Measurement of Horizontal Beam Size of a Stored Beam

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1. Introduction

In electron/positron storage rings the horizontal emittance is one of the fundamental parameters. Its value can be estimated by measuring the horizontal beam size and combining information on optics parameters such as the betatron function and the dispersion function. In this report we present a unique method of measuring the horizontal beam size in which fast kicker magnets for beam injection are used.

2. Measurement of Horizontal Beam Size

In the SPring-8 storage ring there are four kicker magnets for beam injection to make a pulsed-bump orbit in the horizontal direction [1]. Their power supplies generate half-sine wave pulses of 8 μs width. Since the revolution period of a circulating beam is 4.8 μs, this pulsed-bump orbit is mostly dumped after one revolution. The reproducibility of a peak current of each magnet is good, being about 0.2%, and we can measure the horizontal beam size by using these kicker magnets in the following way.

We first store the beam in a single RF-bucket. The stored current of about 1 mA will be enough for the following measurements. Too large beam currents will cause beam instability and too small currents will not be adequate from a viewpoint of signal-to-noise ratio of DCCT. We then generate a pulsed-bump orbit to shift the stored beam toward a septum wall in the injection section. The "tail" of the beam is scraped by the septum wall only once and the beam loss rate is measured. This measurement is repeated by changing the pulsed-bump height and we obtain a set of data points: we obtain the beam loss rate R as a function of the pulsed-bump height x.

By assuming a gaussian density distribution for a circulating beam, we can write the beam loss rate R as

$$R=F\left(\frac{x-x_0}{\sigma}\right)$$

where

$$F(z)=\frac{1}{\sqrt{2\pi}}\int_{-\infty}^{z}e^{-t^2/2}dt=\frac{1}{2}\left(1+erf\left(\frac{z}{\sqrt{2}}\right)\right)$$

and σ is the RMS beam size in the horizontal direction. We then fit the data points with the method of least squares to obtain x_0 and σ.

In Fig. 1 we show the example data. The fitted result is also shown by the solid curve. We see that the gaussian profile fits very well to the measured points. In this case the values of x_0 and σ were evaluated as

x_0 = 16.115 mm ± 0.016mm (random)

σ = 0.393 mm ± 0.012 mm (random).

In estimating errors of x_0 and σ we took account of random errors of DCCT (±5 μA) and a kicker magnet (±0.2%, each) and systematic errors of x are not included.

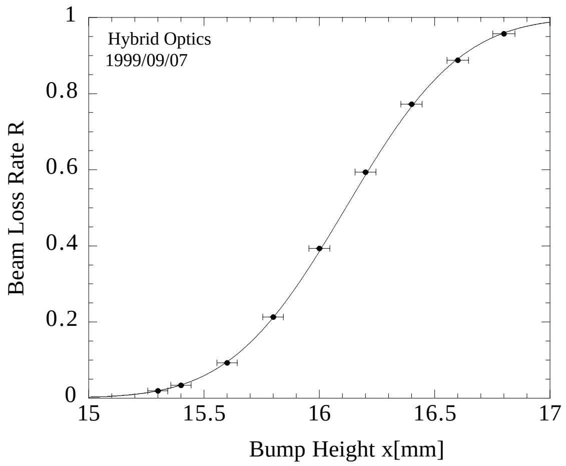

Fig. 1. The beam loss rate R as a function of the pulsed-bump height x. Data points were fitted by assuming the gaussian density distribution (solid curve).

3. Discussion

The systematic errors of x will come in through calibration procedures of kicker magnets or distortion of the betatron function (*i.e.* a model of the ring) to calculate kick angles for a desired pulsed-bump orbit. In general, it is not easy to calibrate the scale of x precisely and remove such systematic errors. To estimate the magnitude of these errors, we did the following.

We stored the beam in a single RF-bucket and made a local DC-bump by using four steering magnets in the injection section in a usual way. A pulsed-bump by fast kicker magnets was then added to this DC-bump and the beam loss rate was measured. The height of the DC-bump was obtained by measuring the closed orbit with BPMs. This measurement was repeated by changing the DC-bump height from 0 mm to 1.85 mm, while the pulsed-bump height was fixed to 14.6 mm. We then obtained the beam loss rate as a function of the DC-bump height. By plotting this data as in Fig. 1 and comparing the results, we can estimate the order of a systematic error of x. The systematic error of x thus estimated was 5-6%.

This method of using the DC-bump, however, has some disadvantages when compared to using only fast kicker magnets. For example, the DC-bump was made across some sextupole and bending magnets. Then, the beam size will be affected by nonlinear fields due to the sextupole magnets and the fringe field of the bending magnets. In addition to this, the accuracy of the BPMs which measure the DC-bump height will become worse as the beam passes farther positions from the center. For these reasons we used this method only to estimate the order of a systematic error of x.

The horizontal beam size measurements by using fast kicker magnets were carried out several times on different dates with the same optics (the so-called "hybrid" optics [2]). All of the results are shown in Fig. 2 by different marks. The best-fitted value of σ for each data set is plotted in Fig. 3. By averaging these values we have

σ = 0.389 mm ± 0.005 mm (random).

The solid curve in Fig. 2 was obtained by using all data points and performing the least-square fitting. The value of σ for this curve is the same as the above.

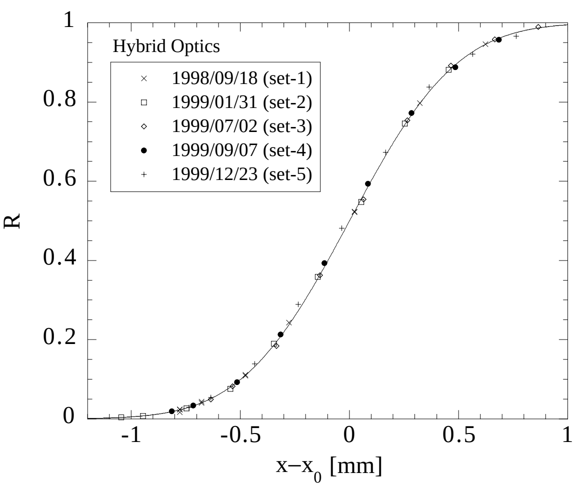

Fig. 2. Comparison of data sets taken at different time. The solid curve was obtained by fitting to all data points.

To convert the horizontal beam size σ to the emittance ε, we must know the horizontal betatron function β_x at the point of beam size measurements.

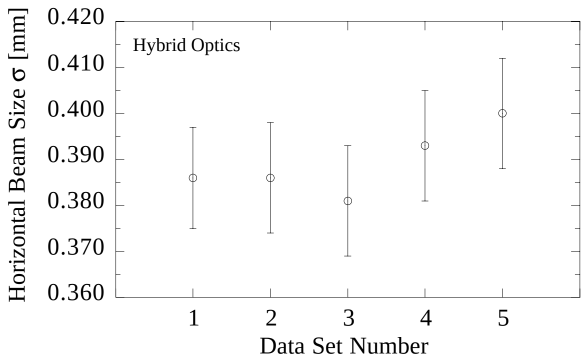

Fig. 3. Fitted values of the horizontal beam size obtained by using five different data sets shown in Fig. 2. Systematic errors are not taken into account.

Since the injection section is dispersion-free, we have $\varepsilon = \sigma^2 / \beta_x$. The design value of β_x is 22.0 m and if we use this, we have

ε = 6.9 nmrad ± 0.2 nmrad (random).

The design value of ε is (unexpectedly) the same as this estimated value of 6.9 nmrad. In this estimation of ε, however, we have not included any systematic errors, which will be of the order of 10%.

The horizontal beam size was also measured in another optics, the so-called "HHLV" optics [2]. The result is shown in Fig. 4. In this case the values of x_0 and σ were obtained as

x_0 = 16.175 mm ± 0.016 mm (random)

σ = 0.383 mm ± 0.012 mm (random).

In Table 1 we summarize the results for the two optics. We see that the agreement between design and measured values of ε is very good for both optics.

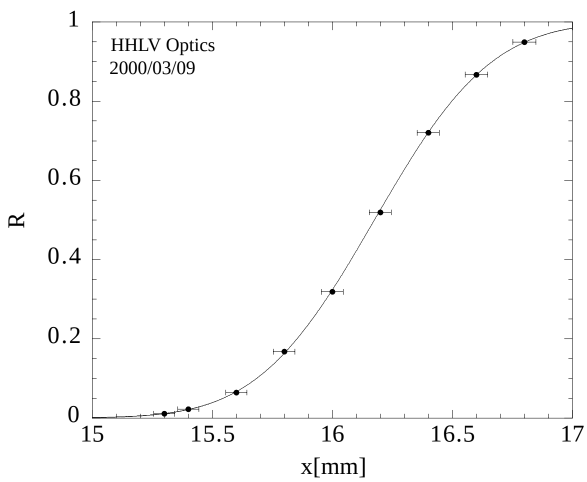

Fig. 4. Same as Fig. 1 but for the "HHLV" optics.

Table 1. Horizontal beam size and emittance. Systematic errors are not taken into account.

	Hybrid Optics	HHLV Optics
σ(meas.)[mm]	389±5	383±12
β_x (design)[m]	22.0	24.6
ε(meas.)[nmrad]	6.9±0.2	6.0±0.4
ε(design)[nmrad]	6.9	6.3

The method presented here can be extended to a more precise one if a beam scraper is equipped instead of the septum wall and combined with fast kicker magnets: by changing the scraper position very precisely, the beam loss rate can be measured with a fixed height of the pulsed-bump orbit. In this case the systematic errors of x will be removed.

References

[1] K. Kumagai and S. Matsui, SPring-8 Annual Report 1995 (1995) 113.

[2] H. Ohkuma *et al.*, Proceedings of the 7th European Particle Accelerator Conference, Vienna (2000), to be published.