MEASUREMENT OF BREMSSTRAHLUNG DEPENDENT ON STORED BEAM CURRENT

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Abstract

Bremsstrahlung was measured as a function of stored beam current using the BGO scintillation spectrometer at the compact superconducting storage ring of Ritsumeikan University. Bremsstrahlung is emitted for collision of stored electrons and residual gas on the beam orbit. Yield of bremsstrahlung depend on stored beam current and residual gas density. We tried to determine gas density on the beam orbit by present measurement.

INTRODUCTION

The compact electron storage ring AURORA, manufactured by Sumitomo Heavy Industries [1], was installed at Ritsumeikan University in 1996 and has been operated successfully since then [2]. It is of the weak focusing type with the simplest lattice composed of a single body superconducting magnet, which produces an axially symmetric strong magnetic field to achieve compactness. The normal operating magnetic field is 3.8 T and the field index is 0.36 at ring energy of 575 MeV. The initial stored beam current is 300 mA in the orbit of 0.5 m in the radius. Table 1 lists the parameters of the injector and the ring. Figure 1 shows the storage ring and beamlines in the experimental hall.

The residual gas density on the beam orbit is very important parameter for storage rings. The pressure in the vacuum chambers is measured by using the vacuum gauge; the base pressure in the vacuum chamber of our storage ring is 1×10^{-8} Pa. On the other hand, the measurement of the pressure on the beam orbit in operation is difficult, because electron beam collide with the vacuum gauge.

We tried to measure bremsstrahlung which was emitted for collision of stored electrons and residual gas on the beam orbit. Yield of bremsstrahlung suggest the density of residual gas.

EXPERIMENTAL SETUP

The maximum energy of bremsstrahlung is 575 MeV to agree with the energy of the stored electron beam. Normal γ-ray survey meters can't measure such high energy bremsstrahlung. We employed BGO (bismuth germanate) scintillation spectrometer (CANBERRA) that could measure ~50 MeV X-ray. Measurement system which was composed by the detector, multichannel analyzer (ASA-100 CANBERRA) and PC was constructed behind the beam extraction port BL-16 at the atmosphere.

Partial pressure in the vacuum chamber was measured by the partial pressure vacuum gauge (M-066QG, ANELVA) and electron beam size was measured by the SR interferometer [3] and the conventional profile monitor. Figure 2 shows schematically the structure of measurement system.

Table 1: Parameters of the injector and storage ring

Injector parameters	
Energy	150 MeV
Repetition	10 Hz
Peak current	1 mA
Pulse width	2 μs

Storage ring parameters	
Energy	575 MeV
Stored current	300 mA
Circumference	3.14 m
Radius of curvature	0.5 m
Field strength	3.8 T
RF frequency	190.86 MHz
Number of cavities	1
Harmonic number	2
Critical energy of radiation	844 eV
Vertical beam size(σ)	0.14 mm
Horizontal beam size(σ)	1.2 mm
Beam lifetime	300 min

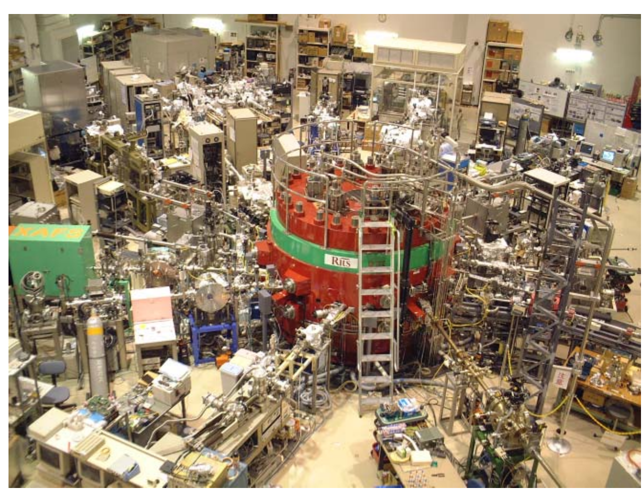

Figure 1: Photograph showing the storage ring and beamlines in the experimental hall.

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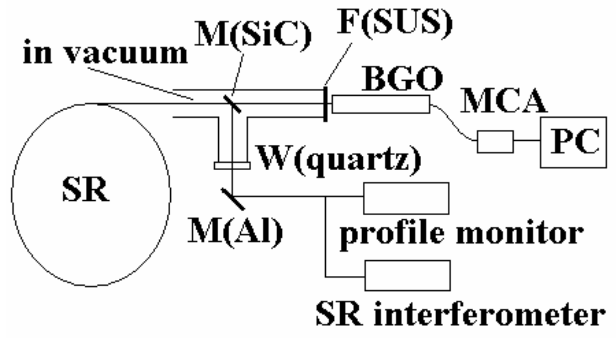

Figure 2: Structure of the bremsstrahlung measurement system at BL-16. M(SiC): silicon carbide mirror in vacuum; M(Al): aluminium mirror in atmosphere; W(quartz): quartz view window; F(SUS): SUS blank flange.

RESULTS AND DISCUSSION

Dependence on the beam current

Figure 3 shows the energy spectrum of bremsstrahlung for beam energy of 575 MeV and beam current of 200mA. Intensity of γ-ray from capture of neutron is negligible low. Normalized integral counts of bremsstrahlung with the photon energy of 3-30 MeV were plotted with open diamonds as a function of the beam current in figure 3. Partial pressures except for hydrogen were less than 1% and vertical beam sizes were about 11μm for each measurements of bremsstrahlung.

Counts of bremsstrahlung (Y_{brem}) are given by

$$Y_{brem} = \sigma_{brem} \cdot I \cdot \rho \tag{1}$$

where σ_{brem} is bremsstrahlung cross section [4], I is beam current and ρ is density of gas on the beam orbit. Plotted points in fig. 4 give ρ depended on the beam current because the vertical axis mean ρ from next equation.

$$Y_{brem}/I \propto \rho(I) \tag{2}$$

Assuming that $\rho(I)$ was given by equation (3), we tried to fit $\rho(I)$.

$$\rho(I) = \rho_o \cdot I^{1-\Delta} + \rho_b \tag{3}$$

Where $\rho_o \cdot I^{1-\Delta}$ is density of gas induced by synchrotron radiation and ρ_b is gas density given by base vacuum in chamber. Gas density $\rho(I)$ is not linear for beam current I, Δ is ~0.2 in beat fit (curve in fig. 4). This physical meaning is not yet clear at the moment.

According to obtained best fitting, density of gas at beam current of 300 mA in normal operation is about 100 times as large as in no operation. The base pressure in no operation in the vacuum chamber is 1×10^{-8} Pa. Hence, pressure on beam orbit is $\sim 1\times10^{-6}$ Pa in normal operation. We reported for the lifetime of gas scattering in the previous paper [5]. The pressure to calculate from this gas scattering lifetime is $\sim 2\times10^{-6}$ Pa.

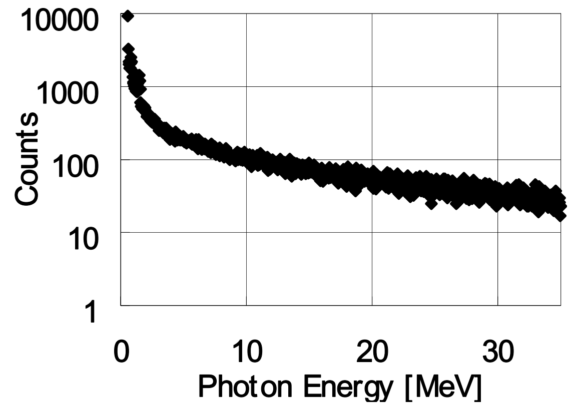

Figure 3: Observed bremsstrahlung spectrum by BGO scintillation spectrometer at the BL-16. Stored electron beam energy is 575 MeV and beam current is 200 mA.

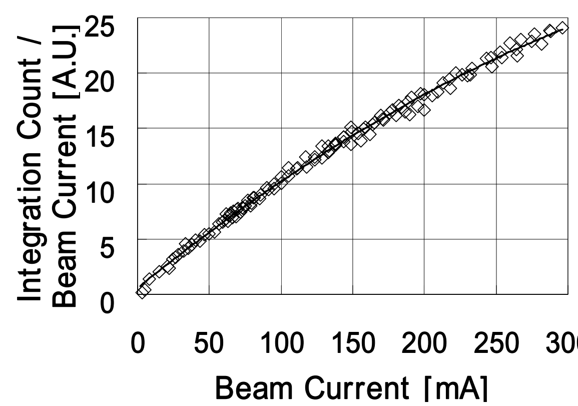

Figure 4: Yield of bremsstrahlung as a function of the beam current. Open diamonds are normalized integral counts of bremsstrahlung with the energy of 3-30 MeV. Solid curve is fitting result.

Dependence on the vertical beam size

We measured bremsstrahlung for various vertical beam sizes at low beam current. The beam size was controlled by RF-KO. Figure 5 shows counts of bremsstrahlung as a function of the vertical beam sizes.

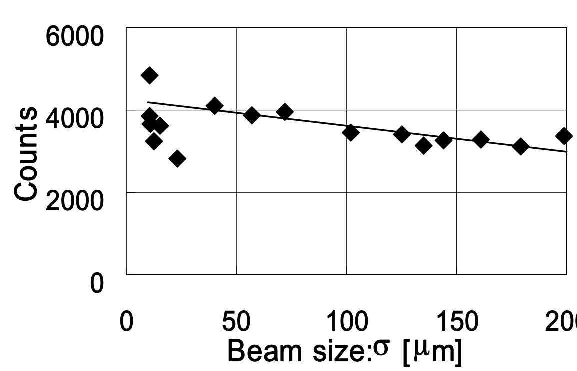

Figure 5: Yield of bremsstrahlung as a function of the vertical beam size. Beam current is about 60 mA. Solid line is linear approximation.

The vertical divergences of electron beam depend on the vertical beam size. This effect is negligible low in our measurements. The divergence for the biggest beam size (~200 μm) in our measurement is less than 1 mrad. The diameter of BGO scintillation detector is 50 mm. This detector was set at a length of about 3 m from light emitting point.

Counts of bremsstrahlung depend on the vertical beam sizes weakly according to figure 5. It is cause of this dependence that ions crowd on the electron beam orbit because of ion-trapping effect. The distribution of trapped ions and residual gas is broader than distribution of electrons in bunches, because the density of electrons in bunches is linear for the vertical beam size and horizontal beam size is constant. The dependence for vertical beam size is not simple. Significant dip is in beam size of 20 μm in fig. 5.

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