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Compensation of Fast Kicker Rolls with Skew Quadrupoles

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COMPENSATION OF FAST KICKER ROLLS WITH SKEW QUADRUPOLES*

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Abstract

The development of the third generation light sources lead to the implementation of the top-up operation, when injection occurs while users collect data. The beam excursions due to the non-closure of the injection bump can spoil the data and need to be suppressed. In the horizontal plane compensation can be achieved by adjusting timing and kick amplitudes. The rolls of the kicker magnets create non-closure in the vertical plane and usually there is no means for correction. In the paper we describe proposed compensation scheme utilizing two skew quadrupoles placed inside the injection bump.

INTRODUCTION

The third generation light sources implement top-up operation firstly introduced at Advanced Photon Source [1]. In this mode the circulating beam current is supported near constant by frequent injection of small charge, while photon beam is delivered for users.

The beam perturbations caused by the mismatched injection bump can provide undesired noise in the user data. Usually the injection trigger is distributed to the users' end stations so that those affected would be able to blank data acquisition. Nevertheless, as good operational practice such transients should be suppressed as much as possible.

In the horizontal plane (which is commonly used for injection) one can adjust individual kicker strength as well as trigger delay while observing motion of the stored beam centroid. In the vertical plane such means are unavailable in the most cases. The possible solutions include dedicated weak vertical kickers and motorized adjustment of the roll angle of the injection kickers. Both abovementioned approaches are expensive and can significantly deteriorate reliability. We suggest two employ two skew quadrupoles (to correct both angle and position) placed inside the injection bump. In this case the beam position itself serves as measure of the kicker strength (assuming that kickers are well matched) and vertical kicks from the skew quadrupoles will be self synchronized with injection bump.

In this paper we will consider the case when injection hardware (kickers and septa) are located in the same straight. Such an approach simplifies consideration but it can be generalized.

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OPERATION PRINCIPLE

Usually the two schemes of the injection bump are utilized. They are shown in Fig. 1. The first one has four identical kickers (Fig. 1a) and septum is located between kickers 2 and 3. The layout is symmetrical and distance between kickers 1 and 2 is equal to the distance between kickers 3 and 4. The layout with the three kickers, shown in Fig. 1b, is symmetrical as well and has central kicker 2 twice stronger then outer kickers 1 and 3.

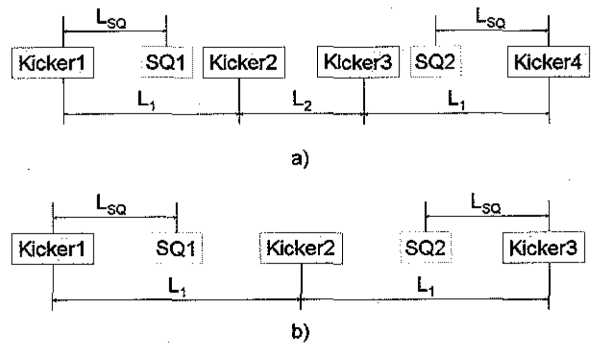

Figure 1: Layout of injection schemes a) with four kickers and b) three kickers.

To preserve the symmetry of the injection bump the location of the skew quadrupoles is also symmetric with equal distance L_{SQ} to the outer kickers.

For a four kicker bump with amplitude α due to the roll angles φ_i the stored beam receives deflection angle ψ and displacement δ :

$$\begin{aligned} \psi &= \alpha(\varphi_1 + \varphi_2 + \varphi_3 + \varphi_4) \\ \delta &= \alpha[\varphi_1(2L_1 + L_2) + \varphi_2(L_1 + L_2) + \varphi_3 L_1] \end{aligned} \quad (1)$$

For a three kicker bump with outer kickers having amplitude α and the center kicker with amplitude 2α the stored beam receives deflection angle ψ and displacement δ :

$$\begin{aligned} \psi &= \alpha(\varphi_1 + 2\varphi_2 + \varphi_3) \\ \delta &= 2\alpha L_1(\varphi_1 + \varphi_2) \end{aligned} \quad (2)$$

The skew quadrupoles shall provide kicks θ_i compensating the beam disturbance. For the four kicker bump the strength of the kicks can be found from the equations

$$\begin{aligned} -\psi &= \theta_1 + \theta_2 \\ -\delta &= \theta_1\left(2L_1 + L_2 - L_{SQ}\right) + \theta_2 L_{SQ} \end{aligned} \tag{3}$$

For the three kicker bump the strength of the kicks can be found from the equations

$$\begin{aligned} -\psi &= \theta_1 + \theta_2 \\ -\delta &= \theta_1\left(2L_1 - L_{SQ}\right) + \theta_2 L_{SQ} \end{aligned} \tag{4}$$

Beam displacement at the skew quadrupole locations is identical for injection schemes:

$$\Delta x = \alpha L_{SQ} \tag{5}$$

The integrated gradients in the skew quadrupoles can be found

$$G_i = \theta_i / \alpha L_{SQ} \tag{6}$$

or for the four kicks bump

$$\begin{aligned} G_1 &= \frac{\psi L_{SQ} - \delta}{2L_1 + L_2 - 2L_{SQ}} \frac{1}{\alpha L_{SQ}} \\ G_2 &= \frac{\delta - \psi\left(2L_1 + L_2 - L_{SQ}\right)}{2L_1 + L_2 - 2L_{SQ}} \frac{1}{\alpha L_{SQ}} \end{aligned} \tag{7}$$

and for the three kick bump

$$\begin{aligned} G_1 &= \frac{\psi L_{SQ} - \delta}{2\left(L_1 - L_{SQ}\right)} \frac{1}{\alpha L_{SQ}} \\ G_2 &= \frac{\delta - \psi\left(2L_1 - L_{SQ}\right)}{2\left(L_1 - L_{SQ}\right)} \frac{1}{\alpha L_{SQ}} \end{aligned} \tag{8}$$

It should be noted that both δ and ψ are directly proportional to the kick value α. Therefore, the gradients do not depend on the bump strength but are defined by geometry only.

PRACTICAL REALIZATION

Optimization of Skew Quadrupoles Location

For the optimization of the location of the skew quadrupoles we can transform both Eq. 7 and Eq. 8 to the same form utilizing the total length of the bump L_0. For the four kick bump its value is $2L_1 + L_2$, and for the three kick bum it is $2L_1$. Now we get

$$\begin{aligned} G_1 &= \frac{\psi L_{SQ} - \delta}{\alpha L_{SQ}\left(L_0 - 2L_{SQ}\right)} \\ G_2 &= \frac{\delta - \psi\left(L_0 - L_{SQ}\right)}{\alpha L_{SQ}\left(L_0 - 2L_{SQ}\right)} \end{aligned} \tag{9}$$

We will minimize

$$G_1^2 + G_2^2 = \frac{\left(\psi L_{SQ} - \delta\right)^2 + \left(\delta - \psi\left(L_0 - L_{SQ}\right)\right)^2}{\alpha^2 L_{SQ}^2\left(L_0 - 2L_{SQ}\right)^2} \tag{10}$$

After transformation and averaging over we get

$$\left\langle G_1^2 + G_2^2 \right\rangle = \frac{L_{SQ}^2 + \left(L_0 - L_{SQ}\right)^2 + L_0^2}{L_{SQ}^2\left(L_0 - 2L_{SQ}\right)^2} 4\varphi_{rms}^2 \tag{11}$$

assuming that (for the four kick bump)

$$\begin{aligned} \left\langle \psi^2 \right\rangle &= 4\alpha^2 \varphi_{rms}^2 \\ \left\langle \psi\delta \right\rangle &= 0 \\ \left\langle \delta^2 \right\rangle &= 2L_0^2 \alpha^2 \varphi_{rms}^2 \end{aligned} \tag{12}$$

If we introduce new variable $u = \dfrac{L_{SQ}}{L_0}$ then we need to minimize

$$f(u) = \frac{1 + u^2 + (1-u)^2}{u^2(1-2u)^2} = 2\frac{u^2 - u + 1}{u^2(1-2u)^2} \tag{13}$$

Its minimum in the interval from 0 to 0.5 is reached at $u \approx 0.259$. Because minimum is rather flat we can choose $L_{SQ} = L_0/4$.

Tuning Procedure

Using beam position monitors with turn-by-turn capabilities it is possible to measure the disturbance of the beam and calculate the required strength of the skew quadrupoles. More practical solution is to utilize the two knobs: "position" with $G_1 = -G_2$ and "angle" with $G_2 = G_1\left(1 - L_0/L_{SQ}\right)$. The knobs are adjusted alternatively until the amplitude of the residual oscillations (observed by any convenient method) is minimized.

Effects on the Stored and Injected Beams

. The stored beam will experience static orbit shift if orbit is not going through the magnetic centers of the skew quadrupoles. This can be easily corrected with trims.

The skew quadrupoles will change machine coupling which needs to be corrected with other skew quadrupoles.

Vertical displacement caused by misalignments of pulsed elements will create horizontal kicks for the stored beam. This is the second order effect and can be neglected.

There is additional substantially non-zero vertical kick on the injected beam due to the separation of the injected and stored beam. This kick can be compensated by the upstream trims in a transfer line.

NSLS-II CONSIDERATIONS

The NSLS-II injection bump will utilize four kick scheme with $\alpha = 8\,mrad$, $L_1 = 1.88\,m$, and $L_2 = 3.44\,m$ [2]. The skew quadrupoles can be placed at $L_{SQ} = 1.5\,m$ only due to the space constrains. With roll angles up to 1 mrad the required integrated strength of the skew quadrupoles will not exceed $0.005\,m^{-1}$ which below the design value of $0.007\,m^{-1}$ for the skew quadrupoles implemented at NSLS-II storage ring.

CONCLUSIONS

The proposed scheme proposed correction of the kicker rolls independently of their setting. The effects of on the stored and injected beam are manageable and should not impede implementation. Similar scheme with vertical steering inside the sextupoles is implemented at the Advanced Photon Source [3].

REFERENCES

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