Measurement of Beam Energy Loss in the SPring-8 Synchrotron

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Abstract

In order to observe closed orbit distortion (COD) at some beam energies, an energy-constant period was formed with a time of 100 ms in the region of the energy-ramping period. Using the horizontal COD, energy loss per turn as to beam energy was observed. The observed energy loss was consistent with the estimated energy loss of the synchrotron radiation.

1. Introduction

The SPring-8 synchrotron accepts an electron beam with an energy of 1 GeV from the SPring-8 linac. The beam is accelerated up to 8 GeV and then ejected to stack into the SPring-8 storage ring [1]. The synchrotron consists of a FODO lattice of 40 cells and its circumference is 396.124 m. There are 64 bending, 80 quadrupole, 60 sextupole, and 80 correction magnets.

In the synchrotron, the beam energy is changed with some acceleration patterns. In normal operation, the beam energy is kept constant in the injection with a period of about 250 ms (flat-bottom). Then, it is increased linearly in the energy-ramping at about 350 ms and is kept constant in the ejection at about 130 ms (flat-top). The magnets are excited with a cycle pattern (Fig. 1).

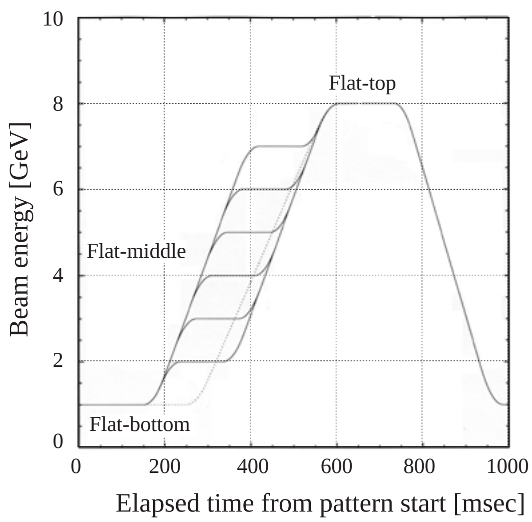

Fig. 1. Flat-middle pattern (solid line) and normal-pattern (dotted line) are shown together. Using the flat-middle pattern, energy-constant regions with a time of 100 ms at different energies were prepared.

This acceleration pattern is called the normal-pattern in this paper. Eight five-cell rf cavities of 508.58 MHz were installed in the straight section of injection side. The effective rf voltage can be changed by controlling phases of two klystrons outputs. Each klystron drives four rf cavities.

To observe the beam orbit at the beam energy during accelerating, an energy-constant region is formed (flat-middle pattern).

2. Measurement

Using 80 beam position monitors (BPMs) [2], the horizontal and vertical CODs were measured at the flat-bottom, flat-top and flat-middle periods. The period of the flat-middle was set to 100 ms. This is because the total measuring time of the BPMs was about 30 ms and it takes about 40 ms to settle the betatron tunes. The energy of the flat-middle period was set from 2 to 7 GeV by 1 GeV. The bending, quadrupole and sextupole magnets were excited with the normal-pattern or flat-middle pattern. The phase control pattern of the klystrons was changed by the difference of beam energy. All the correction magnets were turned off to measure the CODs without correction.

3. Result and Discussion

The Horizontal and the vertical CODs at different beam energies are shown without correction in Fig. 2. The vertical CODs agreed with each other at all beam energies with an error of 80 μm. On the other hand, the horizontal COD changed with the beam energy.

The beam energy due to the synchrotron radiation per turn U is expressed by

$$U[keV]=\frac{4\pi r_c E^4}{3(mc^2)^3\rho}=88.5\frac{E^4[GeV]}{\rho[\mathrm{m}]}, \qquad (1)$$

where mc^2 is the rest mass of an electron, r_c is classical radius of an electron, ρ is the bending radius, and E is the beam energy [3]. In the measured COD at several energies below 3 GeV, the COD is not uniquely since the elapsed time from beam injection is not much longer than the energy and the betatron damping time. To estimate the energy loss, the change in the horizontal position from the value at 3 GeV is calculated at several beam energies of more than 3 GeV. About the position data at two kinds of dispersion function of 0.98 m (32 points) and 0.48 m (30 points), the energy loss per turn at these energies were obtained by least-squares-fitting (Fig.3 and 4). The energy loss at different beam energies is shown in Fig. 5. Experimental result on the energy loss by the synchrotron radiation was consistent with the theoretical value with an error ratio of 8.4 % to the measured value.

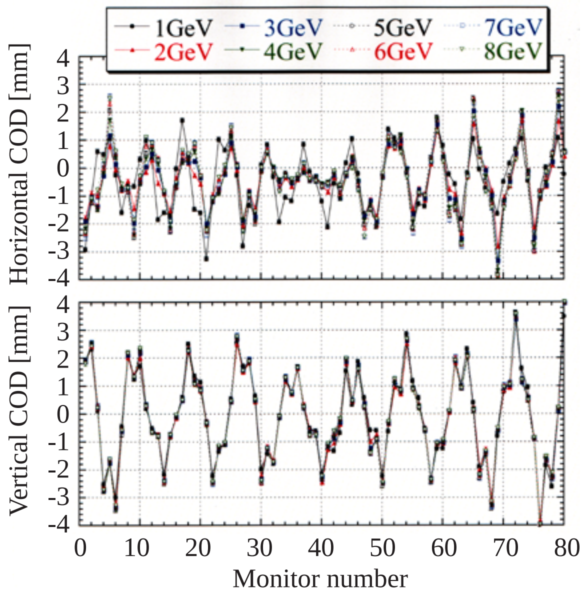

Fig. 2. CODs without correction at different energies are shown together. Error bars indicate the standard eviations of the data on the same condition.

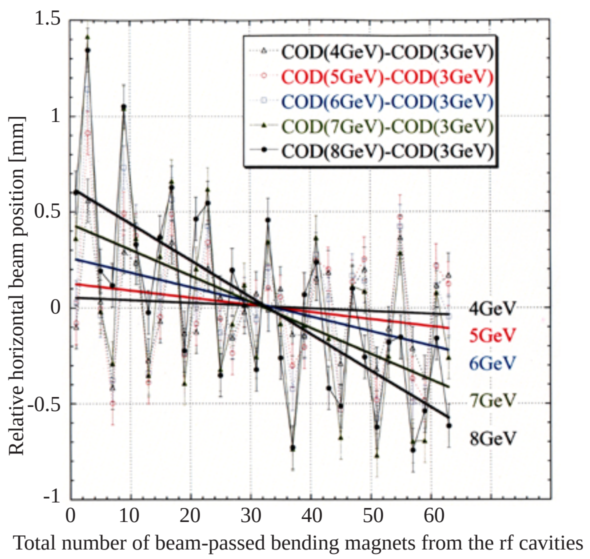

Fig. 3. Horizontal position data at same dispersion function (η = 0.98 m) are shown. Solid lines indicate result of least-squares fit.

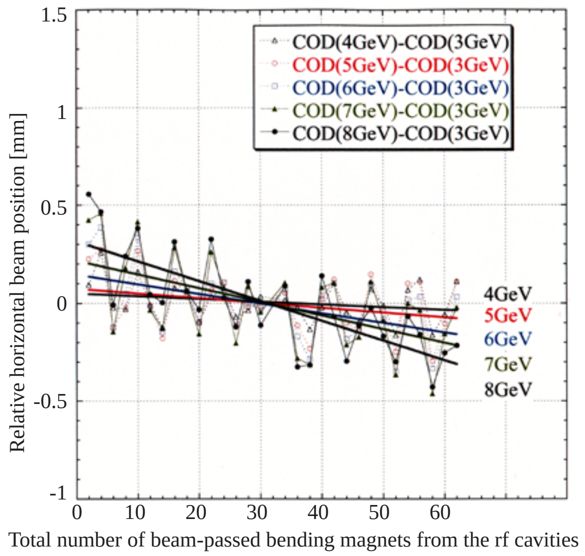

Fig. 4. Horizontal position data at same dispersion function (η = 0.48 m) are shown. Solid lines indicate result of least-squares fit.

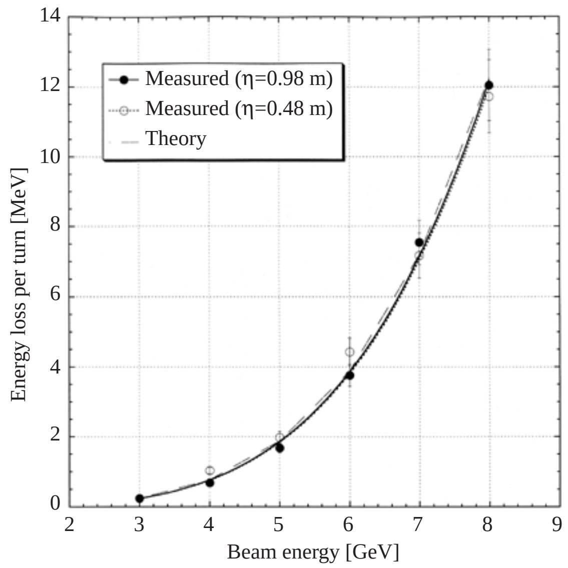

Fig. 5. Measured energy loss per turn at several different beam energies are shown. Error bars indicate the standard deviation of the measured dispersion functions. The ratio of the error to measured value was 8.4 %. Solid lines indicate result of least-squares fit.

4. Conclusion

Using the flat-middle pattern, the beam energy loss per turn was observed at an beam energy during accelerating. Observed energy loss was consistent with the estimated energy loss of the synchrotron radiation.

References

[1] H. Suzuki *et al.*, Rev. Sci. Instrum., **66** (1995) 1964.

[2] T. Aoki *et al.*, Proc. of SRI' 95, Rev. Sci. Instrum. **67** (1996) 3367.

[3] M. Sands, "Physics with Intersecting Storage Rings", B. Touschek (ed.), Academic Press, New York 1971.