-1}$ and one NEG with a pumping speed of 0.55 $m^3 s^{-1}$ were installed on the RF cavity.

3. Operational performance

3.1. *Evaluation of the pumping speed of the cold-bore chamber*

Before the design of the vacuum system of the storage ring, we carried out a test-model experiment (Miura *et al.*, 1989) to estimate the pumping speed attainable with the cold-bore chamber. We found that the cold-bore-chamber pumping speeds for nitrogen gas and hydrogen gas are approximately 7.5 and 17 $m^3 s^{-1}$, respectively, per 1 m^2 of the chamber area at a vacuum pressure of 100 nPa. Based on these experimental results with nitrogen gas, we have estimated that the pumping speed of the cold-bore chamber of the storage ring is 20 $m^3 s^{-1}$, considering that the inner surface of the cold-bore chamber is 2.7 m^2.

After commissioning the storage ring, we examined the pumping speed of the cold-bore chamber. A vacuum pressure of 41 nPa without stored beam was achieved. When we introduced a small quantity of air into the storage ring the vacuum pressure increased and then started to decrease gradually to 41 nPa. From the time constant of this decrease, we obtained a storage ring pumping speed of 24.4 $m^3 s^{-1}$. The sum of the pumping speed of the SIPs and the NEGs was 7.3 $m^3 s^{-1}$. Thus, the pumping speed of the cold-bore chamber was estimated to be 17.1 $m^3 s^{-1}$. This value is in good agreement with the value obtained from the test-model experiment.

As we mentioned before, the magnetic field is thought to be related to the mechanism of PSD. It is, therefore, important to examine the influence of the magnetic field upon the pumping speed of the cold-bore chamber, because the cold-bore chamber in the storage ring is normally used with a magnetic flux density of ~4.0 T. Experimental results are shown in Fig. 3. The vacuum pressure in the storage ring does not vary when the magnetic flux density is below 4.0 T. Therefore, we conclude that a magnetic flux density below 4.0 T does not affect the pumping speed of the cold-bore chamber.

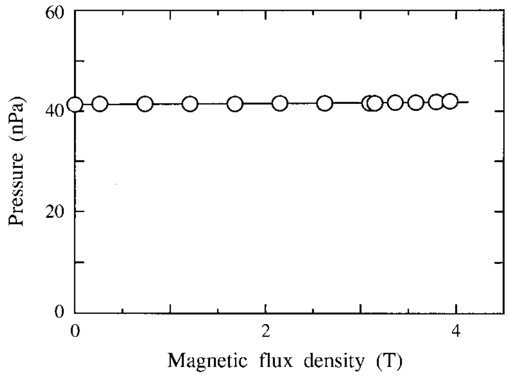

Figure 3
Experimental results on the influence of the magnetic field upon the pumping speed of the cold-bore chamber.

This experiment was performed under a ramping rate of magnetic flux density of 5×10^{-3} T s^{-1}. The eddy current was generated in the cold-bore chamber, because the magnetic flux density was changed in time in the cold-bore chamber. Thus, the cold-bore chamber might be somewhat warmed by the Joule heat. The experimental result showed that the vacuum pressure in the storage ring did not vary when the magnetic flux density was below 4.0 T. Thus, we confirm that this vacuum-chamber heating due to the eddy current does not affect the pumping speed of the cold-bore chamber.

3.2. *PSD due to the diffuse reflection on the absorber*

We measured the vacuum pressure when the electron beam was accumulated in the storage ring. The experimental results are shown in Fig. 4. The horizontal and the vertical axes in Fig. 4(*a*) represent the electron-beam energy and the vacuum-pressure rise, respectively, as compared with the vacuum pressure without stored beam current. Three experiments were performed; the stored current was set to be 70, 100 and 120 mA at a beam energy of 100 MeV. 90% of the stored current remained after energy ramping by which the beam energy was increased to 600 MeV. When the beam energy was lower than 200 MeV the vacuum-pressure rise depended on neither the beam energy nor the stored current. On the contrary, when the beam energy was higher than 200 MeV the vacuum-pressure rise depended on both the beam energy and the stored current. The vacuum performance at the beam loading was therefore varied at around the beam energy of 200 MeV.

The main purpose of this experiment was to examine PSD due to the diffuse reflection on the absorber. If PSD due to the diffuse reflection is dominant in the gas desorption at the beam loading, the vacuum-pressure rise is dependent on the total number of photons. The horizontal axis in Fig. 4(*b*) represents the total number of photons of synchrotron radiation. The three curves in this figure differ from one another. We conclude, therefore, from

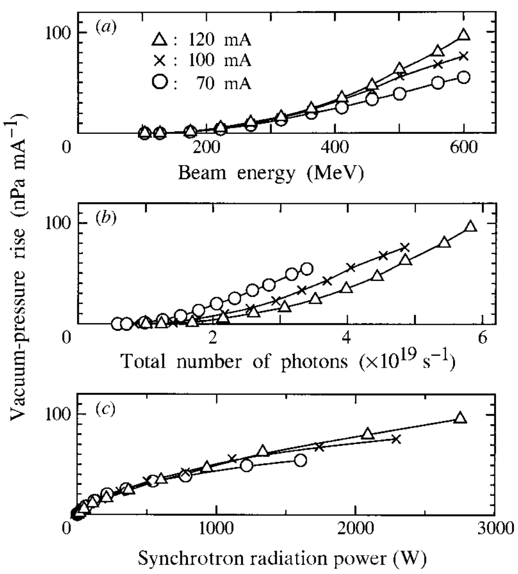

Figure 4
Experimental results on the vacuum-pressure rise at the beam loading. Horizontal axes in (*a*), (*b*) and (*c*) represent the electron-beam energy, the total number of photons of synchrotron radiation, and the total power of synchrotron radiation, respectively. Stored current at a beam energy of 100 MeV was set to be 70 (○), 100 (×) and 120 mA (△).

this experimental result that the PSD due to the diffuse reflection is not dominant in the gas desorption at the beam loading in this ring.

In Fig. 4(*c*) the horizontal axis represents the total power of synchrotron radiation. The three curves in this figure are in good agreement with one another. We conclude, therefore, from this experimental result that the vacuum-pressure rise is attributed to the total power of synchrotron radiation. The cold-bore chamber is thought to be heated due to the power of synchrotron radiation, which desorbs a portion of the gas molecules which have been adsorbed in the vacuum chamber.

The reason why the cold-bore chamber was heated due to the total power of synchrotron radiation should be considered. Temperature and pressure of the coolant for the absorber were measured continuously. We did not observe a change in the temperature, even at the beam loading. On the contrary, we observed that the pressure of the coolant changed, which indicated that a portion of the liquid nitrogen was vapourized in accordance with the beam loading. The absorber was consequently considered to be locally heated to 77 K. The cold-bore chamber heating was, therefore, attributed to the heat transfer with thermal radiation from the absorber.

3.3. *Dependence of gas desorption yield on synchrotron radiation irradiation*

The vacuum-pressure rise per stored current at a beam energy of 600 MeV was measured as shown in Fig. 5. The pressure rise was kept at a constant value of 5 nPa mA^{-1}, when the vacuum chambers in the storage ring were efficiently baked out by synchrotron radiation irradiation. As shown in Fig. 5, an accidental vacuum leak occurred. Air flowed into the vacuum chambers in the storage ring and the vacuum pressure in the storage ring rose to approximately atmospheric pressure. We used a roughing pump to restore the storage ring from the vacuum leak. Just after the restoration the pressure rise showed a very large value of 21 nPa mA^{-1} and subsequently decreased with time with the integrated stored current. The pressure, however, did not recover to 5 nPa mA^{-1} until the integrated stored current reached 7000 A s. After that, we warmed the cold-bore chambers to a temperature of 77 K and cooled them to 4.2 K. Consequently, the pressure rise returned to 5 nPa mA^{-1}.

The above experimental results indicate that the inner surface of the cold-bore chamber was filled with adsorbed gas molecules and consequently the pumping speed decreased. When we warmed the cold-bore chambers the gas molecules adsorbed in the cold-bore chamber were desorbed, and most of the gas molecules were pumped by the SIPs or NEGs which were installed in the storage ring. Such a temperature rise from 4.2 to 77 K acted as a thermal desorption method, which was effective in decreasing the gas desorption in the cold-bore feature.

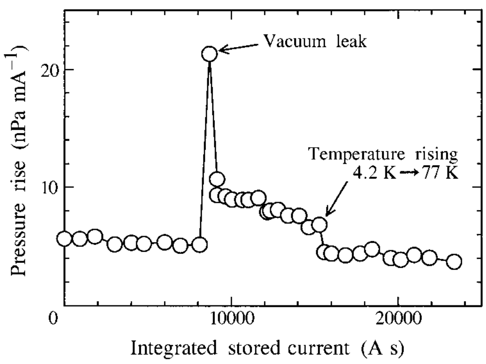

Figure 5
Vacuum-pressure rise due to the beam loading.

4. Conclusions

The operational performance of the cold-bore feature in the NIJI-III superconducting storage ring was studied. We found that the gas desorption at the beam loading was determined with the total power of synchrotron radiation. These experimental results indicated that PSD due to the diffuse reflection at the absorber was not dominant in the gas desorption at the beam loading in this ring.

The gas-desorption yield did not decrease with the integrated time of synchrotron radiation irradiation. This is because the inner surface of the cold-bore chamber had a tendency to adsorb gas molecules and consequently the pumping speed decreased. The temperature rise of the cold-bore chamber from 4.2 to 77 K was found to be effective in decreasing the gas desorption in the cold-bore feature.

References

Emura, K., Haga T., Shinzato, T. & Takada, H. (1995). *Proc. 10th Symp. Accel. Sci. Technol., Hitachinaka*, pp. 26–28.

Ishimaru, H. (1992). *Proc. 8th Meet. Ultra-High Vac. Technol. Accel. Storage Rings*, KEK, pp. 9–20. (In Japanese.)

Jostlein, H. (1990). *J. Vac. Sci. Technol.*, A**8**, 2840.

Kanazawa, K. (1990). *Handbook of Vacuum Technology*, edited by T. Kanaji, p. 797. Tokyo: Nikkan-kougyou-shinbunsya. (In Japanese.)

Mistry, N. B. (1987). *Physics of Particle Accelerators*, edited by M. Month & M. Dienes, pp. 1444–1504. New York: AIP.

Miura, F., Tsutsui, Y. & Takada, H. (1989). *Proc. 7th Symp. Accel. Sci. Technol.*, Osaka, pp. 130–132.

Schuchman, J. C. (1990). *Vacuum Design of Synchrotron Light Sources*, edited by Y. G. Am, S. D. Bader, A. R. Krauss & R. C. Niemann, pp. 300–312. New York: AIP.