TEST OF OPTICS DIAGNOSTICS IN ATF

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Abstract

In beam operations, corrections and measurement of beam qualities, it is important to know the optics of the beam lines. Because there are always some errors in strength of magnets, actual optics will be different from the model. Errors of quadrupole strength of magnets are estimated by changing strength of steering magnets and measuring beam positions. The method of the error estimation and test results in Damping Ring of ATF, Accelerator Test Facility at KEK, will be reported.

1 INTRODUCTION

As reported in another paper [1], we have started commissioning of the damping ring of ATF in January. It is very important to understand the optics of the ring, which can be different from the calculated one due to errors of magnetic fields. The ATF Damping Ring has a race-track shape which has two arc sections and two straight sections. In the arc sections, there are 36 combined bending magnets which are defocusing in horizontal direction and 72 quadrupole magnets which are focusing in horizontal direction. In the straight sections, there are 30 quadrupole magnets. Errors of quadrupole strengths of the quadrupole magnets and the combined bending magnets have been estimated using beams, by steering beam and measuring the orbit in down stream. The measured response coefficients are fit by errors of strength of quads, beam position monitors (BPM) and steerings.

2 METHOD OF ERROR ESTIMATION

In a beam line, let $R_{12}(i,j)$ and $R_{34}(i,j)$ be the response coefficients of j-th BPM to i-th steering magnet, in horizontal direction and vertical direction respectively,

$$\begin{aligned} x_i &= R_{12}(i,j)x'_j \\ y_i &= R_{34}(i,j)y'_j \end{aligned} \qquad (1)$$

where x_i and y_i are position change at the i-th BPM and x'_j and y'_j are change of kick angles at the j-th steering magnet.
Let $R_{12,mo}(i,j)$ and $R_{34,mo}(i,j)$ be the model response coefficient of i-th BPM to j-th steering magnet in horizontal and vertical directions. And define error of the coefficients as follows.

$$\begin{aligned} \Delta R_{12}(i,j) &= R_{12}(i,j) - R_{12,mo}(i,j) \\ \Delta R_{34}(i,j) &= R_{34}(i,j) - R_{34,mo}(i,j) \end{aligned} \qquad (2)$$

Assume the errors come from errors of strength of quadrupoles between the steer and the BPM and calibration factors of the steer and the BPM as follows.

$$\begin{aligned} k_m &= k_{m,mo} + \Delta k_m \\ x'_j &= (1+\Delta S_j)x'_{j,mo} \\ y'_j &= (1+\Delta S_j)y'_{j,mo} \\ y_i &= (1+\Delta B_{y,i})y_{i,mo} \\ x_i &= (1+\Delta B_{x,i})x_{i,mo} \end{aligned} \qquad (3)$$

where left hand sides express real values, '$_{mo}$' means value from the model. Δk_m is error of k-value. ΔS_j, $\Delta B_{x,i}$ and $\Delta B_{y,i}$ are relative errors of calibration factors of j-th steer, i-th BPM in horizontal and vertical, respectively.
We assume all errors are small and take up to the first order of them. When kick angle at the i-th steering changed by x'_j and y'_j, beam position change and angle change at m-th quad in horizontal and vertical directions, x_m, y_m, x'_m and y'_m are

$$\begin{aligned} x_m &= R_{12}(j \to q_m)x'_j \\ y_m &= R_{34}(j \to q_m)y'_j \\ x'_m &= R_{22}(j \to q_m)x'_j \\ y'_m &= R_{44}(j \to q_m)y'_j \end{aligned} \qquad (4)$$

where $R(j \to q_m)$ is the transfer matrix from j-th steer to m-th quad. The change of kick angles just after the quad due to the position change in both directions are $\delta x'_m = -k_m x_m$ and $\delta y'_m = k_m y_m$. The change of position at i-th BPM, x_i and y_i are

$$\begin{aligned} x_i &= R_{11}(q_m \to i)x_m + R_{12}(q_m \to i)x'_m - R_{12}(q_m \to i)k_m x_m \\ y_i &= R_{33}(q_m \to i)y_m + R_{34}(q_m \to i)y'_m + R_{34}(q_m \to i)k_m y_m \end{aligned} \qquad (5)$$

where $R(q_m \to i)$ is the transfer matrix from the quad to the i-th BPM. Then, the response coefficients are

$$\begin{aligned} R_{12}(i,j) = {} & R_{11}(q_m \to i)R_{12}(j \to q_m) \\ & + R_{12}(q_m \to i)R_{22}(j \to q_m) \\ & - R_{12}(q_m \to i)k_m R_{12}(j \to q_m) \end{aligned}$$

$$\begin{aligned} R_{34}(i,j) = {} & R_{33}(q_m \to i)R_{34}(j \to q_m) \\ & + R_{34}(q_m \to i)R_{44}(j \to q_m) \\ & + R_{34}(q_m \to i)k_m R_{34}(j \to q_m) \end{aligned} \qquad (6)$$

From above equations, taking the first order of errors, error of the response coefficients are

$$
\begin{aligned}
\Delta R_{12}(i,j) &= -\sum_m R_{12}(q_m \to i)\Delta k_m R_{12}(j \to q_m) \\
&\quad - \Delta S_j R_{12,mo}(i,j) + \Delta B_{x,i} R_{12,mo}(i,j) \\
\Delta R_{34}(i,j) &= \sum_m R_{34}(q_m \to i)\Delta k_m R_{34}(j \to q_m) \\
&\quad - \Delta S_j R_{34,mo}(i,j) + \Delta B_{y,i} R_{34,mo}(i,j)
\end{aligned} \tag{7}
$$

where index m runs for all quadrupoles between j-thsteering magnet and i-th BPM.

In principle, when the number of pairs of steering magnet and BPM times two is larger than sum of the number of quadrupoles, steerings and two times of number of BPMs, errors can be estimated from linear fitting from equation (7).

3 MEASUREMENT AND ANALYSIS

3.1 Measurement of response coefficients

Before the measurement, orbit correction using steering magnets were performed to store as much beam as possible.

We changed every steering magnets along the ring and measure beam positions at BPMs. In the measurement, sextupole magnets were turned off to make the response linear. Because our BPM system measures beam positions in a single turn, the ring was considered as a transport line starting at the changed steering magnet, and beam positions of the first turn were measured at BPMs after the magnet. It means that beam passes only once before every position measurement and complexities from multi-turns are avoided.

In the ring, there were 46 horizontal and 40 vertical steering magnets available and 83 BPMs were available and used for this measurement.

For each steering magnet, beam positions were measured with three different current settings, -0.8A, 0A and +0.8A from the original setting. Change of 0.8A corresponds to change of kick angle by 0.85 mrad for the operated beam energy, 0.95 GeV. Because a part of beam was lost far downstream for some settings, data of BPMs only in 50m after changed steering magnets were used for the analysis. To reduce the statistical error of BPMs and effects of jitters, data were taken for 25 pulses for each setting. To estimate the response coefficients, difference of averaged positions with three settings were used for a least square fitting. The position difference was fitted as a linear function of the difference of the set current for each pair of steering magnet and BPM. So far, the horizontal-vertical coupling has been neglected in this analysis. The slopes of the fit represent the response coefficients. The statistical errors of the responses from the measurement are estimated from the errors of average positions in the fittings which was set to be $\sigma_x / \sqrt{n-1}$ and $\sigma_y / \sqrt{n-1}$ where σ_x and σ_y are r.m.s. of measured positions with the same setting and n is the number of pulses for which the beam positions were measured successfully. The error includes both resolution of the BPMs and jitters of the beam.

3.2 Fitting orbit with energy offset

Because we measured the first turn orbit, the beam energy can be different from the energy determined by the bending field of the ring. We estimated the energy offset comparing measured average orbit and calculated dispersion in the first arc section. Plots in Figure 1 shows averaged horizontal beam positions at BPMs in the first arc section. Using the optics model, position, angle and energy offset at the entrance of the arc section were fitted as -1100 μm, 801 μrad and 0.2% of the energy determined by the bending field, respectively. The line in the figure shows the orbit using the fitting. Analysis bellow assumes this estimated offset of the beam energy.

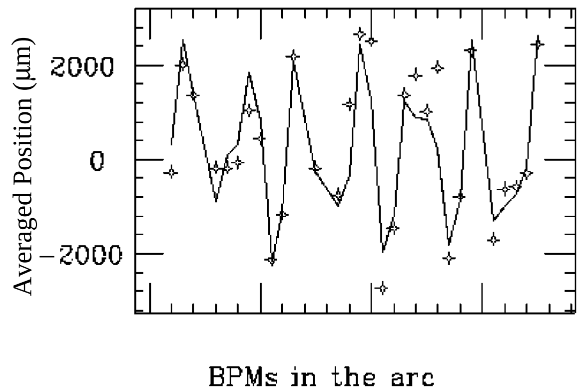

Fig. 1, Average positions at BPMs in the first arc section (plots) and fitted orbit (line).

3.3 Estimation of Machine Errors

Response coefficients $R_{12}(i,j)$ and $R_{34}(i,j)$ are calculated from the current-position responses, multiplied by given factors of kick angles vs. current settings of steering magnets. Figure 2(a) and (b) show measured response coefficients vs. model response coefficients in horizontal and vertical directions, respectively.

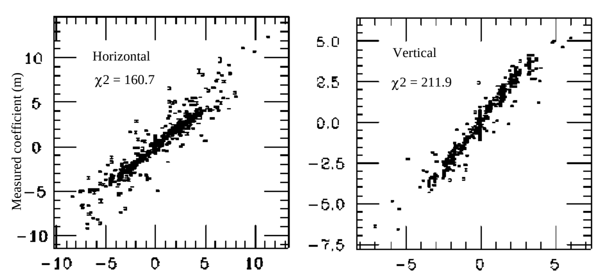

Fig.2, Measured response coefficients vs. model coefficients before fitting, (a) in horizontal direction and (b) in vertical direction.

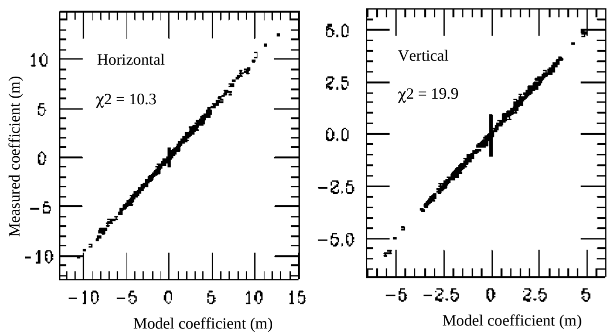

Fig.3, Measured response coefficients vs. model coefficients after fitting, (a) in horizontal direction and (b) in vertical direction.

Errors of quadrupole strengths of magnets, calibration factors of BPMs and current to kick angle factors of steering magnets are fitted using the methods described in section 2. Because the strength of 28 quads called QF1R were very small, their errors were not included in the fitting.

The fitting calculated 108 errors of quadrupole strengths, 86 errors of steering magnets' factors and 166 errors of BPMs' calibration factors. Figure 4 shows estimated relative errors of k-values of magnets, $\Delta k_m / k_{m,mo}$. Large error bars in this figure correspond to quads whose strength are very small. Figure 3(a) and (b) show measured response coefficients vs. model response coefficients in horizontal and vertical directions, respectively, after correction of the model using estimated errors. The corrected model well agrees with the measurement.

The parameters of the model and current setting of each power supply was corrected based on this fitting. After the correction, measured transverse tunes are different from the model by 0.15 in horizontal and 0.02 in vertical where the total tunes are about 15 and 9, respectively. Before the correction, the difference had been more than 0.5 in both directions. More measurements and test of the validity of the correction in detail will be performed near future.

Plots distribute on vertical lines in the figures 3(a) and (b) suggest x-y coupling or rotations of quads, steerings and/or BPMs. The coupling will be studied near future.

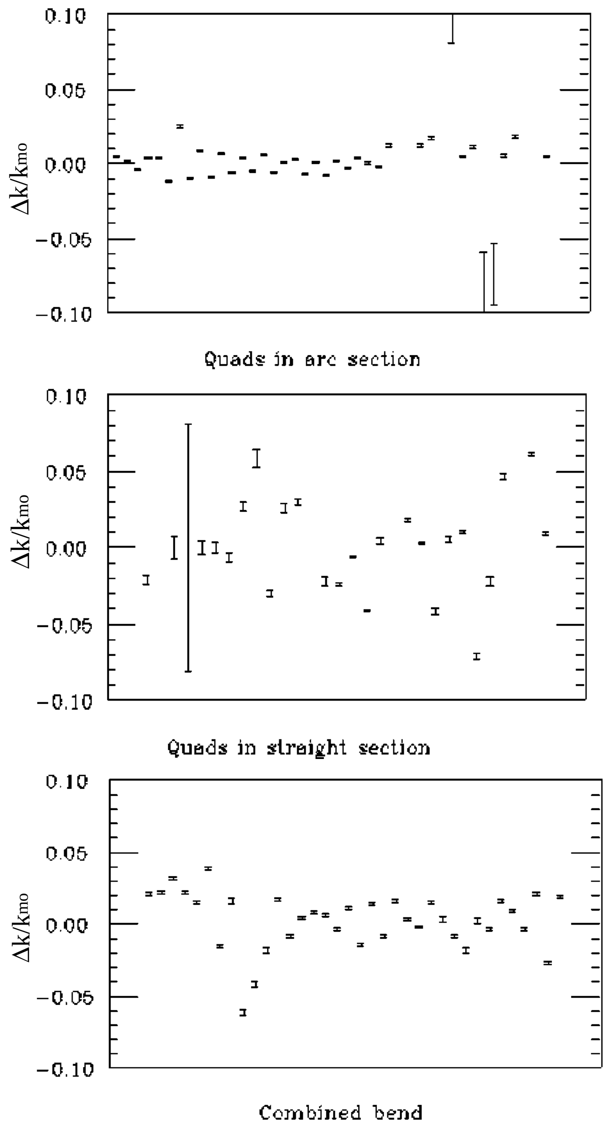

Fig. 4, Fitted relative errors of k-values, quads in arc sections, quads in straight sections and combined bends are shown separately.

4 ACKNOWLEDGMENTS

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REFERENCES

[1] J. Urakawa, in this conference