BEAM TUNING FOR LOW EMITTANCE IN KEK-ATF DAMPING RING

K.Kubo, H.Hayano, S.Kamada, M.Kuriki, S.Kuroda, T.Naito, T.Okugi, N.Terunuma, N.Toge, J.Urakawa, KEK, Tsukuba, Japan
M.Takano, Toho University, Takyo, Japan

Abstract

KEK-ATF is a test facility for future linear colliders producing extremely low emittance beams. The target of the vertical emittance in the damping ring is about 1.5E-11 rad-m, 1% of the designed horizontal emittance. In an electron circular accelerator, the dominant sources of the vertical emittance are the vertical dispersion in arc sections and the x-y orbit coupling, caused by some errors. Previously, it has been reported that a small vertical emittance can be achieved by local orbit bump tuning with a good beam size monitor and a good BPM system [1][2]. We have recently developed a method to correct the vertical dispersion and the coupling by using only the BPM system. Simulations assuming a realistic misalignment, performances of monitors and correctors of the ATF damping ring predict that this method will be effective. Recent beam test showed that the vertical dispersion and the x-y orbit coupling can be made sufficiently small after the corrections.

1 MEASURES OF BEAM QUALITY

The dominant sources of the vertical emittance are the vertical dispersion in arc sections and the x-y orbit coupling. We introduce here two quantities which characterize these sources of the vertical emittance. R.m.s. of the vertical dispersion in the arc sections, η_{arc} and the x-y orbit coupling, $\mathrm{C}xy$.

$$\eta_{arc} \equiv \sqrt{\left\langle \eta_{y,BPM}^2 \right\rangle_{arc}}, \qquad (1)$$

where $\eta_{y,BPM}$ is the vertical dispersion at BPM. and $\langle\ \rangle$ means the average over arc sections.

$\mathrm{C}xy$, is defined as

$$\mathrm{C}xy \equiv \sqrt{\sum_{H-steers}\left(\sum_{BPM}\Delta y^2 \Big/ \sum_{BPM}\Delta x^2\right)\Big/ Nsteer} \qquad (2)$$

this is obtained by measuring the closed orbit distortion while changing several horizontal steering magnets, one at a time. Here, Δx and Δy are beam position change at each BPM in response to each horizontal steering magnet. $Nsteer$ is the number of changed horizontal steerings. An average over several steering magnets is taken.

2 SIMULATION

2.1 Vertical Dispersion vs. Emittance

First, correlation of η_{arc}^2 and the vertical emittance was simulated. Fig.1 (a) and (b) show the correlation in two different conditions where the case (a) simulated a tight orbit correction for a realistic alignment. The case (b) simulated a loose orbit correction for a good alignment.

In the case (a), misalignment of magnets are set as actually measured and additional gaussian random misalignment with sigma=20 μm are set to consider errors in the alignment measurement. COD correction using steering magnets is assumed which minimize

$$\sum_{BPM}\left(x_{meas}^2 + y_{meas}^2\right) \qquad (3)$$

where x_{meas} and y_{meas} are measured horizontal and vertical closed orbit, respectively.

In the case (b), misalignment of magnets are set simply according to a random gaussian distribution with r.m.s. 20 μm. The COD correction in this case was applied to achieve

$$|x_{meas}| < 2 \text{ mm} \quad \text{and} \quad |y_{meas}| < 1 \text{ mm}. \qquad (4)$$

Simulation was done with the computer code SAD [3]. Results from 500 random seeds are shown for both cases. No intra-beam scattering was taken into account in the emittance calculation.

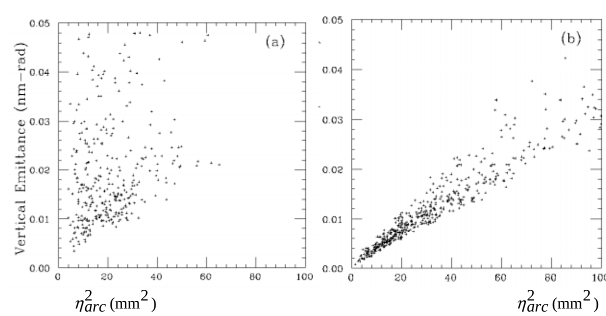

Fig. 1, Simulated η_{arc}^2 (mm^2) vs. vertical emittance (nm-rad) after COD correction in, two different conditions.

In the case (b), η_{arc}^2 and the emittance have a strong correlation. In this case, if the dispersion is made small, the emittance is expected to be also small. On the other hand in the case (a), which is considered more realistic, though the tight COD correction makes dispersion small, reduced dispersion does not necessarily mean small emittance.

2.2 x-y coupling vs. Emittance

Correlation of Cxy and the vertical emittance are shown in Fig.2 (a) and (b) for the same two cases in the previous section. In the case (a), if Cxy is made small, the emittance is predicted to be also small. In the case (b), small Cxy does not necessarily mean small emittance.

These results suggest that to make the vertical emittance small, we should make both η_{arc} and Cxy small.

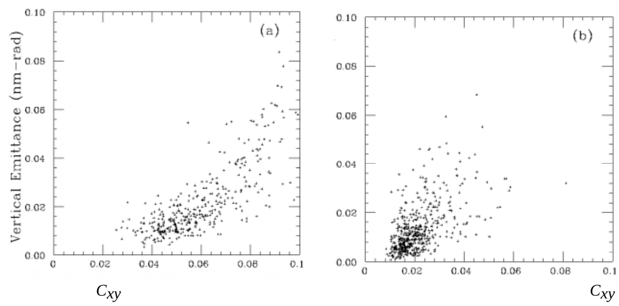

Fig. 2, Simulated Cxy (x-y orbit coupling) vs. vertical emittance after COD correction in, two different conditions.

2.3 Simulation of coupling correction

For the purpose of coupling corrections, the trim windings on all 68 sextupole magnets in the arc sections of the ATF damping ring have been arranged to produce skew quadrupole fields. The x-y orbit coupling parameter Cxy will be affected by introducing these skew quadrupole fields as :

$$C_{xy}^{/} = \sqrt{\sum_{Hsteers} \left(\sum_{BPM} (\Delta y - \delta y)^2 \Big/ \sum_{BPM} (\Delta x)^2 \right) \Big/ Nsteer} \quad (5)$$

Here the δy is the expected changes of Δy due to the skew quadrupole fields. The coupling correction can be achieved by minimizing $C_{xy}^{/}$ by using a suitable combination of skew quadrupole fields.

We have studied the effects of such corrections on vertical emittance in simulation. Two horizontal steering magnets which are apart by $3/2\pi$ in horizontal and $1/2\pi$ in vertical phase advance were used to evaluate the quantity Cxy. There are two families of the sextupole magnets, each with 34 units. All magnets in each family are used to make coupling corrections. During the simulation, the magnet misalignment was set according to the actual measurement. Before applying coupling corrections, a COD correction was done, where each BPM was assumed to have a random misalignment of r.m.s. 300 μm relative to the field axis of the nearest magnet.

Results of the simulations are shown in Fig.3 from 50 random seeds, the distribution of the vertical emittance and the distribution of the orbit coupling, Cxy, before and after the coupling correction .

These simulations show that the coupling correction will be effective in reducing the vertical emittance. The average vertical emittance after COD correction is 2.3E-11 m-rad and 1.0E-11 m-rad after the coupling correction. The average x-y orbit coupling is 0.062 and 0.035, respectively. Though the coupling correction will affect the dispersion in principle, it was found that the COD/dispersion and the x-y coupling can be corrected independently.

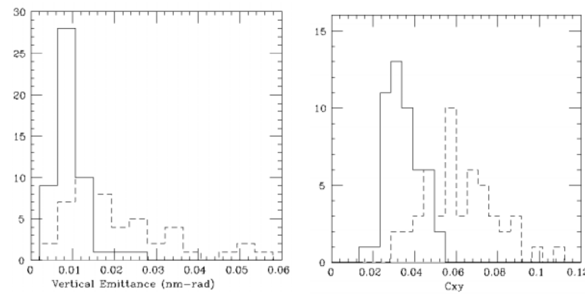

Fig. 3, Distribution of the vertical emittance (nm-rad) (left) and orbit coupling, Cxy (right), before (dashed line) and after (solid line) coupling correction.

2.4 Effect of BPM errors

So far, only the transverse offsets were considered as BPM errors. The offset error will not affect the dispersion measurement and the orbit coupling measurement because they are based on differences of the orbit. In usual dispersion measurement, orbits are measured with momentum offsets of about 1.0%. The changes of the horizontal orbit at BPM in the arc sections is typically 1 mm, where the dispersion is about 100 mm. Since the vertical dispersion should be within roughly ±5 mm for small emittance (see Fig. 1(a)), the vertical orbit change should be measured with an accuracy of 50 μm or better. In orbit coupling measurements, the horizontal orbit is also changed typically by about 1 mm and accuracy for measuring the vertical position difference should be better than 50 μm, because Cxy should be less than 0.05 (see Fig. 2(a)).

Resolution of our BPM system is well within this required accuracy. However, any imperfection of the calibration of the total BPM system will cause systematic errors of the vertical position difference, when the horizontal position difference is large.

This error was simulated as a random rotation around the beam axis of each BPM.

Simulation showed that the BPM rotation will affect the vertical dispersion correction in which steerings are set as

$$\text{minimize} \sum_{BPM} \eta_y^2 . \quad (6)$$

where η_y is the apparent vertical dispersion at BPMs. It was found that it is better to make both apparent offset and dispersion small, or to set steerings as

$$\text{minimize} \quad \sum_{BPM} y^2 + a^2 \sum_{BPM} \eta_y^2 \qquad (7)$$

where y is the apparent vertical beam offset at BPMs, a the constant factor which should be chosen as

$$a \approx m_y / (\eta_x \times r) \qquad (8)$$

where m_y and r are typical vertical misalignment and rotation error (in radian) of BPMs and η_x, typical horizontal dispersion. Simulations of this COD/dispersion correction showed that r.m.s. of the rotation error up to about 0.03 radian is acceptable.

On the other hand, from simulations assuming large random BPM rotation error with r.m.s of 0.1, it was found that the orbit coupling correction will not be significantly affected by the BPM rotation error. The real orbit coupling should have special patterns defined by the optics and the random rotation error will hardly produce such patterns. The random error will be smeared out and will not affect the correction though apparent Cxy will be increased.

3 EXPERIMENT

In usual beam operation of the ATF damping ring, COD and vertical dispersion corrections are done first, then orbit coupling correction is tried.

Fig. 4 shows typical measured vertical dispersion as a function of s(m) after COD/dispersion correction. The factor a in the Eq. 7 was chosen to be 0.1. η_{arc} was 2.6 mm.

Fig. 5 shows the response of vertical beam position (μm) to two horizontal steering magnets as functions of BPM number before and after the coupling correction. The two steering magnets were chosen whose betatron phase distance was about $3/2\pi$ in horizontal and $1/2\pi$ in vertical. The horizontal orbit was changed by about 1 mm with each magnet. The settings of the steering magnets were the same in the both cases. Cxy was 0.056 before the coupling correction and 0.041 after the correction.

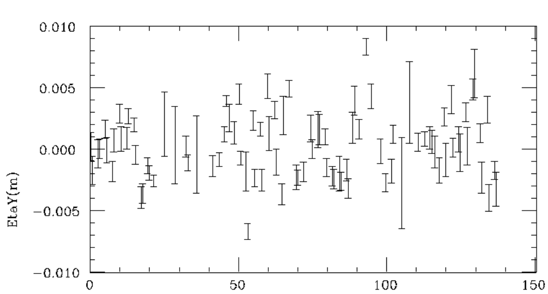

Fig. 4, Typical vertical dispersion as a function of s(m) after COD/dispersion correction.

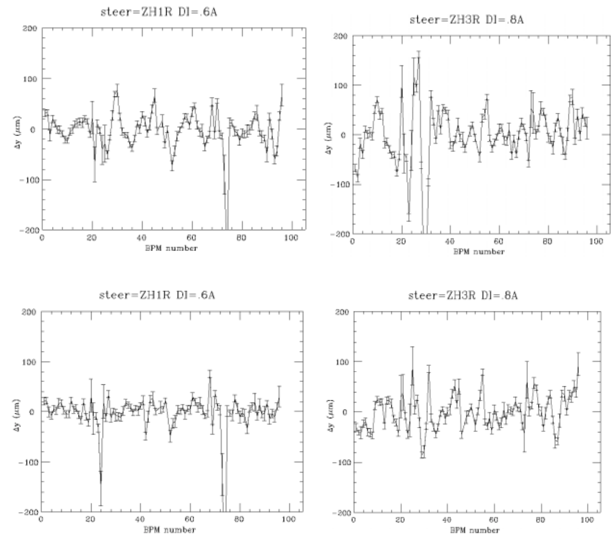

Fig. 5, Response of vertical beam position (μm) to two horizontal steerings as functions of BPM number before (top) and after (bottom) coupling correction.

The simulations shown in Figs 1 and 2 predict the vertical emittance about 0.01 nm-rad or less with the obtained η_{arc} and Cxy. However, the measured emittance was still typically about 2~3 % of the horizontal emittance, 2~3 times bigger than our prediction and goal. The result is not consistent with the simulations. Error of monitors, unknown nonlinear magnetic field in the extraction line before the beam diagnostic region, corrective effect in the ring and in the extraction line are suspected as the source of the discrepancy and under investigation in recent operation[4].

4 ACKNOWLEDGMENT

The authors thank all members of the ATF collaboration group, especially M.Ross of SLAC and other members, F. Zimmerman, S.Takeda, S.Araki, H.Sakai, K.Dobashi, T.Imai and I.Sakai for operation of the machine, and for useful discussions. The authors also would like to thank professors H.Sugawara, M.Kihara and K.Takata of KEK for continuous support and encouragement.

REFERENCES

[1] K .KUBO, et.al., 1999 Particle Accelerator Conference, New York, p3432-3434, 1999.

[2] K .KUBO, et.al., 12th symposium on Accelerator Science and Technology, Wako, Saitama, P814, 1999.

[3] SAD is a computer program complex for accelerator design, http://www-acc-theory.kek.jp/SAD/sad.html.

[4] J. URAKAWA, this conference.