The 12th Symposium on Accelerator Science and Technology, Wako, Japan 1999

Simulation study on Low Emittance Beam Tuning in KEK-ATF Damping Ring

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Abstract

KEK-ATF is the test facility for future linear colliders producing extremely low emittance beams. The target of the vertical emittance in the damping ring is 1% of the designed horizontal emittance which is about 15 pm-rad. Beam tuning such as orbit corrections, dispersion corrections, local bumps and skew quadrupoles have been performed trying to achieve low emittance. In the actual operation, apparent vertical emittance has been typically about 3 % of the horizontal emittance after the tuning. Simulations of the beam tuning have been done with realistic misalignment and performances of monitors and correctors. The results show that 1% coupling could have been achieved. The possible reasons of the discrepancy are discussed.

1 Introduction

The target of the vertical emittance in the damping ring of KEK-ATF is 1% of the designed horizontal emittance which is about 15 pm-rad. Beam tuning such as orbit corrections, dispersion corrections, local bumps and skew quadrupoles have been performed to achieve low emittance. In the actual operation, apparent vertical emittance has been typically about 3 % of the horizontal emittance after the tuning [1], [2]. Simulations of the beam tuning have been done with realistic misalignment and performances of monitors and correctors to test our tuning methods.

2 Dispersion Correction

It is essential to make the vertical dispersion small in the arc sections for producing low vertical emittance beams. Relation between the dispersion and emittance was simulated using SAD [3]. In the simulation, all magnets were misaligned randomly with r.m.s. 20 micron. The vertical dispersions at the BPMs were tried to be zero using the steering magnets. Simulation was done for 2000 different random seeds. Fig. 1 shows square of the vertical dispersion averaged over the BPMs in the arc section vs. the vertical emittance calculated by SAD. Because other effects such as the intrabeam scattering were not considered, 1% of the horizontal emittance is about 10 pm-rad in this case. One point corresponds to one random misalignment. The emittance has linear dependence on the square of the vertical dispersion at BPMs as

$$\varepsilon_y(\mathrm{nm-rad}) \approx 0.0006 \left\langle \eta_{y,BPM}^2(\mathrm{mm}^2) \right\rangle_{arc} \qquad (1)$$

where $\langle\ \rangle_{arc}$ means the average in the arc sections. The line is shown in the figure.

Though we assumed the random misalignment of 20 micron, results of further simulations with other realistic misalignment assumptions give almost the same dependence as the equation (1).

The result shows that the r.m.s. of the vertical dispersion at BPMs should be about 4 mm to achieve our goal, 10 pm-rad.

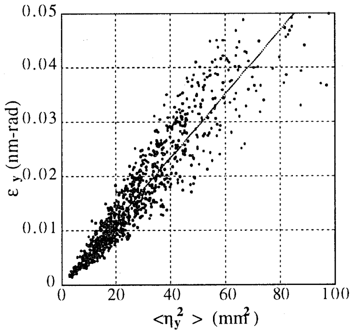

Fig. 1 Square of the vertical dispersion averaged over BPMs in the arc section vs. the vertical emittance from simulation.

Simulations of dispersion correction were done with more realistic conditions also using SAD. We set misalignment of the all magnets as measured in the vertical direction and randomly in the horizontal direction because the vertical misalignment has been measured well but there was not reliable data for the horizontal misalignment. The vertical misalignment is shown in Fig. 2 as a function of the position in the ring.

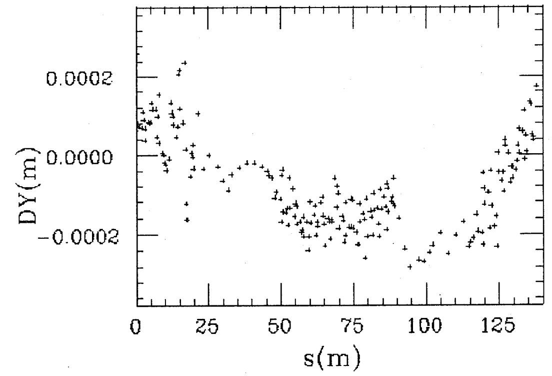

Fig. 2 Measured vertical misalignment in the ring.

There are 52 horizontal and 51 vertical steering magnets for beam tuning. In the simulation of the COD and dispersion corrections, SAD searches a set of steerings to satisfy or close to given requirements. Here the requirements are

$$\begin{cases} |\eta_y| < 5 \text{ mm} \\ |x| < 3 \text{ mm} \qquad \text{at all BPMs} \\ |y| < 1.5 \text{ mm} \end{cases} \tag{1}$$

There are 96 BPMs in the ring and x, y and η_y are the horizontal COD, the vertical COD and the vertical dispersion, respectively. Because we concentrate on the dispersion here, requirement for COD (the second and the third ones) are set to be loose. The vertical dispersion is required to be less than 5 mm which is roughly consistent with the requirement for the r.m.s. of less than 4 mm. Still in most cases, the requirement for the vertical dispersion were not completely satisfied.

Fig. 3 shows the vertical emittance after the correction vs. r.m.s. of the horizontal misalignment of the magnets. It shows the average of 50 random seeds and the error bars show the standard deviation of the distribution. The result shows that the expected vertical emittance is about 50 pm-rad which is much bigger than our target. It is also shown that the emittance has broad distribution according to the horizontal misalignment but the r.m.s of the misalignment is not important if it is less than 70 microns.

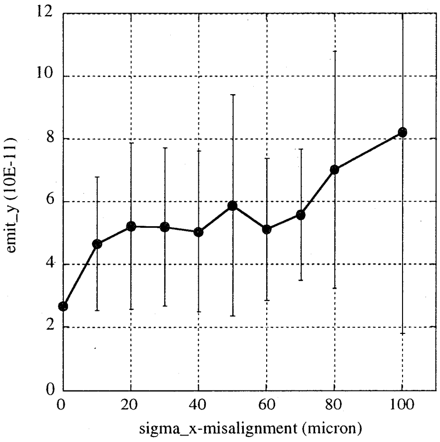

Fig 3 Emittance after COD and dispersion correction, simulation with measured vertical misalignment and random horizontal misalignment (50 seeds).

3 Beam tuning monitoring beam size

Simulation of local bump tuning after the dispersion correction was also done. In the simulation, a local bump using 4 vertical steering magnets to produce a vertical offset or a vertical angle at every sextupole magnet is tried. At each sextupole magnet, vertical offset of -1, -2/3, -1/3, 1/3, 2/3 and 1 mm and vertical angle of -1/2, -1/3, -1/6, 1/6, 1/3 and 1/2 mrad are tried one by one. Because there are 68 sextupole magnets in the ring, total 816 bumps are tried for each case. In the tuning, the vertical beam size was assumed to be monitored at the synchrotron radiation monitor [4] with relative resolution of 0, 0.05 and 0.1. Each local bump is set if the beam size is reduced by more than the resolution. In the case of the accuracy 0.05, a bump is set if the beam size is reduced more than 5% compare with the size without the bump. The white circles in Fig. 4 shows the vertical emittance after the local bump tuning vs. the relative beam size resolution. R.m.s. of the horizontal misalignment was assumed to be 30 micron and average and standard deviation of 25 random seeds are shown. The realistic resolution will be about 0.05 and this tuning is expected to reduce the expected emittance from 50 pm-rad to 30 pm-rad, still it is bigger than our target.

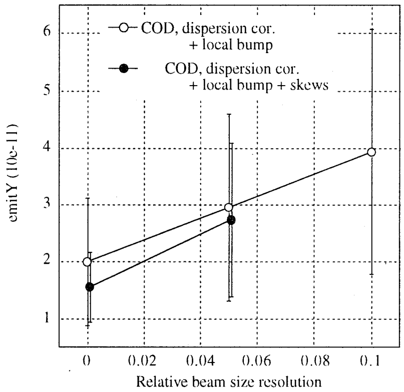

Fig. 4 Simulated vertical emittance after local bump tuning (white circles) and after local bump - skew quads tuning (black circles). Average of 25 random seeds, the error bars show the standard deviation.

Tuning with skew quadrupoles after the dispersion correction and the local bump tuning was also simulated. In the actual operation, all sextupole magnets have correction coils which connected to produce approximate skew quadrupole field whose strength (k2) can be up to 0.003 m^{-2}. In the simulation, excitation of 8 pairs of skew quads fields at focusing sextupole magnets were tried. Each pair consists of two magnets between which the horizontal phase advance is about 270° and the vertical phase advance is about 90°. -1, -2/3, -1/3, 0, 1/3, 2/3, 1 of the maximum strength of skew quadrupole fields were tried for both magnets, 49 settings for each pair or total 8x49 settings. The vertical emittance after the skew tuning is shown in Fig. 4 as filled circles. This tuning will be not very effective especially unless the beam size monitor is extremely good.

4 Tuning with Good COD Correction

So far, as the first correction using steerings we have required the inequality (1) where the essential requirement is the small vertical dispersion. From further studies, it has been found that tightening the requirements for orbit and ignoring the dispersion could give smaller vertical emittance as the result. The reason has not well understood but probably because the response of the dispersion to steerings are much complicated than the response of the orbit and the dispersion can not be well corrected.

Here we set new requirement

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

x_{meas}^2 and y_{meas}^2 are square of the horizontal and vertical BPM readings. BPMs were assumed to be misaligned randomly as gaussian with respect to the nearest magnets. The results of the simulations are shown as white circles in Fig 5 and 6, the vertical emittance vs. r.m.s. of the misalignment of BPMs. Horizontal misalignment of the magnets was assumed to be 30 micron for the Fig. 5 and 50 micron for the Fig. 6.

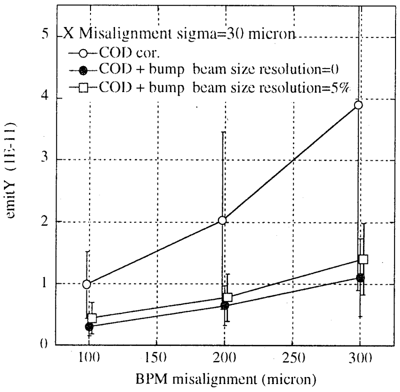

Fig. 5 Vertical emittance vs. misalignment of BPM, after COD correction (white circle), after local bump correction with resolution of 0 (filled circle) and 0.05(rectangular). R.m.s. of the horizontal misalignment 30 micron.

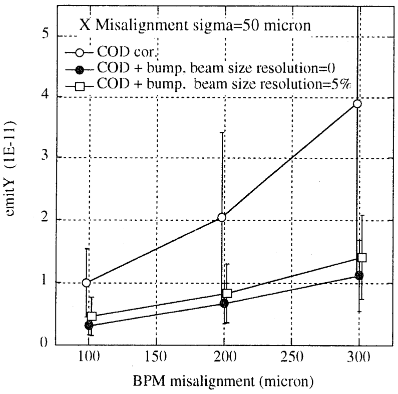

Fig. 6 Vertical emittance vs. misalignment of BPM, after COD correction (white circle), after local bump correction with resolution of 0 (filled circle) and 0.05 (rectangular). R.m.s. of the horizontal misalignment 50 micron.

The emittance strongly depends on the BPM misalignment or the accuracy of the orbit measurement. If that is better than 100 micron, the vertical emittance can be as small as our target value without any further beam tunings. It should be noted that two figures with different r.m.s. of the horizontal misalignment of the magnets are almost the same, which means the accuracy of the horizontal alignment of magnets is not important in this region.

Results of local bump tuning are also shown in the figures in the case of the beam size resolution of 0 (filled circles) and 0.05 (rectangular). With beam size resolution of 0.05 and BPM misalignment of 200 micron, which is reasonable assumption, the expected emittance will be reduced to smaller than our target.

5 Summary and Discussion

In actual operation, typical COD is about 2 mm in horizontal and about 1 mm in vertical and measured vertical emittance is about 3% of the horizontal emittance [1], [2]. The simulations in section 2 and 3 look consistent with these observations.

In section 4 we found that COD correction ignoring dispersions would be better than the dispersion correction simulated in section 2. And with reasonable assumptions, the vertical emittance could be as small as our target after the COD correction and the local bump corrections.

The results of the section 4 are not consistent with the actual operation. The COD could not be better than 2 mm in horizontal and 1 mm in vertical and the measured vertical emittance could not be less than 3% of the horizontal emittance. To understand the discrepancies, performances of the monitors, accuracy of the alignment and the stability of the beam etc. should be studied more.

Acknowledgment

The authors would like to thank all members of the ATF collaboration. We also thank Professors Sugawara, Kihara and Takata for continuous support and encouragement.

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