INSERTION DEVICES INFLUENCE ON THE BEAM DYNAMICS AT SIBERIA-2 STORAGE RING

S.Tomin[#], V.Korchuganov, NRC "Kurchatov Institute" Moscow, Russia

Abstract

2.5 GeV SR source Siberia-2 is now running with 7.5 T wiggler and the installation of additional two 3 T SC wigglers is under consideration. Besides that the insertion of an undulator with very short period up to 7 mm is discussed. We compared an influence of the insertion devices on the dynamic aperture (DA) using two different tracking methods. In first method ID was considered as nonlinear lens. The second method with new computer code permits to find an electron beam trajectory in ID by Runge-Kutta method. By using two independent approaches it was shown that ID`s nonlinear components of magnetic field lead to significant decrease of dynamic aperture in vertical direction. Nonlinear components of ID magnetic field are shown. Results of numerical calculation of Siberia-2 dynamic aperture are presented as well.

INTRODUCTION

Siberia-2 is the Russian's national SR source, located at the NRC "Kurchatov Institute" in Moscow. With energy of 2.5 GeV, electrons travel along a 124.1 m circumference storage ring. At Siberia-2 ring a power SC wiggler operates with maximal amplitude of 7.5 T magnetic field and period length 164 mm, $N_{periods}$=10. The installation of two SC 3 T wigglers and an in-vacuum undulator with very short period is planed additionally. Main specifications of the IDs are listed in Table 1. A layout of the Siberia-2 storage ring with the proposed SC 3 T wigglers and the in-vacuum undulator are presented in Fig. 1.

Table 1: Main Parameters of IDs

Parameter	Wiggler	Wiggler	Undulator
Electron energy, GeV	2.5	2.5	1.3
Number ID	1	2	1
B_{max}, T	7.5	3	0.75
λ_{period}, mm	164	44	7
N_{period}	10	34	200
Deflection parameter	114.9	12.3	0.46
ε_{crit} (W) and ε_1(U), keV	31.2	12.5	2

The 3 T wigglers will be installed in free dispersion straight sections in contrast with the undulator. We note the values of β-functions at the azimuth of undulator are several times higher ($\beta_x/\ \beta_z$ ~ 12.1/6 m) then at the wiggler azimuth ($\beta_x/\ \beta_z \sim 4/0.6$ m), see Fig. 2.

Nonlinear fields of additional IDs leads to the amplification of the amplitude-dependent tune shift, a distortion of phase space and a reduction of the dynamic aperture (DA). We have estimated this influence and the sizes of dynamic aperture.

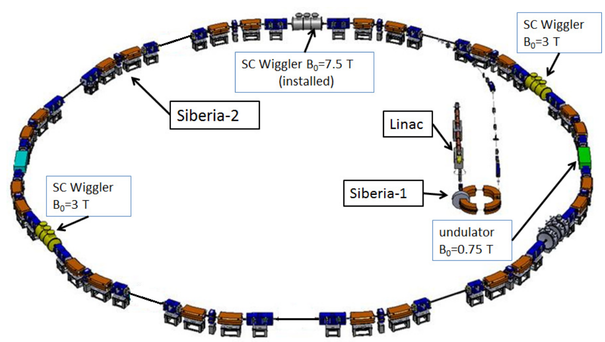

Figure 1: Siberia-2 storage ring with two 3 T sc wigglers and undulator.

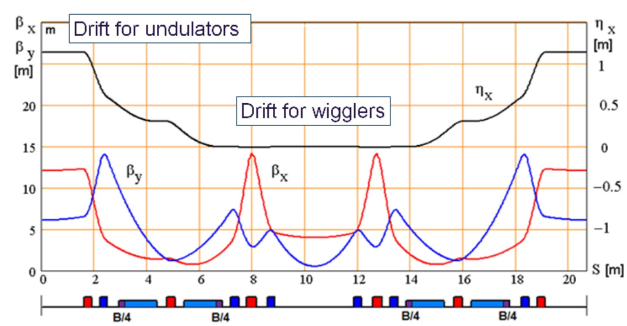

Figure 2: Optical function of Siberia-2 storage ring.

On first stage we represent insertion device as nonlinear lens and find dynamic aperture (DA) by tracking.

ID INFLUENCE ON THE DYNAMIC APERTURE

Before consideration of different approaches of for the estimation of insertion device influence on the beam dynamic we show dynamic aperture of Siberia-2 without any insertion devices (see Fig. 3) with the sizes of dynamic aperture of ±40 mm and of ±25 mm in horizontal and vertical directions respectively.

[#]tomin.sergey@gmail.com

ISBN 978-3-95450-122-9

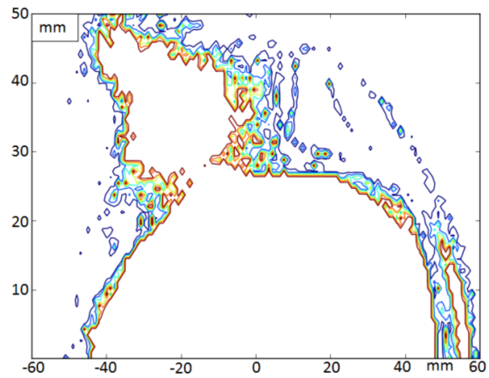

Figure 3: Dynamic aperture without ID.

Nonlinear kick

The components of the insertion device magnetic field used for the derivation of its influence on beam dynamic are as follows [1]:

$$\begin{aligned} B_x &= (k_x/k_z)B_0\sinh(k_x x)\sinh(k_z z)\cos(k_s s) \\ B_z &= B_0\cosh(k_x x)\cosh(k_z z)\cos(k_s s) \\ B_s &= -(k_s/k_z)B_0\cosh(k_x x)\sinh(k_z z)\sin(k_s s) \\ k_s &= 2\pi/\lambda_u,\ k_x^2+k_z^2=k_s^2 \end{aligned} \tag{1}$$

with x, z, s – horizontal, vertical ▯ longitudinal coordinates respectively; B_0 – peak field; k_x – measures the transverse variation of the field due to the limited pole width or curved pole face. In particular, damping of the field in the x-direction can be expressed by the replacement $k_x \rightarrow ik_x$.

To obtain field components on beam trajectory we shall pass to moving coordinate system (x^*, z^*, s^*) (Fig.4):

$$x = x_0 + x^*;\quad s = s_0 - \alpha x^*;\quad z = z^* \tag{2}$$

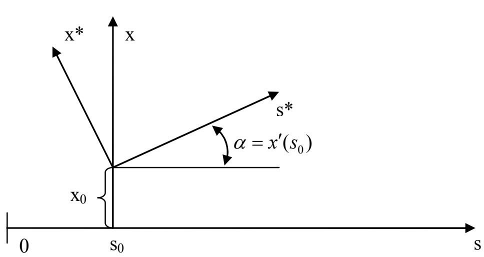

Figure 4: Moving coordinate system.

Transformation of magnetic fields in the moving coordinate system looks like this:

$$\begin{aligned} B_x^* &= B_x\cos\alpha - B_s\sin\alpha \\ B_s^* &= B_x\sin\alpha + B_s\cos\alpha \\ B_z^* &= B_z \end{aligned} \tag{3}$$

The hyperbolic and trigonometric functions are expanded to third order in x and z. After changing old variables by new ones (see eq. 2) we collect the coefficients of x^*, z^*, x^{*2}, z^{*2} ... and so on. We note that we use the following approximation for $\cos(k_s s)$ and $\sin(k_s s)$:

$$\begin{aligned} \cos\left(k_s\left(s_0 - x'x^*\right)\right) &\approx \cos(k_s s_0) + k_s\alpha x^*\sin(k_s s_0) \\ \sin\left(k_s\left(s_0 - x'x^*\right)\right) &\approx \sin(k_s s_0) - k_s\alpha x^*\cos(k_s s_0) \end{aligned} \tag{4}$$

Taking into account the approximate equations of particle motion

$$a = x' = \frac{\sin(k_s s)}{k_s\rho},\qquad x_0 = \frac{\cos(k_s s)}{k_s^2\rho} \tag{5}$$

and, when averaging the coefficients over period insertion devices, with neglecting small quantities we finally obtain the expressions for the magnetic field linear and nonlinear components near the equilibrium orbit:

$$\begin{aligned} \bar{B}_x(x^*,z^*) &= \frac{B_0}{2\rho}\left(\frac{\left(k_s^2-k_x^2\right)}{k_s^2}z^* + \frac{k_x^2\left(k_x^2-3k_s^2\right)}{2k_s^2}z^*x^{*2} + \frac{k_z^2\left(k_s^2-k_x^2\right)}{6k_s^2}z^{*3}\right) \\ \bar{B}_z(x^*,z^*) &= \frac{B_0}{2\rho}\left(\frac{\left(k_s^2-k_x^2\right)}{k_s^2}x^* + \frac{k_z^2\left(k_s^2-k_x^2\right)}{2k_s^2}x^*z^{*2} + \frac{k_x^2}{2}x^{*3}\right) \end{aligned} \tag{6}$$

If we take $k_x = 0$ (infinite pole width) and normalize obtained field $\bar{B}_x(x^*,z^*)$ and $\bar{B}_z(x^*,z^*)$ by $B\rho$ the resulting effect on the transverse momentum of beam will be $\Delta p_x \propto \frac{B_0^2}{\lambda^2}xz^2$ and $\Delta p_y \propto \frac{B_0^2}{\lambda^2}z^3$.

The undulator will have bigger influence on the beam dynamic in contrast to other IDs. Furthermore as mention above the undulator will be installed in straight section with rather large values of β-functions so it will worsen the situation for sizes of the dynamic aperture (Fig. 5).

We have introduced the ID as drift space (neglecting a focusing in vertical plane) with a lumped nonlinear element positioned in the center of ID (6). All simulations were carried out at the energy of electron beam 2.5 GeV. As a result the vertical dynamic aperture size is decreased significantly (till ~ 6 mm) in comparison with dynamic aperture for Siberia-2 optics without IDs (~ 25 mm) (Fig. 3).

The expressions (6) are just preliminary result because the expressions were obtained for zero initial conditions (z = x = 0). In fact, the influence on the beam is much more complicated and it is not allowed to obtain the resulting impact on the particles motion with non-zero initial conditions x, z ~ ± 20 mm with accuracy, which is required for calculating DA. However, this result has initiated a further study of the impact of insertion devices on the dynamic aperture.

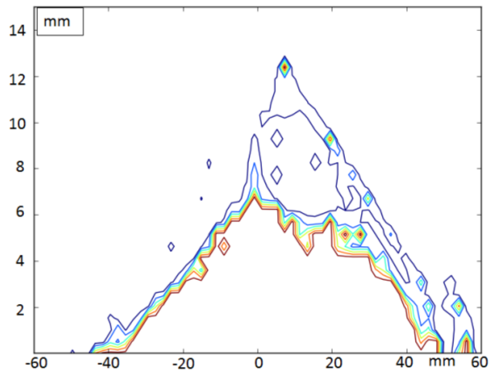

Figure 5: Dynamic aperture without IDs and with the undulator.

Runge-Kutta approach

To solve this problem a solver for calculation of electron trajectory in ID by Runge-Kutta method was developed. Magnetic fields was used as indicated in (1). This solver was designed as module for framework XCODE. XCODE is common project of scientific groups of XFEL, DESY and Kurchatov Institute [2]. The architectural features of this framework allow relatively easy to carry out the tracking of particles through complex structures containing IDs, lenses, bending magnets and more.

Fig. 6 also shows small vertical size of ~ 3 mm obtained by Runge-Kutta method for Siberia-2 DA with in-vacuum ondulator.

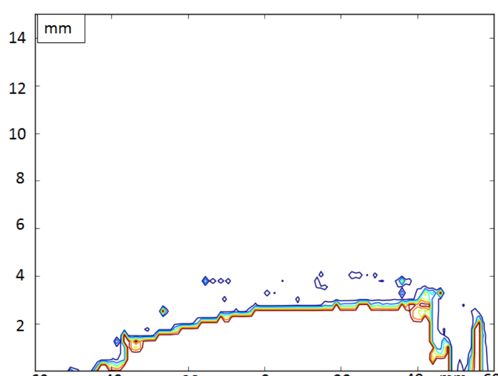

Figure 6: Dynamic aperture with the undulator (Runge-Kutta method).

Thus, the expression (6) for the insertion device allowed us to predict the reduction of the vertical aperture. At the same time, the effect on the aperture of the 3T wiggler and 7.5T wiggler are small (Fig. 7).

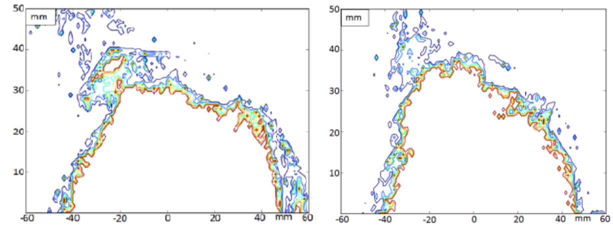

Figure 7: Dynamic aperture with 3T wiggler (left) and 7.5 T wiggler (right). Runge-Kutta integrator was used.

Fig. 8 shows dynamic aperture of storage ring Siberia-2 with all insertion devices installed on the ring (Table 1). The trajectory of the electrons inside ID was calculated by the Runge-Kutta method. As seen dynamic aperture decreased and in the horizontal direction up to ± 25 mm.

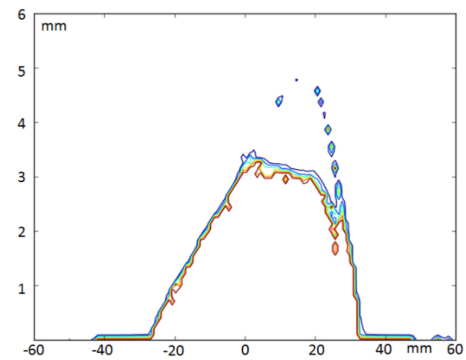

Figure 8: Dynamic aperture with all IDs.

CONCLUTIONS

The expressions for the integral influence of the undulator field provides a qualitative understanding of the effect insertion devices on the beam dynamics. The calculations have shown a significant decrease in the size of the dynamic aperture under the influence of the undulator. It is necessary to consider the possibility to compensate the effect on the dynamic aperture of the undulator, even though the minimum gap of the undulator is 2 mm.

One of the easiest ways to extend the dynamic aperture is to install the undulator in straight section with small amplitudes β-functions. In this case vertical aperture will be the order of ± 10 mm.

REFERENCES

[1] K.Halbach, “Field of undulators and wigglers“, Workshop on magnetic errors, Brookhaven (1986).
[2] Towards realistic modeling of FEL radiation, these proceedings.

ISBN 978-3-95450-122-9