OBSERVATIONS OF BREMSSTRAHLUNG CAUSED BY ION TRAPPING

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ABSTRACT

Bremsstrahlung caused by trapped ions was observed in the stored electron beam of the Photon Factory. Variation of count rates was related with the variation of the beam lifetime.

INTRODUCTION

The accumulation of ions in electron and positron storage ring is well known phenomena and ion accumulation causes detrimental effect on the beam emittance in electron machine. Some theoretical analyses have been done and a proposal for clearing the trapped ions was presented[1,2,3]. It is difficult to measure and control directly the number of trapped ions in the stored beam. Changes of the emittance and instabilities have been observed as a result of the ion trapping. To analyze ion trapping, the direct observation is wanted and bremsstrahlung is a good candidate that is caused by neutral atoms and trapped ions. The density of the neutral atoms in the vacuum duct is easily measured so the effect of trapped ions can be estimated.

In the operation of the electron storage ring of the photon Factory in KEK, we have had some experiences on abnormal decays of beam lifetime in autumn and winter runs in 1983. Some of the deteriorations of the beam lifetime were guessed to be caused by ion trapping in the beam. The trapped ions were stayed in the beam space and some electrons with 2.5 GeV interact with the ions. The electrons interacted with the ions and neutral residual gas molecules are scattered and generate bremsstrahlung. It is interesting to observe the bremsstrahlung together with the beam lifetime, though the lifetime is related with not only the numbers of the trapped ions and residual gas molecules but other instabilities caused by RF etc.

This paper shows the first observations of the bremsstrahlung in relation to the electron beam lifetime. Though the experimental setup was not sufficient, the results obtained show directly the ion tapping in the stored electron beam.

EXPERIMENTAL SETUPS

Experimental arrangement was shown in Fig. 1, schematically. A detector for bremsstrahlung was a lead glass with a photomultiplier (HAMAMATSU R594). The length of the lead glass was 300 mm. It was covered by lead blocks to prevent from the residual radiations. An entrance for the bremsstrahlung was an opening slit on the lead blocks and the aperture was 2 mm in height and 50 mm in width. Imaginary source point was in the vacuum duct of the bending magnet B20 and was apart from the detector by 3530 mm. The bremsstrahlung generated by the interaction with the residual gas molecules and with the trapped ions passed through the blind flange of the exit port for the synchrotron radiation. The flange was made of stainless steel and had a radiation absorber made of copper tubes cooled by water. The output pulses of the photomultiplier were measured by a multichannel analyser (CANBERA 8100). In PHA mode, the energy of pulses was chosen to discriminate the lower energy and the only pulses was observed with the energy of 0.41 GeV to 2.5 GeV in MCS mode. The pulses were recorded on the magnetic tapes and stored. The results were compared with the record of the lifetimes of the stored beam, after the ring operations were stopped.

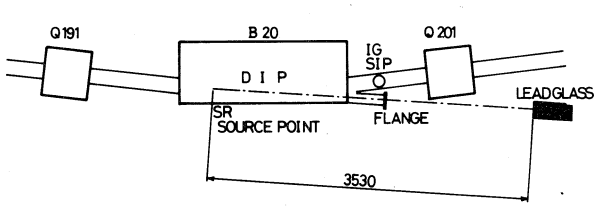

Fig. 1 Schematic drawing of the experiments. Vacuum duct set in the bending magnet B20 and the quadru pole magnets Q191 and Q201. Stored electrons run through them in counterclockwise direction. The distributed ion pump (DIP) was installed in the duct of the bending magnet section. Bremsstrahlung was measured by the lead glass covered by lead blocks which are omitted in the figure.

Pressure in the vacuum duct of the B20 was not measured directly and estimated by an ionization gauge (nude BA-type) installed in the pumping port which was just downstream of the B20. The components of the residual gas were measured by a quadru pole type residual gas analyser mounted on the side wall of the duct B20. The duct had a distributed ion pumps (DIP) in itself, so the local pressure in the duct could be reduced by working of the DIP.

RESULTS

Results on the counting rate I_B against the stored current is shown in Fig. 2. This result gives the following relation,

$$I_B(\text{cps}/10^{-10}\ \text{Torr}) = 2.5I_e + 0.004I_e^2$$

where I_e is stored current in mA. In figures 3a, 4a and 6a variations of the stored current are shown against time and are shown in figures 3b, 4b and 6b the variations of the counting rate in MCS mode of the multichannel analyzer. Time units in the abscissas in the figures are different. In Fig. 3a beam current and its lifetime suddenly decreased at 3:16. This accidental decrease corresponded to the abrupt increase of counting rates in Fig. 3b. The counting rates decreased gradually but kept higher value than the initial values. Similar results are shown in Fig. 4a and 4b where at 8:42 counting rate increased abruptly and kept higher values. These results were assumed to indicate that some gas molecules ionized and trapped in

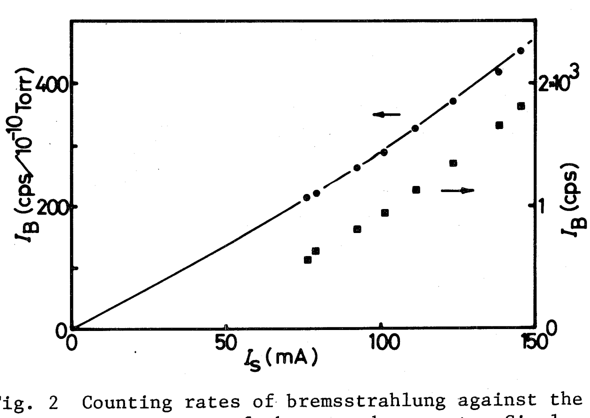

Fig. 2 Counting rates of bremsstrahlung against the beam current of the stored current. Circles indicate the counting rates and squares show the counting rates normalized by pressure.

the stored electron beam. The increment of target atoms in the beam caused short lifetimes and high counting rates of bremsstrahlung.

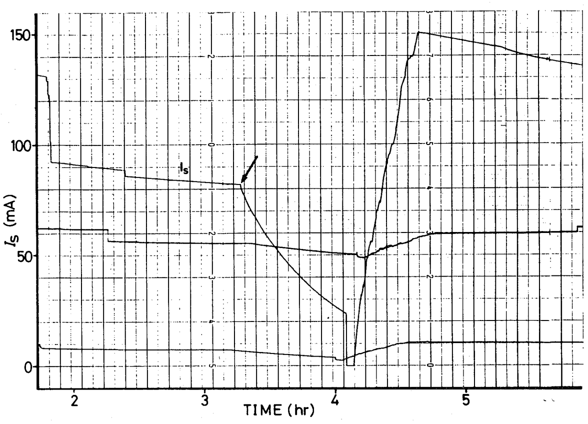

Fig. 3a Beam current I_s variation against the time. An abrupt decrease of the current is shown by an arrow.

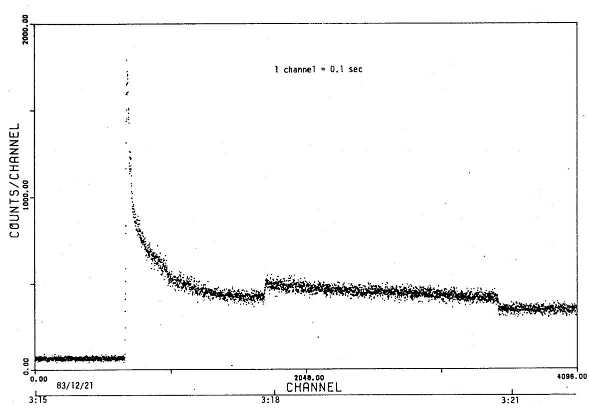

Fig. 3b Counting rates of the bremsstrahlung against the time in MCS mode of the MCA. The burst time corresponds to the time indicated by the arrow in the figure a. The rates after the burst were higher than those before the burst, though the stored current decreased.

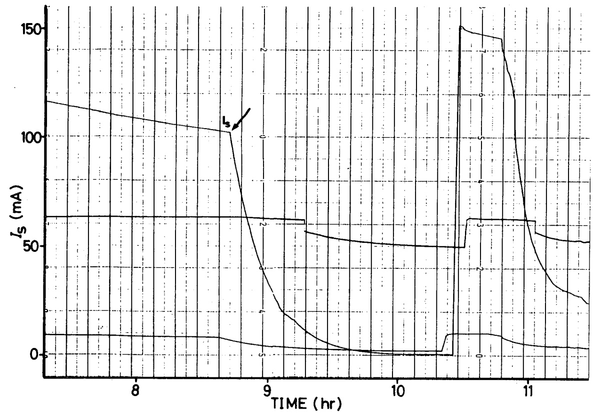

Fig. 4a Beam current I_s variation against the time. An abrupt decrease of the current is shown by an arrow.

In advance to these measurements, we used a plastic scintilator temporarily in place of the lead glass. Though higher energy bremsstrahlung could pass through the detector and the observed results were uncertain quantitatively, results were shown in Fig. 5.

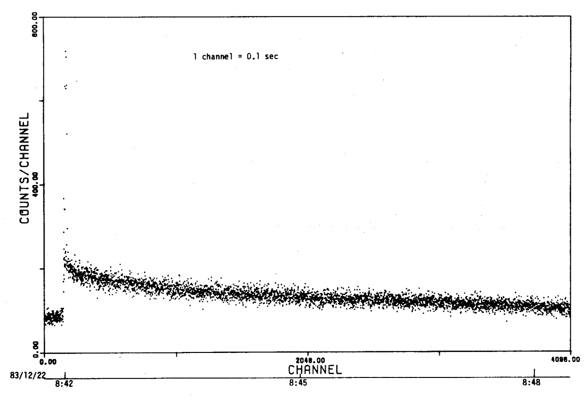

Fig. 4b Counting rates of the bremsstrahlung against the time in MCS mode of the MCA. The burst time corresponds to the time indicated by the arrow in the figure a. The rates after the burst was higher than those before the burst, though the stored current decreased.

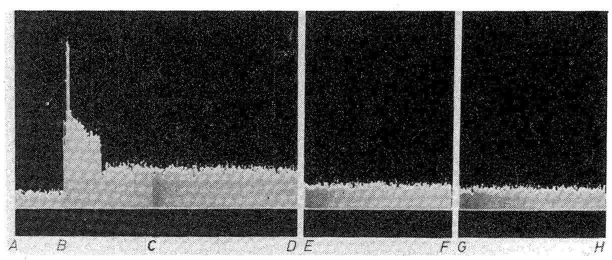

Fig. 5 CRT pictures of the MCA for the pulses from a plastic scintillator. The DIP was switched off in the section between A and B. The DIP was switched on only between B and C. The stored current was 32 mA at 17:27 at A. At D, time was 17:29. In each picture, scanning speed was same and 60 seconds per width of AC, CD, EF and GH. The time was 17:31 at E, and at G the time was 17:47 and the current was 26 mA.

At that time pressure in the ring was higher so many gas molecules could adsorb on the cathode surfaces of the DIP in B20 and on ignition of the DIP many molecules could be released from the surface. These molecules enhanced the bremsstrahlung and some of them trapped in the electron beam as ions, so the counting rates kept higher after the DIP was switched off. As the beam current decreased from 32 mA to 26 mA, pressure in the duct also decreased while the counting rate was kept still higher values compared with those before the ignition. This was the direct observation of ion trapping by using the measurements of bremsstrahlung.

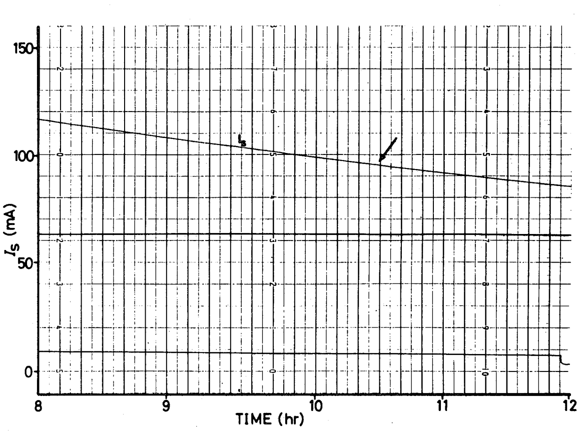

Fig. 6a Beam current I_s variation against the time. An arrow shows the time of ignition of the DIP.

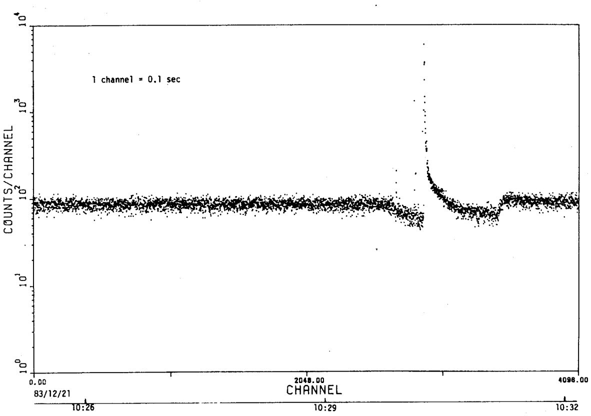

Fig. 6b Counting rates of the bremsstrahlung against the time in MCS mode of the MCA. The burst time corresponds to the time indicated by the arrow in the figure a.

In order to confirm this assumption, the DIP in B20 was switched on after long switched-off periods. The Fig. 6b shows the counting rate increased abruptly, because main discharge could release many adsorbed gas molecules from the cathode surface and instantaneously pressure rose up in the vacuum duct. As the pressure reduced by the DIP working, the counting rates were also decreased. After the DIP was switched off the pressure and counting rate recovered to the initial values so ion trapping did not occur. The stored current I_s, shown in Fig. 6a, was not affected by this DIP operation. Thus the results shown in Figs. 3 and 4

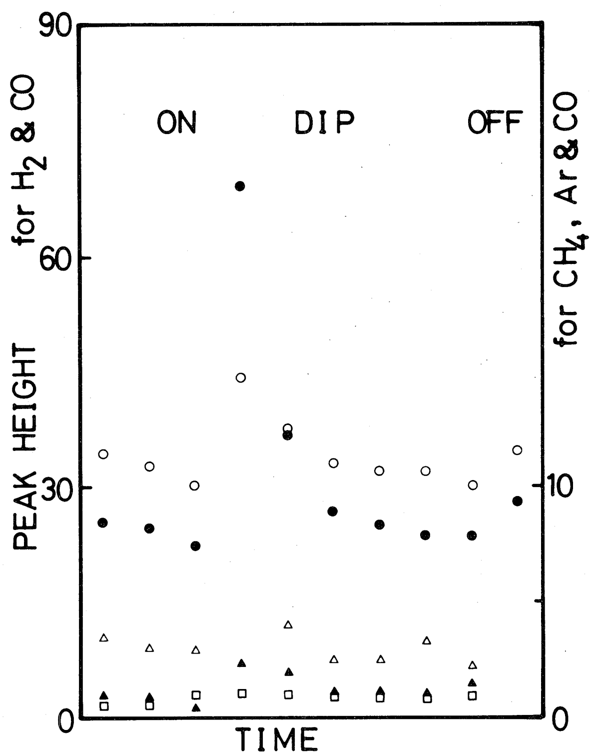

Fig. 7 Residual pressures variation in the DIP operation. Left ordinate shows peak heights of the mass spectrum for hydrogen and carbon monoxide, which are indicated by open circles and filled circles, respectively. Right ordinate shows peak heights for methane, argon and carbon dioxide, which are designated by open triangles, filled triangles and squares, respectively.

indicate that increment of bremsstrahlung was not related to residual gas molecules but to trapped ions. Components of the desorbed gas molecules are shown in Fig. 7 when the DIP was switched on/off, where the abscissa is time and the ordinate indicate peak heights of the mass spectrometer in arbitrary units. Hydrogen and carbon monoxide molecules were mainly desorbed and methane, carbon dioxide and argon were less desorbed. Carbon monoxide, filled circles, can be considered to be the main contributor to the increment of the counting rates of the bremsstrahlung.

DISCUSSIONS

Counting rates I_B of bremsstrahlung is estimated by the following equation

$$I_B(\mathrm{cps}/10^{-10}\ \mathrm{Torr/mA}) = N_o/(760\times22.4\times10^{3})(273/T) \times 10^{-10} \times (S(C)+S(O))rtN_e$$

where N_o is Avogadro number, r is the ratio of partial pressure of CO to total residual pressure, t is the circumference of beam orbit which the detector can see, T is absolute temperature, N_e is the number of electrons, and S(C) and S(O) are 8.1×10^{-25} and 1.4×10^{-24} of the cross sections for bremsstrahlung of carbon and oxygen atoms, respectively. This equations gives 3cps/10^{-10} Torr/mA and fairly good agreement with the experimental values.

When the beam lifetime becomes short, we have had some experiences that RF knock out is effective to restore the beam lifetime. It is already reported that RF knock out can remove the trapped ions from the electron beam. We have tried to restore the short beam lifetime by the RF knock out but the vacuum of the storage ring became better and abrupt deteriorations of the beam lifetime caused by ion trapping have become to occur scarcely. Moreover, the desorption from the DIP on the ignition after long switched-off period became less and not effective. Thus this trial by using the RF-KO has not been succeeded.

In further experiments, a scintillator will set before the lead glass and pulses from it will introduce into an anti-coincidence gate of the MCA. This setup will give more correct informations on the bremsstrahlung of 2.5 GeV separated from the pulses caused by lossed electrons.

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