EFFECTS OF SUPERCONDUCTING MAGNET ON THE BEAM DYNAMICS IN SRRC STORAGE RING

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Abstract

Different types of superconducting magnets are considered to add in the storage ring of SRRC. The possibility to replace the central conventional bending magnet of the TBA lattice by a superconducting bending magnet is investigated. Two possible locations for the installation of the superconducting wiggler in the storage ring are also studied and presented.

1 INTRODUCTION

TLS of SRRC is a 1.5 GeV storage ring dedicated for VUV and soft X-ray application. In order to raise the photon energy and flux for research the possibilities to add high field superconducting magnet in the ring are studied.

One is to replace the central conventional bending magnet of the TBA lattice by a superconducting bending magnet(SCB). The impact of replacing such superconducting bending magnet on the ring lattice is studied. The effort to bring back the design lattice is made and the results are shown.

The other is to install a superconducting wiggler(SCW) in the storage ring. A preliminary study for the effect of the SCW at one long straight section has been performed[1]. Work is continued and the possibility to put the SCW in the achromat region is also investigated. The pole length is modified to 20 cm to save space. The results of the effects on the ring lattice, emittance and dynamic aperture are presented.

2 EFFECTS OF SUPERCONDUCTING BENDING MAGNET

The benefit of introducing superconducting bending magnets into the ring is that the energy and flux of emitted photon energy is increased. A comparison of photon flux between conventional bending magnet of 1.43 T and SCB of 7.5 T at beam energy 1.5 GeV is shown in Fig. 1. Moreover, using the SCB the space in the ring can be saved. For a well developed ring the spared space can be used for the installation of new devices into the ring.

The combined function bending magnet of TLS is a 1.22 m long rectangular type magnet with bending radius of 3.495 m. The bending angle of this magnet is 20 degree. The bending field is 1.43 tesla and a defocusing gradient of 1.851 T/m. A superconducting bending magnet with bending angle 20 degree and magnetic field of 7.5 T is planned to replace the middle bending magnet of the TBA lattice. The corresponding bending radius is 0.66713 m and the effective length is 0.23287 m. The total circumference is increased to 0.01015 m due to this change.

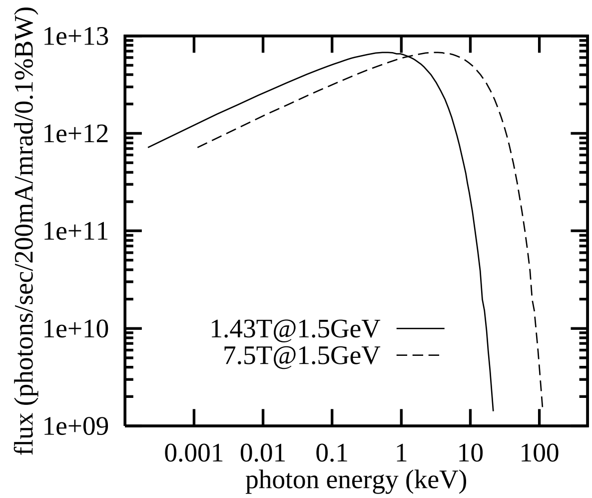

Figure 1: Comparison of photon flux of conventional bending magnet and SCB.

The path lengthening should be accompanied by reducing the fundamental RF frequency by 42 kHz. A pure SCB without field gradient is assumed. The effect of eliminating the defocusing gradient in the SCB and different strong edge focusing due to such high field are studied. The comparisons of these magnets are listed in Table 1 . The emittance and tune changes by SCB are shown in Table 2.

Table 1: Comparison of conventional bending magnet and superconducting bending magnet.

	conventional	SCB (I)	SCB (II)
θ (degree)	20	20	20
B_0 (T)	1.43	7.5	7.5
ρ (m)	3.495	0.66713	0.66713
ℓ (m)	1.22	0.23287	0.23287
type	rectangular	sector	rectangular
edge (m^{-1})	-0.0504	0.0	-0.2643
gradient ($\frac{T}{m}$)	-1.8513	0.0	0.0

Table 2: Parameters of the unmatched SCB lattice.

	conventional	SCB (I)	SCB (II)
ϵ_0 10^{-8}m.rad	2.56	5.96	4.31
ν_x	7.18	7.1863	7.2350
ν_y	4.13	4.2855	4.1432

In Table1, conventional represents the conventional bending magnet, SCB(I) is a sector magnet and SCB(II) is a rectangular magnet. In SCB(II), the strong edge focusing effect approximately compensates the combined function gradient in the vertical plane. So it does not need to put additional defocusing quadrupole in the new lattice. On the contrary in SCB(I), the lack of edge focusing requires a defocusing quadrupole to compensate the field gradient. Therefore a 20 cm long quadrupole SQ5 with field strength 2.4 m^{-2}, 10 cm from SCB(I), is added. The lattice is rematched by adjusting the strength and position of quadrupole SQ4(and SQ5 in SCB(I)) in the achromat to match the condition of dispersion free in the long straight section. Here SQ4 is the original Q4 in the TBA lattice for dispersion matching in SCB section. The other three pairs of quadrupoles in the long straight section are used to match the twiss function at both ends to the design value. For each type of SCB two different matching conditions are constrainted. One is to get a minimum emittance without rematching the tune. The other is to match both tune and twiss functions. The matched twiss functions are shown in Fig 2, 3 and 4. The ring parameters of matched lattice are given in Table 3. It shows that the emittance of the SCB lattice is higher than the design lattice. The beam size might be enlarged. An effort to keep the emittance growth less than 10% is made.

Table 3: Parameters of matched SCB lattice.

	smaller emittance match		tune, α, β match	
	SCB (I)	SCB (II)	SCB (I)	SCB (II)
$\epsilon_0\, 10^{-8}$m.rad	3.36	3.70	6.33	5.83
ν_x	7.386	7.342	7.18	7.18
ν_y	4.245	4.149	4.13	4.13
SQD1 (m^{-2})	2.38	2.0	2.19	1.98
SQF2 (m^{-2})	3.31	3.26	2.97	3.045
SQD3 (m^{-2})	0.68	1.21	0.21	0.806
SQF4 (m^{-2})	3.60	3.14	2.99	2.846
SQD5 (m^{-2})	2.61	–	1.75	–

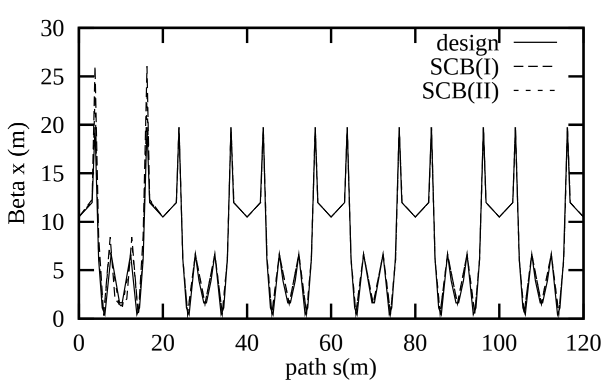

Figure 2: Matched SCB and the design β_x.

3 EFFECTS OF SUPERCONDUCTING WIGGLER

The superconducting wiggler used in this study consists of one full pole and two half poles with equal pole period length of 20 cm and tip magnetic field strength of 7.5 T. The first and second integral of the SCW is zero. Therefore there are no orbital offset and angle deflection after the beam passing through the SCW. An analytical expression for tield pattern of the SCW is given by[2]:

$$\begin{aligned} B_y &= B(m)\sin(k_p(z-(m-1)A_p/2)) \\ &\quad (1+\{(k_p y)^2/2! + (k_p y)^4/4!\}) \\ B_z &= B(m)\cos(k_p(z-(m-1)A_p/2)) \\ &\quad (k_p y + \{(k_p y)^3/3!\}) \end{aligned} \tag{1}$$

Where m indicates the pole number. For a one-full-pole and two-half-pole SCW, $B(m)$ is given by $B(1) = -B_0/2$, $B(2) = B_0$ and $B(3) = -B_0/2$. k_p is the wave number of the field. The first term in B_y gives the deflection in the trajectory, while the first term in B_z causes vertical focusing. These are the linear optics perturbation due to the SCW. In order to simulate the effect of SCW on the ring lattice, the SCW is cut into pieces of rectangular magnets in lattice input file in program like

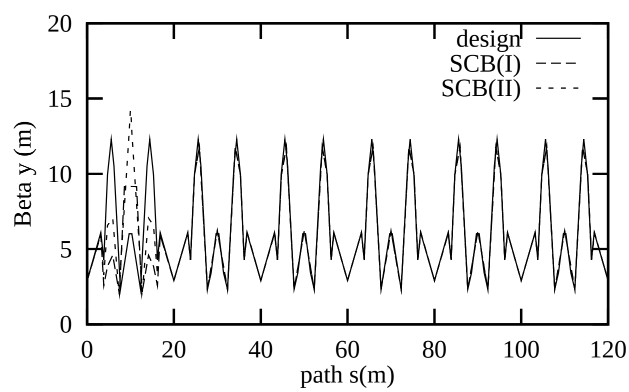

Figure 3: Matched SCB and the design β_y.

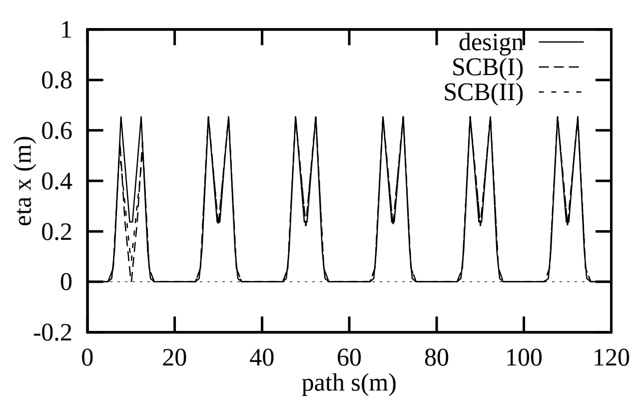

Figure 4: Matched SCB and the design dispersion function.

MAD or PATPET[3]. The arrangement of the rectangular magnets is chosen to have the introduced deflection angle and effective vertical focusing strength. Each pole of the SCW is cut into five rectangular magnets of equal length. The corresponding sinusoidal field strength at the center of each piece is the same as the field strength of the rectangular magnet.

Two different proposed locations for SCW in the ring, one in the achromat region and the other in the long straight section, are simulated by using the program MAD. The input of SCW in the program uses the hard edge model described in the previous paragraph. Compared with the original lattice, the vertical beta function is distorted by the effective vertical focusing of SCW. While the horizontal beta function keeps the same. The dispersion function is also the same. In order to restore the distorted lattice, two steps are adapted. First the twiss function of the other sections are restored by using each quadrupoles triplet in the dispersionless region at both sides of the SCW section. Then the tune of the lattice is matched to the designed value by using the global quadrupoles Q1 and Q2. After matching, the tunes and emittance of both position are given in Table 4 and Table 5 respectively. The vertical tune changes from 4.13 to 4.2115 when SCW is in the achromat, and changes to 4.2266 when SCW is in the long straight section without compensation. The emittance grows from 2.56×10^{-8}m.rad to 5.68×10^{-8}m.rad in the achromat and grows to 3.33×10^{-8}m.rad for that in the long straight. The emittance growth is larger when the SCW is in the achromat. After the lattice is restored, the emittance is reduced for SCW in the achromat. But it increases in the long straight section case. However after the lattice is restored the emittance for SCW in the achromat is still larger than that in the long straight section.

The dynamic aperture trackings were performed by using the modified program PATPET[3]. The dynamic aperture tracking of SCW lattice without matching is done at the insertion middle. Then with lattice compensation the SCW lattice is tracked while still neglecting the nonlinear field effect of SCW. The dynamic aperture tracking includes the nonlinear field of SCW as shown in Equation(1) up to 5th order. At last a set of ring multipole errors in other magnets as listed in reference[1] are added to simulate the dynamic aperture. The results of dynamic aperture are also listed in Table 4, 5. In the tables, DA1 represents dynamic aperture tracking without nonlinear field of SCW, DA2 represents with nonlinear field and DA3 represents dynamic aperture tracking with nonlinear field of SCW and a set of multipole error of the ring magnets. It shows that the reduction of the dynamic aperture of SCW in the achromat is due to the linear field of the SCW in both planes. The reduction of the dynamic aperture in the long straight case is due to the linear field of the SCW for vertical plane. While the dynamic aperture of the horizontal plane decreases as more field errors are added. The restoration of the lattice will gain some dynamic aperture. It shows that putting the SCW in the long straight section is better than in the achromat region from the beam dynamics point of view.

Table 4: Parameters of matched SCW lattice in the achromat region.

	unmatch	$\alpha,\ \beta$ match	$\alpha,\ \beta$, tune match
$\epsilon_0\ 10^{-8}$m.rad	5.68	4.57	4.81
ν_x	7.18	7.176	7.18
ν_y	4.2115	4.295	4.13
DA1	10.2	8.96	12.11
(H) mm	-12.77	-8.96	-12.11
DA1	8.21	21.67	11.39
(V) mm	-8.21	-21.67	-11.39
DA2	10.2	5.38	6.1
(H) mm	-12.77	-8.33	-4.9
DA2	8.21	13.96	5.16
(V) mm	-8.21	-13.96	-8.96
DA3	4.46	5.48	—-
(H) mm	-4.46	-5.48	—-
DA3	4.84	18.84	—-
(V) mm	-4.84	-13.9	—-

Table 5: Parameters of matched SCW lattice in the long straight.

	unmatch	$\alpha,\ \beta$ match	$\alpha,\ \beta$, tune match
$\epsilon_0\ 10^{-8}$m.rad	3.33	3.61	3.49
ν_x	7.18	7.17	7.18
ν_y	4.2266	4.23	4.13
DA1	23.68	24.85	28.40
(H) mm	-23.68	-19.85	-23.44
DA1	5.735	12.78	11.33
(V) mm	-5.735	-12.78	-11.33
DA2	17.96	19.59	28.4
(H) mm	-17.07	-19.59	-23.44
DA2	5.03	9.0	4.68
(V) mm	-5.03	-9.0	-4.68
DA3	6.14	6.84	6.7
(H) mm	-6.14	-6.84	-6.7
DA3	5.55	9.09	2.69
(V) mm	-5.55	-9.09	-2.69

4 REFERENCES

[1] J.C. Lee, "Preliminary Study of the Wavelength Shifter Effect in SRRC Storage Ring", PAC'97, Vancouver, May 1997.

[2] Dan Y. Wang, F. C. Younger and H. Wiedemann, "Incorporation of a 5T Superconducting Wiggler in the MIL Model 1.2-400 Synchrotron Light Source", 1991 IEEE PAC.

[3] The modified program PATPET is provided by Professor H. Wiedemann.