A CRYOGENIC CURRENT MEASURING DEVICE FOR THE LOW-INTENSITY BEAM AT THE STORAGE RING TARN II

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Abstract

In the cooler ring experiments, an accurate and non-destructive current measurement is essential to determine the reaction cross sections. In order to measure a low beam current from some nA to some micro-A, we made a cryogenic current measuring device using a SQUID (Superconducting QUantum Interference Devices) and measured a circulating ion current at the cooler ring TARN II. This paper gives the design and performance of the device.

1 INTRODUCTION

Electron-ion collision experiments have been performed on heavy ions, molecular ions and negative ions at the storage ring TARN II. One important result concerning physics is the absolute values of the cross sections. In order to determine the cross sections, accurate intensity measurements of ion beams are required without interfering with the circulating ion beams in the ring. A standard current measuring device which has widely been used so far in circular accelerators is the DC current transformer (DCCT), the sensitivity of which is some μA. On the other hand, the intensities of the ion beams used in atomic-physics studies at the TARN II ring, such as molecular ions, are mostly below the lowest measurable limit by the DCCT. Furthermore, such ions are fragile, and their lifetimes are typically a few seconds. The intensities are supposed to be from some nA to 1 μA for these ions. A new type of beam-intensity monitor using a SQUID was designed in order to non-destructively measure low-intensity ion beams circulating in the ring. The system was completed and installed in the ring. First measurements were carried out recently. The paper describe the design and performance of the device.

2 DESIGN OF THE CRYOGENIC CURRENT MEASURING DEVICE

The underlying principle of the cryogenic current comparators has been described by Grohmann et al. [1] and the application to the beam current measurements was reported by Grohmann et al. [2] and Peters et al. [3]. However, the device has not yet been designed for the use of the ion current measurements in storage rings, where problems peculiar to the ring have to be solved. They are a large-size warm bore, the compatibility with ultra-high vacuum of the beam pipe, fitting to the narrow space, shielding the high level electro-magnetic noise and mechanical vibration. Prior to the design, a small test device [4] was made and some fundamental tests were made with it, which included the sensitivity, shielding efficiency from an external field, zero drift and noise. After these test, the full scale device was designed. The system consists of a superconducting magnetic shielding, a flux coupling coil and a SQUID. The ion beam is simulated with a one-winding wire loop around the magnetic shielding. The loop current induces an azimuthal magnetic-field component, which turns on a surface current on a superconducting shielding made of lead (Meissner effect). As a type of shielding cavities, a folder type structure composed of several ring cavities [1] was chosen due to the narrow width and easiness of manufacturing. The dimensions of the cavity is as follows,

Inner diameter: 290 mm
Outer diameter: 470 mm
Gap width: 0.5 mm
Number of ring cavities: 8
Total width: 100 mm.

Because of the shielding structure, the azimuthal magnetic-field component can enter into the shielding with small attenuation, while the other field components are strongly attenuated. The magnetic field induced by the surface current can then be detected independently of the beam's location by a one-turn flux-coupling coil composed of a Nb cavity surrounding a toroidal core. Several types of toroidal cores were tested in our model studies and "VITROVAC 6025F" was chosen since it has lowest noise figures at the liquid helium (L-He) temperature. The dimensions of the toroidal core is as follows,

Inner diameter: 322 mm
Outer diameter: 400 mm
Width: 25 mm.

The inductance in the room temperature is 120 μH, which decreases by a factor of about four in the L-He temperature. The flux-coupling coil is coupled to a DC SQUID. The magnetic-flux sensor used in this experiment was a double-washer DC SQUID with direct feedback coils developed as a magnetic-flux sensor for a multi-channel biomagnetometer at Shimadzu Corporation [5]. For the optimum condition, the white-noise flux density is 5×10^{-6} $\phi_0/\sqrt{Hz}$ (ϕ_0: flux quantum).

The entire system is immersed in a L-He cryostat as shown in Fig. 1. In order to match the limited space spared

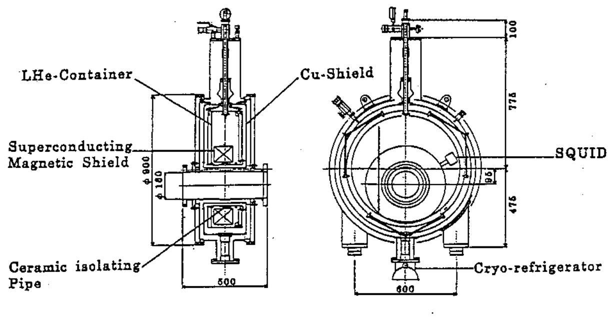

Figure 1: Design of the cryostat for the cryogenic current measuring device.

for this device in the ring, the total width is designed to be only 50 cm. The vacuum of the cryostat is much inferior to that of the beam pipe of the ring (typically $10^{-11} Torr$). Therefore, the vacuum of the beam pipe with a inner diameter of 16 cm is isolated from that of the cryostat, so as not to affect the ultra-high vacuum of the ring. To avoid wall currents induced by the ion beam, ceramic isolating pipes have been inserted into both the beam tube and the liquid-helium container tube. The copper radiation shield is cooled by a cryo-refrigerator at a temperature of around 40 K. The whole copper shield is wrapped up in superinsulation foils. The L-He container is suspended by two thin rods of titanium and also reinforced by FRP rods from side walls to avoid conduction of heat. The total heat loading is about 0.29 W, which corresponds to a liquid-helium boiling rate of 9 l/d. With this system a holding time of 1 day was achieved with an effective liquid-helium stock volume of 15 l.

Low frequency noise due to mechanical vibration seriously deteriorates the resolution of the system. In order to isolate the device from the vibration of the floor, it was installed on four rubber bearings. Furthermore, thin-walled metal bellows on each side of the device damped vibrations on the beam pipe. As the refrigerator is a type of low mechanical vibration, it was unnecessary to stop during measurements. The device installed in the TARN II ring is shown in Fig. 2.

3 PERFORMANCE

In order to cool down the cryostat and to fill with L-He, several steps are required: First L-He container is cooled by liquid nitrogen (L-N) and then L-N is expelled. After confirming that the temperature is high enough to evaporate L-N, the container is filled with L-He. This process takes about 10 days, because the weight of the L-He container with the detection system is no less than 300 kg. Figure 3 shows the output of the SQUID electronics as a function of the calibration current of the ion-beam simulation loop. A good linearity was obtained up to 2.8 μA. The current sensitivity was 5 mV/nA, which is high enough to measure the current of the order of nA. To determine the resolving power of the system, the noise spectrum was measured using a spectrum analyzer. As can be in Fig. 4, the low-frequency noise between 10 and 20 Hz limits the resolution. The shielding efficiency was tested adding uniform external magnetic fields with Helmholtz coils wound outside of the cryostat. An external field of $10^{-5}T$ yields the following apparent currents:

$$\vec{B} \parallel \vec{I} \quad \sim 4nA,$$

$$\vec{B} \perp \vec{I} \quad \sim 80nA.$$

In order to raise the shielding efficiency against the external magnetic field furthermore, the entire system was covered with μ -metal with a thickness of 1 mm. Although there are a lot of normal- and super-conducting magnets and an rf system in the TARN II room, the SQUID system was not affected even during operation of the whole system. Despite all these electromagnetic shielding, however, the use of portable phone in the room interrupted the operation of the system. At the beginning of the cooling, the output of the SQUID system shows a strong zero drift. The drift rate gradually decreased with time. At the end of May 1998, first measurements were performed with a 14 MeV HD^+ ion stored in the cooler ring TARN II (coasting beam). A typical example of measurements is given in Fig. 5. The device is now working as a powerful tool to determine absolute cross sections for the atomic physics experiments.

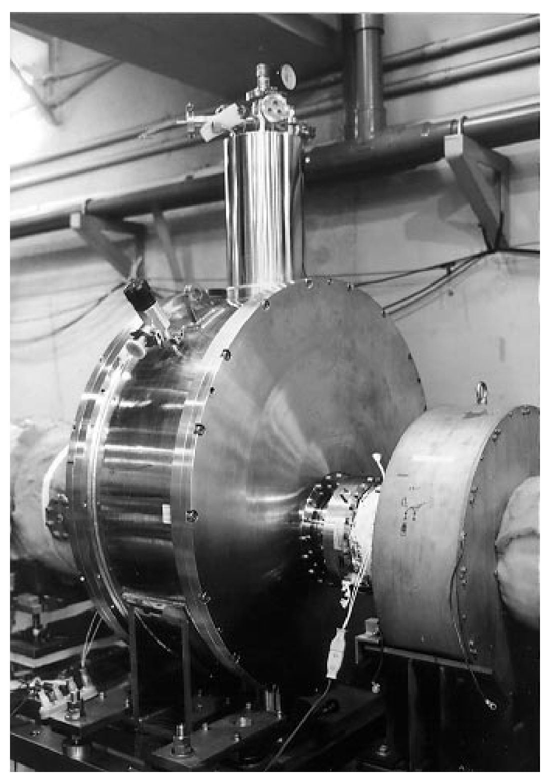

Figure 2: Photograph of the cryogenic current measuring device installed at the TARN II ring.

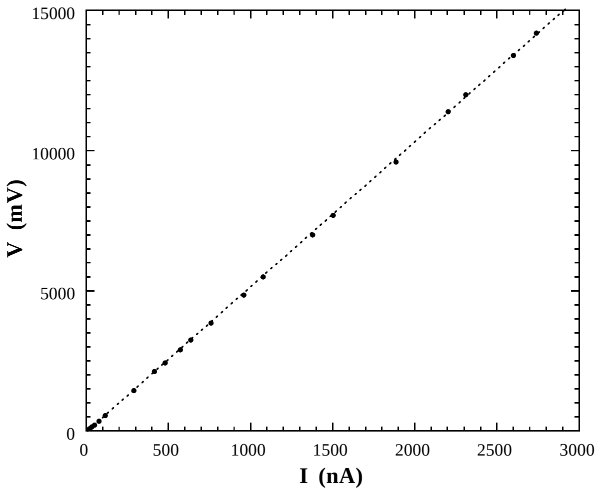

Figure 3: Current calibration data.

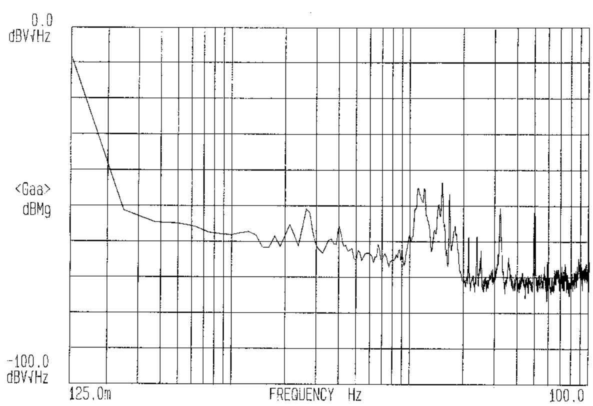

Figure 4: Noise spectrum.

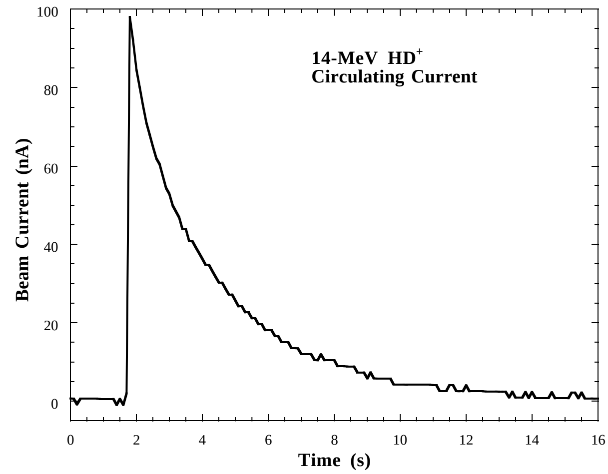

Figure 5: Measured ion current stored in the TARN II. The current decreases due to the dissociation of the molecular ion HD^+.

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