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RESEARCH OF LOCALLY-ROUND BEAM IN HEPS STORAGE RING USING SOLENOIDS

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Abstract

"Round beam", that is, a beam with equivalent transverse emittance, is expected for a significant fraction of the beamline users in light sources. We investigate the possibility of reaching round beam in a storage ring, by means of a local exchange of the apparent horizontal and vertical emittance, performed with solenoids in a dedicated insertion line in the storage ring. In this paper, we show that a locally-round beam can be achieved by using solenoid in High Energy Photon Source (HEPS) storage ring, particularly to one of the design having natural emittance of 34.2 pm·rad.

INTROUDUCTION

The so called ultimate storage rings(USR) or 4th generation storage ring light source, with electron emittance smaller than 100 pm·rad, and on the scale of the diffraction limit for hard X-rays in both transverse planes, have the potential to deliver photons with much higher brightness and higher transverse coherence than currently operational light source [1]. The High Energy Photon Source (HEPS), with a beam energy of 6 GeV, a natural emittance of 34.2 pm·rad and a storage ring circumference of 1360.4m, is a 4th generation storage ring light source to be built in Beijing [2].

In general, the intrinsic bending layout is horizontal, the vertical dispersion is generally very small or ideally zero. So the horizontal emittance is much larger than vertical plane, it is denoted that

$$\kappa = \varepsilon_y/\varepsilon_x \quad \varepsilon_x = \frac{\varepsilon_0}{1+\kappa} \quad \varepsilon_y = \frac{\kappa\varepsilon_0}{1+\kappa} \tag{1}$$

where ε_0 is the natural emittance, which can not be changed once the storage ring is determined. κ is the coupling factor, which is generally about 1% in the normal storage ring. However, for round beam, $\kappa = 1$.

To meet some users requirement on round beam, in this paper, we follow the work [3] to use a module with solenoid, insertion device and anti-solenoid(S-ID-AS) to realize locally-round beam in a straight section. As an application on HEPS storage ring, a S-ID-AS module is used in a 6m straight section to realize round beam, and particle tracking studies with the ELEGANT code [4], is consistent with theory very well.

S-ID-AS THEORY

Solenoid can introduce coupling between horizontal plane and vertical plane. If a flat beam passes through a solenoid, then the coupling factor is $\kappa = \varepsilon_y/\varepsilon_x = (\tan KL)^2$, so a round beam can be obtained by setting $KL = \pi/4$, where $K = B_z/(2B\rho)$, $C = \cos(KL)$, $S = \sin(KL)$. B_z is the field strength inside the solenoid, $(B\rho)$ is the magnetic rigidity, and L is the effective length of solenoid. If it is followed by an anti-solenoid with the length L and strength –K, one can remove the strong coupling [3]. With S-ID-AS moduler, the strong coupling region is in the moduler, and weak coupling region is in arc region, they can be well separated. Thus an insertion device can be used between solenoids to generate synchrotron radiation from round beam, such as a helical undulator, which has the same transfer matrixes in the horizontal and vertical planes [5]. S-ID-AS transfer matrix [6] is denoted that

$$M_{S-ID-AS} = M_{Asol} M_{hu} M_{sol} = \begin{bmatrix} R & 0 \\ 0 & R \end{bmatrix} \tag{2}$$
$$R = \begin{bmatrix} r_{11} & r_{12} \\ r_{21} & r_{22} \end{bmatrix}$$

$$M_{hu} = \begin{bmatrix} M1 & 0 \\ 0 & M1 \end{bmatrix} \tag{3}$$
$$M1 = \begin{bmatrix} \cos(\frac{B_0 l}{\sqrt{2}B\rho}) & \frac{\sqrt{2}B\rho}{B_0}\sin(\frac{B_0 l}{\sqrt{2}B\rho}) \\ -\frac{B_0}{\sqrt{2}B\rho}\sin(\frac{B_0 l}{\sqrt{2}B\rho}) & \cos(\frac{B_0 l}{\sqrt{2}B\rho}) \end{bmatrix}$$

where B_0 is the peak field of wiggler, l is the length of wiggler, $(B\rho)$ is the magnetic rigidity. M_{Asol} is the transfer matrix of anti-solenoid, M_{hu} is the transfer matrix of helical undulator, and M_{sol} is the transfer matrix of solenoid.

S-ID-AS SECTION IN HEPS

The HEPS storage ring consists of 24 superperiods, and each superperiod contains one high-beta 10 m straight section and one low-beta 6 m straight section. Table 1 lists the main parameters of the ring. Figure 1 shows the optical function in one superperiod.

In a low-beta straight section, we adopt a solenoid and anti-solenoid with length of 2.125 m and field 14.79 T, which can be realized by now [7], and place a 1.75 m helical undulator with period of 2.5 cm and peak field of 0.5 T between them. The above parameters are conceptual design. From Eq.(2)(3), we can get

$$R = \begin{bmatrix} -0.3241 & 3.5772 \\ -0.2502 & -0.3241 \end{bmatrix} \tag{4}$$

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Table 1: Main Parameters of the HEPS Storage Ring

Parameter	HEPS
Beam energy/GeV	6
Beam current/mA	200
Bunch number	680/63
Natural emittance/pm·rad	34.2
Damping time(x/y/z)/ms	10.2/18.8/16.4
Momentum compaction	1.561×10-5
Betatron tune/(ν_x/ν_y)	114.14/106.23
Straight section length/m	6/6.07
Beta functions in low-beta and high-beta straight section (H/V)/m	2.802/1.912 (10.12/9.64)

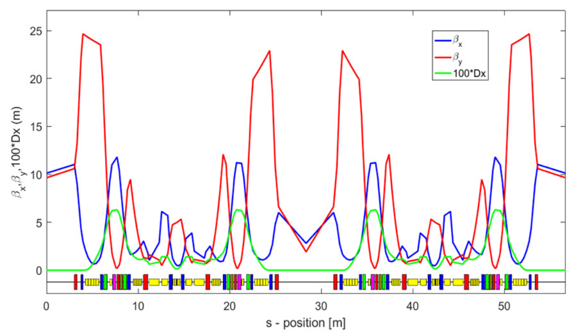

Figure 1: Optical function in a superperiod of the designed HEPS storage ring.

The S-ID-AS section will bring in large perturbations to the global optics. If without correction, the linear optics is unstable. We just adjust parameters of two quadrupoles next to straight section to match linear optics, Figure 2 shows the optical functions in low-beta straight section, the upper is original optical function, the bottom is optical function with correction including S-ID-AS section.

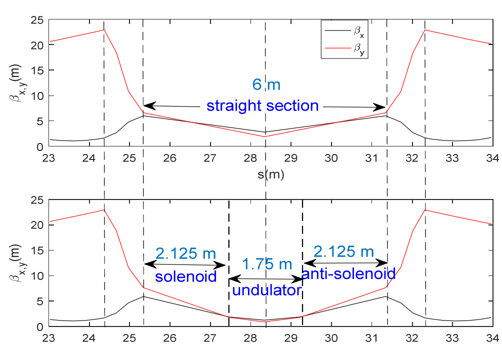

Figure 2: Optical functions in a low-beta straight section.

We separately analyzed dynamic aperture and frequency map for HEPS storage ring without error and including S-ID-AS in a high-beta straight section. If without correction, the horizontal dynamic aperture is reduced to less than 1 mm, horizontal and vertical tune increases by 0.11, thus we completely correct horizontal and vertical tune by adjusting slightly 4 quadrupoles nearby the straight section of each superperiod except for the superperiod with S-ID-AS moduler. Figs. 3 and 4 show it. By contrast, we can find that the horizontal and vertical tune completely corrected. The horizontal dynamic aperture is reduced from 6 mm to 3.5 mm and the vertical dynamic aperture is reduced from 4.5 mm to 3 mm. Optimizing dynamic aperture is in progress.

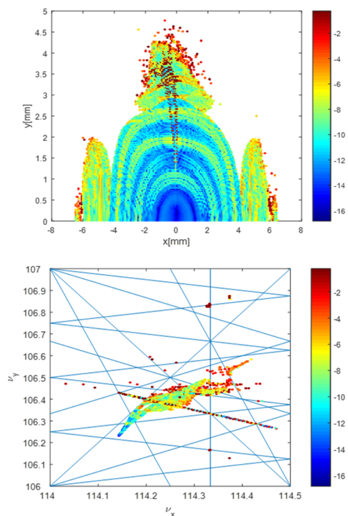

Figure 3: Dynamic aperture (upper) and frequency map (bottom) for HEPS storage ring without error.

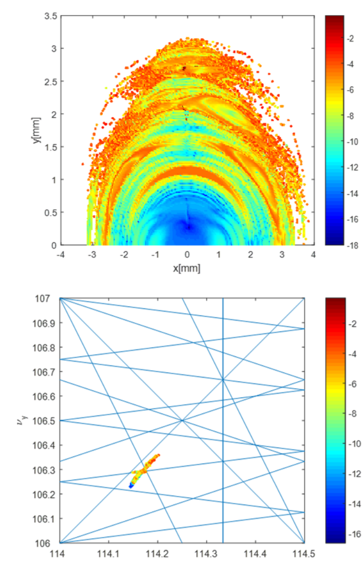

Figure 4: Dynamic aperture (upper) and frequency map (bottom) for HEPS storage ring including S-ID-AS section in a low-beta straight section.

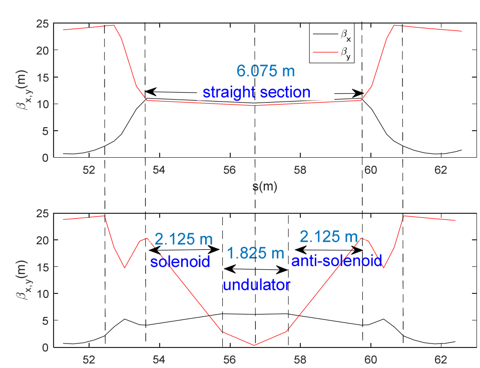

Figure 5: Optical functions in a high-beta straight section.

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Moreover, we use same method in one high-beta 10 m straight section, specific parameters are as shown in Fig. 5. Figure 6 shows the dynamic aperture and frequency map with S-ID-AS section in high beta section after tune correction. By contrast, we can find that the horizontal dynamic aperture is reduced from 6 mm to 4 mm and the vertical dynamic aperture is reduced from 4.5 mm to 3 mm, the horizontal and vertical tune completely corrected. Optimizing dynamic aperture is in progress.

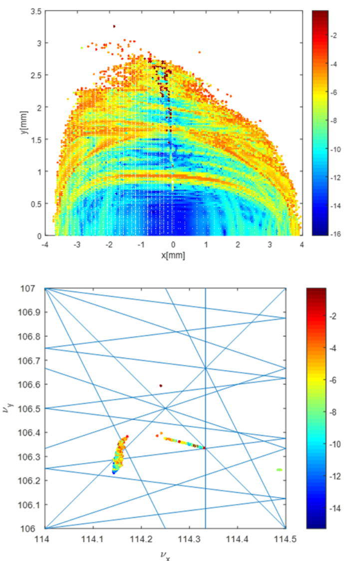

Figure 6: Dynamic aperture (upper) and frequency map (bottom) for HEPS storage ring including S-ID-AS section in a high-beta straight section.

TRACKING WITH ELEGANT

To verify the S-ID-AS section theory, we use the ELEGANT code to track particles for the HEPS storage ring including S-ID-AS section. In the simulation, the parameters are as follows: RF cavity voltage is 3.4 MV, RF cavity frequency is 166.6 MHz, the bunch length is 4.8 mm, and the energy spread is 1.06×10^{-3}. We track 2000 particles for 20000 turns with ELEGANT, there is no particle loss. Figure 7 shows the evolution of phase space distribution at the solenoid start, helical undulator and anti-solenoid end, we can intuitively see the evolution of "flat beam—round beam—flat beam", which is consistent with the theory well. Figure 8 shows the evolution of transverse emittance at the solenoid start, helical wiggler and anti-solenoid end, we can find that the transverse emittance reach equilibrium value after 10000 turns, $\varepsilon_x = \varepsilon_y \sim 17.25$ pm·rad in the helical undulator, $\varepsilon_x = \varepsilon_y \sim 34.5$ pm·rad in the solenoid start and anti-solenoid end, which is consistent with the theory well.

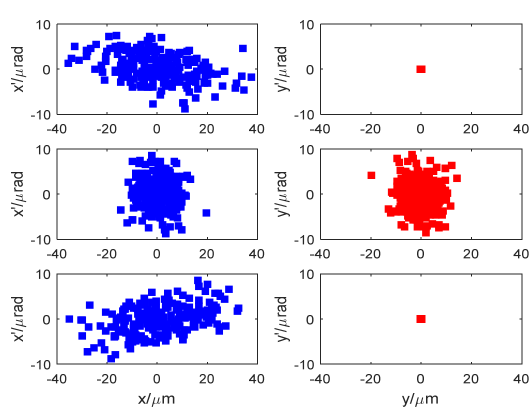

Figure 7: The evolution of phase space distribution at the solenoid start (upper), helical undulator (middle) and anti-solenoid end (bottom).

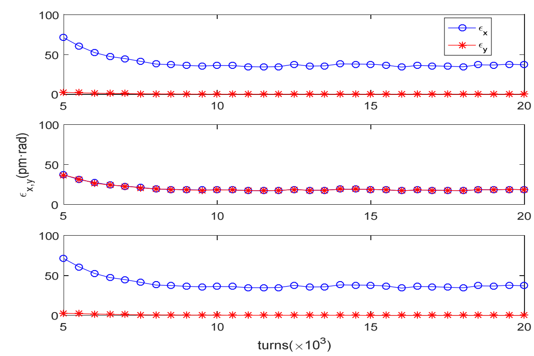

Figure 8: The evolution of transverse emittance at the solenoid start (upper), helical undulator (middle) and anti-solenoid end (bottom).

CONCLUSION

A locally-round beam by using solenoid is realized in High Energy Photon Source (HEPS) storage ring straight section. In the case of limited space and limited variables, we found separately matching parameters in high and low beta straight section without changing the position of the magnets, and verify the result of locally-round beam by tracking particles with ELEGANT. Although the horizontal and vertical tune completely corrected, we are at the expense of smaller dynamic aperture. However, no particles loss is observed during tracking. If without space limit and variables limit, we can try to optimize the dynamic aperture, which is now under way.

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