Measurement of the Internal Beam Position and Profile at the INS 1.3 GeV Electron Synchrotron

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ABSTRACT

The internal beam position and profile of the 1.3 GeV electron synchrotron at Institute for Nuclear Study, University of Tokyo have been measured by observing the synchrotron radiation with a CCD camera. The adiabatic damping agrees with the calculation while the radiation anti-damping is measured to be larger than the calculation. The beam position is unexpectedly found to be outside of the nominal central orbit by 12 mm.

1. INTRODUCTION

It is not easy to observe the internal beam in the rapid-cycle electron synchrotron if one would use electrostatic probes or ionization detectors as measuring tools, since either the electronic noise or the synchrotron radiation may disturb the measurements. At INS 1.3-GeV electron synchrotron which is operated with 21 Hz resonance current, we had no position nor profile monitors for practical use up to recently. Now the TV camera employing charge-coupled device (CCD), which can be gated and can hold digitized image signal, is popular, and we have introduced it for the observation of the synchrotron radiation to measure the internal beam position and profile. In the INS synchrotron, the injected beam is accelerated up to a end-point energy during 20 msec, and it is expected that the transverse damping and anti-damping behavior of the beam along the acceleration can be clarified with a time resolution of the CCD camera, typically 1 msec. In the following, the principle of the measurement, the outline of the measuring system and some of the results are presented.

2. PRINCIPLE OF THE MEASUREMENT

The synchrotron radiation power from a definite point of the bending section is concentrated in a narrow angular range approximated by $1/\gamma$ radian. It is, for example, 0.43 mrad for 1,200 MeV electron. On the other hand, the CCD is most sensitive for the radiation with the wavelength around 800 nm which shows much larger angular spread, nearly 7 mrad. Overall output from the CCD, however, is dominated by the power spectrum of the synchrotron radiation. Thus the following consideration will be valid.

The synchrotron radiation from the various point along the beam in the bending section sweeps over the angular acceptance of the measuring system θ, as shown in Fig. 1. For this situation, the spatial resolution in the measurement of horizontal beam position Δx is given as

$$\Delta x = R\theta^2 / 8$$

where R is the bending radius of the electron beam. For the actual acceptance of the measuring system, the Δx may be sufficiently small. The diffraction of the radiation is also not significant, and the overall resolution will be dominated by the size of the CCD element.

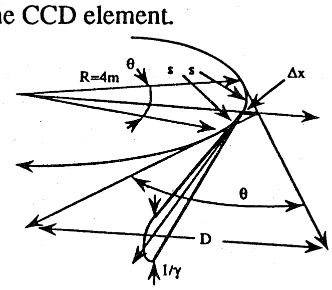


Fig. 1 Measurement of the horizontal beam position by the synchrotron radiation.

3. MEASURING SYSTEM

Measuring setup is shown in Fig.2. In the vacuum chamber at a straight section, a mirror is installed outside of the central orbit to reflect the synchrotron radiation towards the inside of the ring. The mirror is a chromium-plated OFHC and is 90 mm and 15 mm wide in horizontal and vertical directions, respectively.

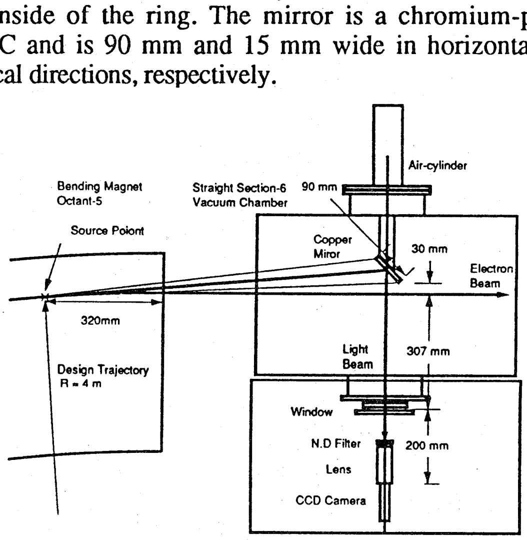


Fig. 2 Setup for observing the synchrotron radiation.

The edge of the mirror is 27 mm from the central orbit. This arrangement views the synchrotron radiation from the point upstream by 320 mm from the bending magnet edge. Since the total radiation power accepted by the mirror is only a few watts at maximum, no special cooling system is installed. The mirror has a shutter to protect the surface from depositing of carbon under the effect of the synchrotron radiation. The CCD camera is situated at 1491 mm from the source point and has a lens opening of 3 mm, for which Δx

is only about 0.01 mm. Instead the position resolution is determined by the size of the CCD element to be 0.14 mm and 0.28 mm in horizontal and vertical planes, respectively. Camera setting can be corrected by viewing a calibration mark through additional mirror.

The camera is triggered by the timing pulse of the synchrotron through a delay circuit and, by varying the delay time, we can observe the beam at any acceleration phase. The minimum gate time of the camera is 1 ms, which is sufficient to follow the beam acceleration process in about 20 ms for the INS synchrotron. The read-outs of the CCD are, through a 8-bits digitizer, stored in a computer.

4. RESULTS AND DISCUSSION

The INS synchrotron is excited by the DC-biased AC of 21 Hz, as shown in Fig.3. The DC is close to the peak value of AC. Since the injection beam energy is so low as 15 MeV, the acceleration takes place in nearly half the period of AC, about 20 ms.

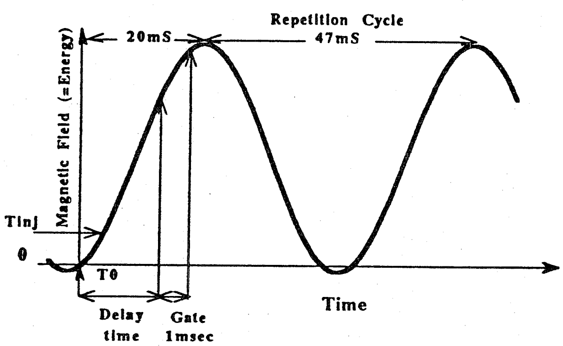
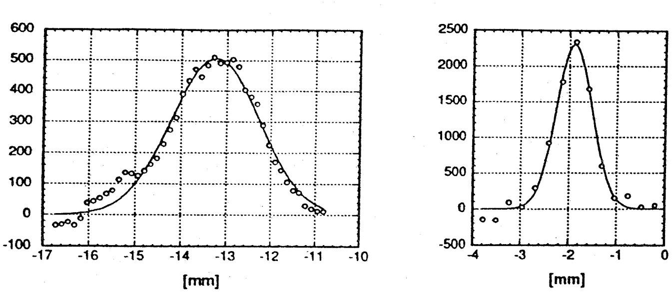


Fig. 3 Acceleration scheme of the INS electron synchrotron.

The CCD camera has a sensitivity for the synchrotron radiation from the electron beam with energies over 100 MeV, which corresponds to the acceleration phase range after 4 msec from the zero field point shown in Fig.3. Hence we



(a) (b)

Fig. 4 An example of the beam profile as scanned in horizontal(a) and vertical(b) direction.

cannot, by present method, observe the internal beam behavior for about 4 ms after the injection.

An example of the horizontal and vertical scan of the measured beam profile are shown in Fig. 4. They are the result after back ground subtraction and are well fitted by Gaussian function as shown in the figure,

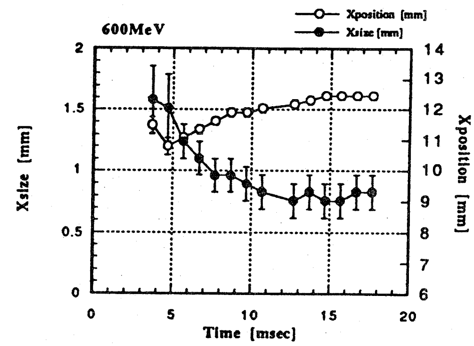


Fig. 5 (a)

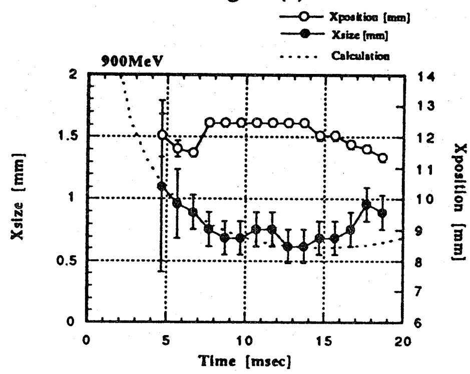


Fig. 5 (b)

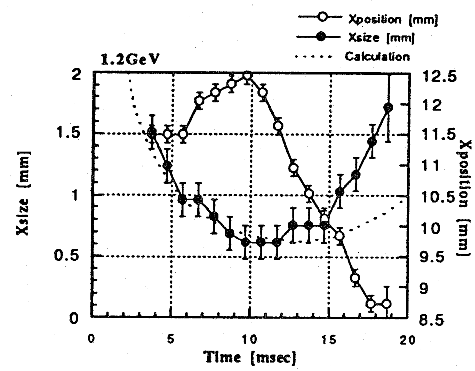


Fig. 5 (c)

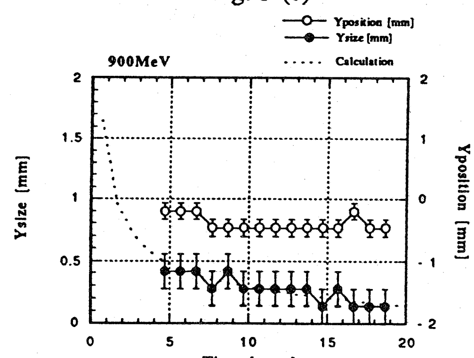


Fig. 5 (d)

Fig.5(a)~(d) The beam position and size in the horizontal plane for the electron energies of 600, 900 and 1,200 MeV (a~c), and those in the vertical plane for the electron energy of 900 MeV (d).

and we have defined its peak to be the beam position and its standard deviation to be the beam size. Measured results of the beam position and size, defined above, in horizontal plane for the synchrotron energies of 600, 900 and 1,200 MeV are shown in Figs.5(a)~(c). Those in the vertical plane for the synchrotron energy of 900 MeV are shown in Fig.3(d). Since the INS synchrotron is of strong focusing type, the beam size is expected to decrease after the injection by adiabatic damping and increase somewhat in horizontal direction by radiation anti-damping effect around the end-point energy. The measurements clearly show these features. Dotted curves in the figures are the calculated results. They are, in general, consistent with each other, but radiation anti-damping effect measures stronger than the calculation for high electron energies. Further examination in both of the measurement and the calculation is underway.

The beam position measurement gives the result much different from the expectation. In all the measurements, including the one after recalibration of the measuring system, the beam position is observed to be about 12 mm outside of the nominal central orbit for prescribed rf frequency. This beam position and the rf frequency are supposed to be determined based on the requirement from the synchrotron radiation users long time ago, and have been kept unchanged. The relation between the beam position and the rf frequency as measured in present work is shown in Fig 6. According to it, the rf frequency should be 138.242 MHz, which is 0.24 MHz higher than the present value, to bring the beam to a correct position. We are discussing on the effects of changing the rf frequency and the beam position from present setting.

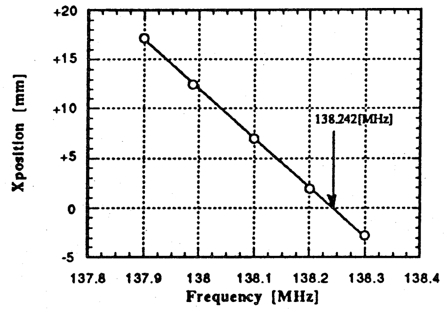


Fig. 6 The relation between the beam position and the rf frequency.

We will use this beam-position and -profile monitor to study also the beam spill characteristics around the end-point energy in near future.

5. REFERENCES

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