Physics design of SSRF synchrotron radiation security*

XU Yi(徐毅)[1)] DAI Zhi-Min(戴志敏) LIU Gui-Min(刘桂民)

(Shanghai Institute of Applied Physics, CAS, Shanghai 201800, China)

Abstract High brightness of SSRF brings about synchrotron radiation security problems, which will be solved in physics design. The main radiations are generated from bending magnets and insertion devices. Since the fact that radiation power and radiating area are different in these two kinds of synchrotron radiation, the arrangements of photon absorbers, diaphragms and other vacuum components need to be treated distinctively. In addition, SSRF interlock protection threshold is defined and the beam orbit in the straight line is limited. Hence, beam orbit in the bending magnets and IDs are also restricted by the threshold. The orbit restriction is calculated and helps us to arrange the vacuum components. In this paper, beam orbit distortion restricted by interlock protection threshold, radiation power, radiation angle and illuminating area are calculated. From the calculation results, the physics designs in manufacture and installation vacuum components are put forward. By commissioning, it is shown that physics requirements are met rigidly in the engineering process.

Key words SSRF, synchrotron radiation, interlock protection threshold

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1 Introduction

The SSRF is a third generation light source[1]. The electron energy attains 3.5 GeV, runs at 300 milliamperes with emittance at 4.8 mm·rad. Hence, the synchrotron radiation of SSRF is of high energy density. When the synchrotron radiation illuminates some vacuum components, they may be destroyed and the vacuum divulgence will happen. For example, if high brilliance radiation illuminates directly the vacuum chamber, it is probable to cremate the vacuum chamber, and arouses the vacuum divulgence. For another example, when the high brilliance radiation illuminates the flanges, the flanges temperature will rise, and the vacuum leaking will happen.

Therefore, for the third generation light source, thermal security problem will be treated carefully on wide range. Every segment that is probable to bring about the thermal security problems should be checked. The quantitative calculation is needed, and finally it should be judged if there are any thermal security problems and how to solve them.

In the following paragraphs, firstly, we will present settings of SSRF interlock threshold protection. Secondly, we calculate the phase distribution evolution of electron beam in the SSRF storage ring, and describe these evolutions with graphs. On the third part, the arrangement of SSRF absorbers is presented, and the installation status of vacuum components will also be mentioned. With the SSRF commissioning experiences, we estimate the design and accomplishment of the SSRF vacuum thermal security in the final part.

2 Settings of SSRF interlock threshold protection

During the SSRF commissioning period, when the close orbit is more than 2.5 mm in horizontal direction and 0.5 mm in vertical direction, the electron beam current is limited strictly to less than 5 mA. In this case, the synchrotron radiation will not do harm to the vacuum components.

But, during the normally machine running, if the beam with 3.5 GeV energy runs at 300 mA, the total radiation power generated by the bending magnets reaches 434 kW and the max radiation power density

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1) E-mail: xuyi@sinap.ac.cn

attains 20 W/mm^2 on the absorber. All radiation from bending magnets should be absorbed effectively by photon absorbers.

On the other hand, the radiations from insertion devices are even much powerful than bending magnets. If the nearby photon absorbers were illuminated by IDs' radiation, the radiated max power density on absorbers would be about 600 W/mm^2 and the absorbers would be melted. So these radiations should be wholly released to beamlines.

To protect the machine from synchrotron radiation damage, we set the SSRF interlock protection threshold. If the beam position departed the center orbit more than the threshold at any one of high precision BPMs, which are located at the ends of straight sections, the interlock protection should be waken and the RF would be power off at once, then the machine would stop working. Interlock protection threshold settings have been described in some other light sources. Certainly, the values of interlock protection threshold in different light sources[2] are different. As for SSRF, the threshold values are (2.5 mm,0.5 mm). It means that, at the end of every straight section, if the electron beam position is large than 2.5 mm in horizontal direction or 0.5 mm in vertical direction, the interlock protection would play its role.

As a part of the lattice design, we should discuss the influence on the beam orbit because of the interlock threshold protection. By calculating the max orbit distortion permitted by the threshold, we will reasonably arrange the vacuum components and protect vacuum system from heat hurt. Because the threshold is set on high precision BPMs that are located at the end of straight sections, it is easy to get a conclusion that the beam position and momentum shift at the center of the straight section should meet,

$$-X_{\max} \leqslant X \pm X' \times L/2 \leqslant X_{\max}, \\ -Y_{\max} \leqslant Y \pm Y' \times L/2 \leqslant Y_{\max}, \tag{1}$$

where, $X_{\max} = 2.5$ mm, $Y_{\max} = 0.5$ mm, which present the interlock protection threshold. X and X' are the possible shift of beam position and momentum in horizontal direction respectively. Y and Y' are the possible shift of beam position and momentum in vertical direction respectively. L is the distance between two BPMs located at the end of one straight section.

3 Beam phase distribution at radiation point

Because of interlock threshold protection, the beam transverse position and momentum shift at the center of straight section should be restricted strictly. From formula (1), we can express it with the following two graphs. The x-axis presents beam position shift and the unit is meter. The y-axis presents beam momentum shift and the unit is radian.

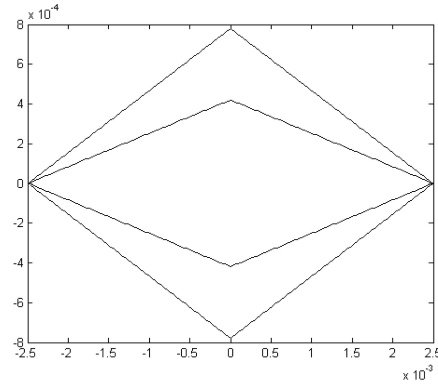

Fig. 1. X-X' distributions at different straight sections center.

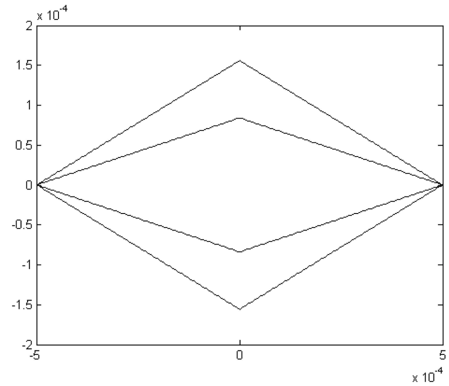

Fig. 2. Y-Y' distributions at center of different straight sections.

There are two kinds of straight sections with different lengths in SSRF. One is 6.5 meters long in length, and the other is 12 meters. In the upper two graphs, the covered area by the small diamond represents the possible beam phase status of the long straight sections, and the large one represents that of the short straight sections. The upper two graphs also represent the restriction of transverse phase space of radiation center point in IDs.

After the straight section, the beam passes through several quadrapole and sextrapole magnets, then arrives at the entrance of the bending magnet. At this point, the beam transverse phase space distribution changes. Transverse phase space distribution also changes in bending magnets, and the evolving process can be simulated by code AT[3]. We have simulated the evolvement and plot the process with the following figures.

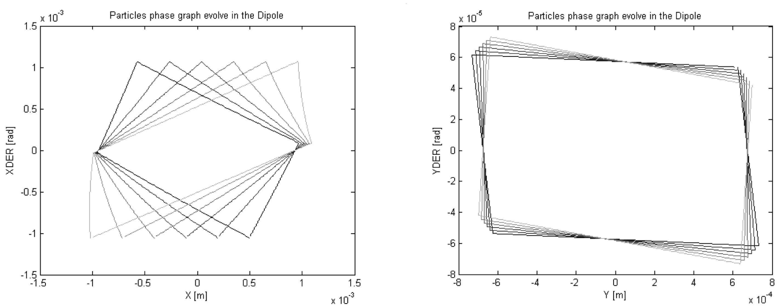

Fig. 3. Horizontal and vertical beam phase space distribution evolvement in the bending magnet.

From the upper figures, because of the restriction of interlock protection threshold, the max position and momentum shift in horizontal direction are less than 1.2 mm and 1.2 mrad respectively. At the same time, the max position and momentum shift in vertical direction are less than 0.8 mm and 0.08 mrad respectively.

In this simulation, we neglect the effects of magnetic field errors. There are two reasons that we do not set the corrector strength and field errors. Firstly, the correctors are used to correct the orbit shift to zero. Secondly, after using BBA and LOCO[4] technologies, the beam orbit should be corrected to be very close to ideal orbit.

4 Physics design for the heat loading components

a) Shield of bending magnets radiation

The SSRF vacuum system is made up of beam chamber and antechamber. The photon absorber is installed in the antechamber. Fig. 4 is a structural map of the absorbers arrangement in a unit of SSRF. The absorbers position is labeled by AB and the blue area represents the synchrotron radiation. From this graph, it is clear that all the radiation will be absorbed by the photon absorbers in horizontal direction. To guarantee this target, the absorbers are designed with 5 mm's remainder in length to compensate for the alignment and installation errors, which is less than 1.5 mm in the real installation process.

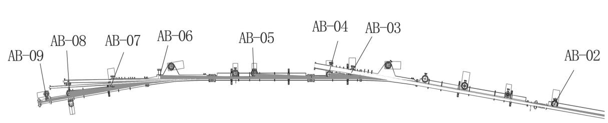

Fig. 4. Photon absorbers arrangement in a unit of SSRF.

In the vertical direction, the radiation vertical shift is brought about by the radiation angle and beam orbit shift. It is well known that the radiation angle is $\sim 1/\gamma$. And from the previous discussion, we know that the max position shift Δy and momentum shift $\Delta y'$ are less than 0.8 mm and 0.08 mrad respectively. So it is easy to get the upper limit of radiation area,

$$Y_{\max} = \Delta y + (1/\gamma + \Delta y') \times L + y_{\text{err}}\,, \tag{2}$$

where, L is the distance from the light source point to the absorber, and y_{err} is the installation errors of absorber in vertical direction. The designed vertical size of absorber should be larger than $Y_{\max}$, then the bend radiation security in vertical direction will be met.

b) Extraction of bending magnets radiation

In the SSRF vacuum chamber, the bend radiation is extracted through the center of absorber and a flange hole at the end of chamber. Then, the light is released to beamline. We pay attention to whether the light would illuminate the flange. To calculate the horizontal shift of light at flange hole, we do some geometrical analysis and then get the result,

$$\delta_{\text{h}} = D_2 \times \frac{\Delta x}{D_1}, \tag{3}$$

where D_1 is the distance from the radiation point to absorber, and D_2 is the distance from the absorber to the flange. Δx is the beam horizontal position shift at radiation point. The influence of beam horizontal momentum shift can be neglected. By the way, δ_{h} is the remainder of the flange hole that should be saved by the SSRF design.

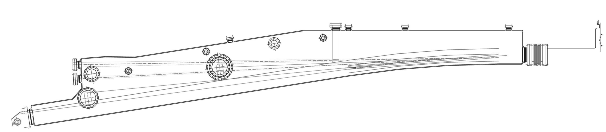

Fig. 5. Extraction of SSRF bending magnets radiation.

As well as in the front-end designation, the diaphragm size is designed under this way. Here, D_2 represents the distance from the absorber to the diaphragm.

c) Extraction of IDs radiation

In the first installation stage of IDs, there are five IDs to be installed in five straight sections. These IDs have different radiation power and radiation angles. We calculate the horizontal radiation angle and vertical radiation angle respectively by the following formula[5],

$$\sigma'_\theta \approx \sqrt{1+K^2}/\gamma, \qquad \sigma'_\psi = 0.665/\gamma, \tag{4}$$

where, K is the wiggler parameter. And the total radiation power is[5],

$$P_T[\mathrm{kW}] = 0.64E^2[\mathrm{GeV}]B_0^2[T]I[A]L_\mathrm{W}[m], \tag{5}$$

where E is the electron energy. B_0 is the induced magnet field of wiggler. I is the current of beam. L_W is the effective length of wiggler.

Then, the radiation power at the center of the illuminated area arrives,

$$A = \frac{P_T}{2\sqrt{2\pi}\Sigma_{xp}\sigma_{yp}}, \tag{6}$$

where

$$\Sigma_{xp} \cong \sqrt{1.2\varepsilon_x\beta_x + L^2\left(1.2\frac{\varepsilon_x}{\beta_x} + \sigma'^2_\theta\right)}$$

is the radiation size in horizontal direction, and

$$\sigma_{yp} = \sqrt{\varepsilon_y\beta_y + L^2\left(\frac{\varepsilon_y}{\beta_y} + \sigma'^2_\psi\right)}$$

is the radiation size in vertical direction.

Using the upper formulae, we get the light way of IDs' radiation. During the installation process, the absorber hole and vacuum chamber in beamline are installed carefully to let IDs' light pass through sufficiently.

5 Conclusion

Manufacture and installation of the SSRF vacuum components have been accomplished before the end of 2007. These two processes are carried out rigidly under the previous discussions. A lot of detailed technologies are neglected. But it will not produce disadvantages to our topic. Now, the commissioning of SSRF is going on and physics design of bend radiation security is being verified. When the beam current arrives at 100 mA at 3.0 GeV, we don't find any abnormal temperature rise on vacuum chamber. It means that the physics design is suitable for the SSRF bend radiation security. Insertion devices will begin to be installed in the SSRF storage ring at the end of 2008. So the design for insertion devices will be tested in later commissioning.

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