OPTICS MEASUREMENT AT THE INTERACTION POINT USING NEARBY POSITION MONITORS IN KEKB

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Abstract

Optics parameters at the interaction point, beta, x-y coupling, dispersion and their chromatic aberrations, seriously affect the beam-beam performance as is shown in experiments and simulations. The control of the optics parameters is essential to maintain the high luminosity in KEKB. They drift day by day, or before and after the beam abort. They were often monitored at intervals of the operation with taking the study time. They are recently measured during the physics run using a pilot bunch without collision. We show the measured the optics parameters and their variations and discuss the relation to the luminosity.

INTRODUCTION

Figure 1 show the layout of the interaction region of KEKB. Two position monitors with 8 button electrode, which is called OCTPOS, are installed inside of the final superconducting quadrupole magnets.

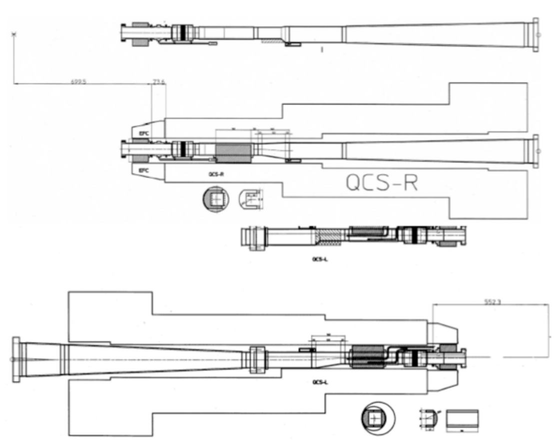

Figure 1: Layout of the interaction region in KEKB. Courtesy of K. Kanazawa. Top and bottom are right and left side of the interaction point.

The distances from the interaction point are 552mm and 773 mm for left and right OCTPOS monitors, respectively. Only solenoid magnetic field exists in the space between the two monitors. Both of electron and positron beams pass through the two monitors. The positions of the two beams are measured with the monitors separately; sharing the time. Though the monitor has capability to measure the two beam position simultaneously with the eight electrodes, we did not use to avoid complex of separation of the two beam position.

The beam is kicked in the horizontal plane and its transverse position is measured turn by turn. Horizontal mode is excited by the kicker basically and a small amount of vertical mode is excited depending on the x-y coupling at the kicker. The phase space coordinates at the interaction point ($\mathbf{x}=(x,p_x,y,p_y)$)is expressed by those at the two monitors ($\mathbf{x}_L,\mathbf{x}_R$) using the transfer matrix,

$$\mathbf{x} = M_{L(R)}\mathbf{x}_{L(R)} \tag{1}$$

The positions x,y at the monitors are expressed by

$$x_{L(R)} = M_{L(R),1j}x_j \qquad y_{L(R)} = M_{L(R),3j}x_j \tag{2}$$

where L,R is suffix for the monitors, and j=1,4 is the suffix for the phase space coordinates. The phase space coordinates are determined by the

$$\mathbf{x} = T\mathbf{x}_m \qquad T = \begin{pmatrix} M_{L,1j} \\ M_{L,3j} \\ M_{R,1j} \\ M_{R,3j} \end{pmatrix}^{-1} \tag{3}$$

where $\mathbf{x}_m=(x_L,y_L,x_R,y_R)^t$. When the beam is kicked with single mode, the trajectory is an ellipse in 4-D phase space.

x-y coupling is characterised by eigenvectors which diagonalize the revolution matrix into block wise 2x2 sub-matrices,

$$M_{2\times 2} = R^{-1}MR \qquad R = \begin{pmatrix} r_0 & 0 & r_4 & -r_2 \\ 0 & r_0 & -r_3 & r_1 \\ -r_1 & -r_2 & r_0 & 0 \\ -r_3 & -r_4 & 0 & r_0 \end{pmatrix} \tag{4}$$

where $r_0^2 = 1-r_1r_4+r_2r_3$. The block diagonal 2x2 matrix (M_{2x2}) is the well-known revolution matrix for betatron motion in x and y plane,

$$M_{2\times 2,xy} = \begin{pmatrix} \cos\mu_{xy} + \alpha_{xy}\sin\mu_{xy} & \beta_{xy}\sin\mu_{xy} \\ -\gamma_{xy}\sin\mu_{xy} & \cos\mu_{xy} - \alpha_{xy}\sin\mu_{xy} \end{pmatrix} \tag{5}$$

The parameters for x-y coupling is visible from the trajectory of the kicked beam in the phase space. Figure 2 shows schematic view how the x-y coupling parameters appear in the trajectory. The normal vector of the ellipse in y-x- p_x plane and p_y-x-p_x characterises r_1, r_2 ans r_3, r_4, respectively. Lower picture shows an example of measured data. The size of ellipse shrinks with keeping similarity due to the radiation damping.

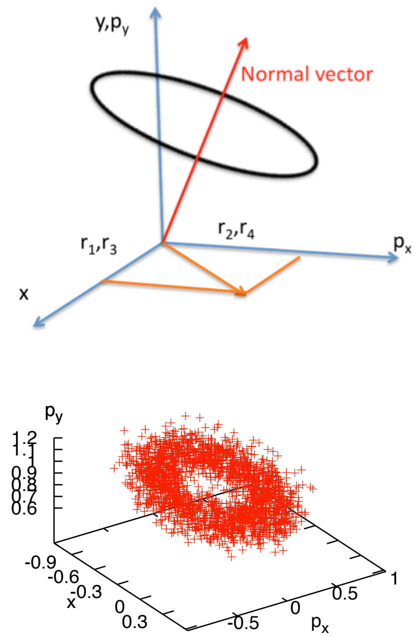

Figure 2: Sketch for the x-y coupling parameters in phase space trajectory, and a measured example.

CORRELATION MATRIX

An ellipse in the phase space is characterized by a correlation matrix,

$$E=\begin{pmatrix} \langle x^2\rangle & \langle xp_x\rangle & \langle xy\rangle & \langle xp_y\rangle \\ \langle xp_x\rangle & \langle p_x^2\rangle & \langle p_x y\rangle & \langle p_x p_y\rangle \\ \langle xy\rangle & \langle p_x y\rangle & \langle y^2\rangle & \langle yp_y\rangle \\ \langle xp_y\rangle & \langle p_x p_y\rangle & \langle yp_y\rangle & \langle p_y^2\rangle \end{pmatrix} \qquad (6)$$

where <> is the average for turn by turn. The ellipse is expressed by

$$\mathbf{x}^t E^{-1}\mathbf{x} = a \qquad (7)$$

where a is a scaling factor for the ellipse size.

When only horizontal mode, which has frequency ν_x, is excited, phase space variables at the interaction point oscillate as

$$\begin{pmatrix} x \\ p_x \\ y \\ p_y \end{pmatrix} = RB\begin{pmatrix} a\cos\psi_x \\ -a\sin\psi_x \\ 0 \\ 0 \end{pmatrix} \qquad B_{x,y}=\begin{pmatrix} \sqrt{\beta_{x,y}} & 0 \\ \alpha_{x,y}/\sqrt{\beta_x} & 1/\sqrt{\beta_x} \end{pmatrix} \qquad (8)$$

where B is a block diagonal matrix for $B_{x,y}$. The correlation matrix for the excitation is expressed by

$$\langle \mathbf{x}\mathbf{x}^t\rangle = RBAB^tR^t \qquad (9)$$

where A is a diagonal matrix with the elements of (a^2,a^2,0,0). The explicit form of left bottom elements is written in Eq.(10), note that it is a symmetric matrix.

$$\begin{pmatrix} \mu^2\beta_x & & & \\ -\mu^2\alpha_x & \mu^2\gamma_x & & \\ \mu(-\beta_x r_1+\alpha_x r_2) & \mu(\alpha_x r_1-\gamma_x r_2) & \beta_x r_1^2-2\alpha_x r_1 r_2+\gamma_x r_2^2 & \\ \mu(-\beta_x r_3+\alpha_x r_4) & \mu(\alpha_x r_3-\gamma_x r_4) & \beta_x r_1 r_3-\alpha_x(r_1 r_4+r_2 r_3)+\gamma_x r_2 r_4 & \beta_x r_3^2-2\alpha_x r_3 r_4+\gamma_x r_4^2 \end{pmatrix} \qquad (10)$$

Comparing the measured correlation matrix Eq.(6) with Eq.(10), Twiss parameters including x-y coupling are obtained.

ERRORS OF MONITORS

The correlation matrix is related to another correlation matrix for raw data as

$$\langle \mathbf{x}\mathbf{x}^t\rangle = T\langle \mathbf{x}_m\mathbf{x}_m^t\rangle T^t \qquad (11)$$

Twiss parameters are determined by the relative position variation. The measurement is insensitive for offset errors of monitors. While rotation errors of monitor reflect to the measured coupling. When the monitors rotate with (θ_L, θ_R), the true position $\mathbf{z}_m$ is,

$$\mathbf{z}_m=\Theta\mathbf{x}_m \quad \Theta_{L(R)}=\begin{pmatrix} \cos\theta_{L(R)} & -\sin\theta_{L(R)} \\ \sin\theta_{L(R)} & \cos\theta_{L(R)} \end{pmatrix} \qquad (12)$$

where Θ is a block diagonal matrix of Θ_L and Θ_R. The true correlation matrix is expressed by the measured correlation matrix as follows,

$$\langle \mathbf{z}\mathbf{z}^t\rangle = T\Theta T^{-1}\langle \mathbf{x}\mathbf{x}^t\rangle (T\Theta T^{-1})^t \qquad (13)$$

Expanding for (θ_L, θ_R),

$$\begin{aligned} \bar{r}_1 &= r_1-0.417\theta_R-0.583\theta_L \\ r_2 &= r_2-0.322\theta_R+0.322\theta_L \\ r_3 &= r_3+0.754\theta_R-0.754\theta_L \\ r_4 &= r_4-0.583\theta_R-0.417\theta_L \end{aligned} \qquad (14)$$

where ri's are the true value. The coefficients are given by the transfer matrix (T). The deviations from the true values are the same for the both beams, because the monitors measure the both beams. The difference of r between the two rings is independent of the monitor rotation errors. The deviations are similar values (order of $\theta_{L,R}$) for every r parameters.

MEASURED X-Y COUPLING

x-y coupling parameters and their momentum dependence at the interaction point have been often measured in the KEKB operation. For example every run end, before and after short maintenance shutdown and so on. The measurement is performed with a low current of 20mA. In the measurement of one ring, the other ring is out of operation.

Figure 3 shows measured phase space plot for r_2 and r_4 before and after optics correction. The correlations, which correspond to r_2 and r_4 respectively, are improved by the optics correction. The coupling parameters are corrected r_2=0.094->0.0038, r_4=-0.049->-0.0030.

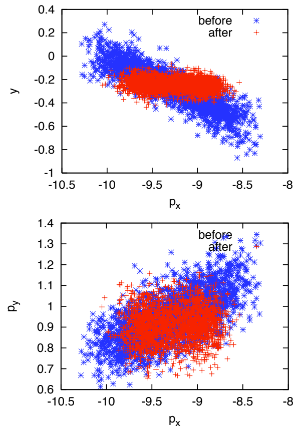

Figure 3: Correlations of the phase space plot before and after optics correction. Top and bottom plots the correlation of p_x-y and p_x–p_y, which correspond to r_2 and r_4, respectively.

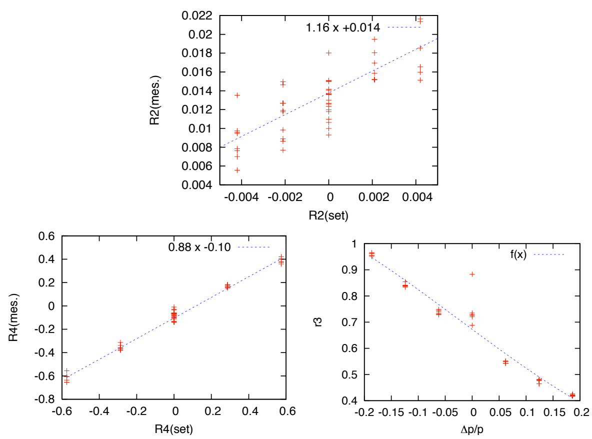

Figure 4: Response for coupling knob scan and energy scan.

x-y coupling is important parameter for the collision performance. Tuning knobs for the x-y coupling parameters using orbit distortions at sextupole magnets are used to optimize the luminosity every day. Figure 4 shows whether the knobs really change the coupling parameters. The slopes, which are around 1, indicate the knobs work well. The bottom picture depicts the chromatic coupling.

Table 1 shows the coupling measured at three dates in 2009. They are measured just after the physics run, therefore luminosity is optimized. r_1's of LER and HER are finite but are similar. This result of r_1 may be due to monitor rotation. r_2's have discrepancy around 0.01 between LER and HER. The value 0.01 is very big for r_1 and r_2. Figure 5 shows a beam-beam simulation result for r_2 scan. The luminosity degrades 30 % of the optimum for r_2=0.01. We had suspicion on the tuning of r_2, but could not find clear answer for the luminosity, which is less than the simulated value.

Tolerance of r_3 and r_4 is larger compare than those of r_1 and r_2. However r_3 of LER is sufficiently large. This means positron beam collides with a twist at the luminosity-optimized condition.

Table 1: Measurements of the Coupling Parameters in 2009.

		4/30	5/13	5/26
HER	r1	0.0112	0.0142	0.00974
	r2	0.00163	0.00139	0.00169
	r3	0.0616	0.111	0.0618
	r4	-0.0547	-0.0926	0.0245
LER	r1	0.0104	0.0085	0.00961
	r2	0.0137	0.0137	0.0131
	r3	0.673	0.189	0.221
	r4	-0.144	0.0277	-0.061

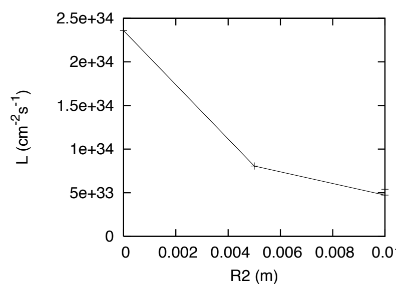

Figure 5: Luminosity as a function of r_2 given by a strong-strong simulation.

FUTURE WORK: MEASUREMENT DURING PHYSICS RUN

Though the x-y coupling parameter knobs are tuned every day, the optimized values of the knobs are not kept constants for the luminosity. For example after the beam abort, a big change of the coupling knob is sometimes necessary. This fact means x-y coupling parameters drift day by day and change at the beam abort. Heating due to synchrotron radiation power may change position of magnets.

The coupling measurement during the physics run is necessary for the next step. A pilot bunch, which does not collide with another bunch, is stored at the tail part of bunch train in the physics run in each ring. The pilot bunch is shaken by PLL [3] and its position is measured turn by turn using gated position monitors. The measurement is on going.

REFERENCES

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