CALCULATION OF GAS BREMSSTRAHLUNG FOR DEFENSE IN THE LINEAR SECTION OF THE ELECTRON STORAGE RINGS OF THE BEPCII

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Abstract

The Beijing Electron Position Collider (BEPC) currently under IHEP will be one of the world's class synchrotron radiation (SR) facilities. The radiation dose problem in the BEPC is always attractive. From the whole range of the BEPC, the reason of the radiation is various and complex. The gas bremsstrahlung produced by the interaction of the primary storaged beam with residual gas molecules or ions in the storage ring vacuum chamber dominates the SR beam line shielding, which has not been sufficiently understood all time. We analyse the reason and effect of the bremsstrahlung, calculate the dose in the linear section of the storage rings, and propose the defense project to shield it

INTRODUCTION

The Beijing Electron-Positron Collider (BEPC) was constructed for both high energy physics (HEP) and synchrotron radiation (SR) researches. The BEPC-accelerator consist of a 202 m long electron-positron linac injector, a storage ring with a circumference of 240.4 m, and transport lines with the total length of 210 m. There are two interaction points in the storage ring. A general-purpose detector, the Beijing Spectrometer (BES), is installed in the south interaction region. The Beijing Synchrotron Radiation Facility (BSRF), equipped with 9 beamlines and 12 experimental stations, is flanking the east and west of the southern area of the storage ring. In present running conditions the beam energy can reach 1.55Gev @100mA in the colliding mode and 2.2Gev @137mA at the SR mode.

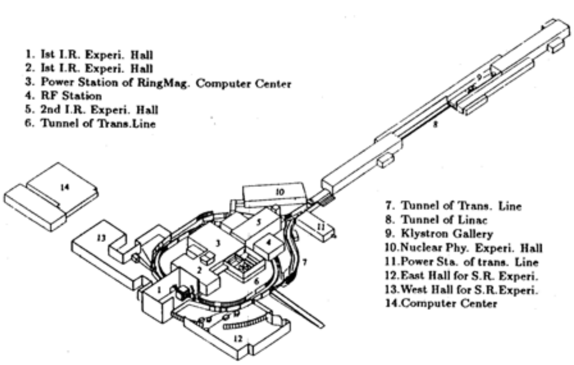

Figure 1: Layout of the BEPC

The BEPCII is an upgrading scheme from BEPC with a higher luminosity and the multibunch collision by means of pretzel orbits and bunch trains. The BEPCII will operate in the beam energy region of 1̃-2.0 GeV . In order to obtain a high duty factor of the collision, the injection time should be shorter than half an hour. The injector should be capable of the full-energy topoff injection up to 1.89 GeV, and the positron injection rate should be higher than 50 mA/min. As the machine will also be operated as a SR source, the upgrade of the collider should also provide an improved SR operation performance with higher beam energy and intensity, i.e. 250 mA at E = 2.5 GeV

Because some of the high-energy electron will be lost during the beam acceleration, an added radiation field is composed by kinds of sub-radiation produced by the photons and neutrons. According to the radiation defense, the main component are the photons, the neutrons and the μ particles. This paper discusses the bremsstrahlung which was brought by the electrons and residual gas at the end of the linac.

Currently, when the high-energy electrons run around the storage ring, their energy will loss. For the reason of radiation, once the electrons lost, the place where the electrons lost will be the radiation source ineluctably. The reason arousing the lost are many kinds: 1) when the BM and the KICKER change the movement direction of the beam., the electrons distributing around the beam envelope will strike the vacuum chamber wall and lose their energy; 2) because of the change of the beam aperture, the electrons distributing around the beam envelope would be scattered at the pipeline wall when they move linearly; 3) because the absolute vacuum can not be obtained, the residual gas molecules exist and collide with the high speed electrons , which leads to loss of electron energy and products the radiation; 4) due to quanta Effect, the electrons' athwartships displacement would change because they send photons in the storage ring. When the displacement overrun the dimension of the vacuum chamber, the electrons would knock the wall and be lost[2]. According to the distributed place of the radiation, we found the energy loss due to the BM and the change of the beam aperture only concentrate at some places in the ring, but the energy loss for the vacuum reason and the Quanta Effect distributes around the storage ring.

Although the reasons of the beam loss are so many, the reason for the radiation at the end of linear section is exclusive. Without the BM and the KICKER magnets or the obvious alteration of the beam aperture, the main reason for the radiation is the interaction between the high speed electrons and the residual gas molecules ,which products the bremsstrahlung. The bremsstrahlung spectrum of photons extends up to the energy of the primary beam. The number of the radiation dose increases obviously measurement.

Considering the eastern linear section connecting with the NO.12 hall and the collision area connecting with the NO.12 hall and NO.13 hall, the radiation dose here are high than the normal , although the long-short walls shield the wall. So we can conclude the main radiation is the bremsstrahlung. Now we can calculate the radiation dose by the material parameter

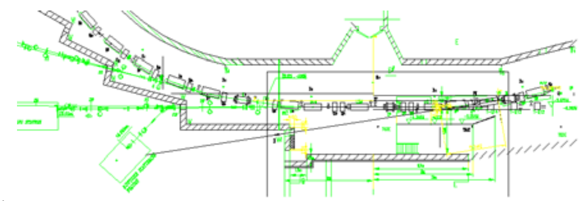

Figure 2: The east linear section of the ring IV area

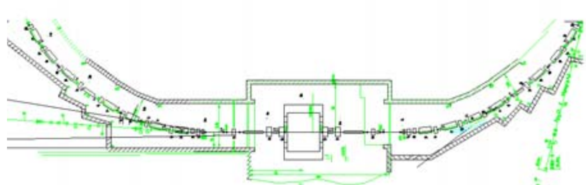

Figure 3: The linear section of the collision area

THE CALCULATSION OF THE GAS BREMSSTRAHLUNG IN THE STORAGE RING OF THE BEPCII

Gas bremsstrahlung is produced by the interaction of the primary storaged beam with residual gas molecules (H_2, CO, CO_2, CH_4, etc.) or ions in the storage ring vacuum chamber. It is produced in a narrow cone and the characteristic emission angle is given by 1/γ, where

$$\gamma = E_0 / m_0 c^2. \qquad (1)$$

E_0: primary beam energy;

m_0c^2: rest mass energy of electron/positron

As the primary beam energy E_0 increases the characteristic emission angle decreases, and the gas bremsstrahlung becomes more forward peaked. Gas bremsstrahlung becomes very important for straight sections in the storage ring, since the contribution from each interaction adds up to produce a narrow monodirectional beam. But at the corner of the storage ring where the beam swerves, the radiate energy produced a sector shape and the dose would not be so high. So the bremsstrahlung the main radiation contributed to the dose of the end of beam line.

(1) Ferrari's experiential formula

According to Ferrari et al., the maximum gas bremsstrahlung dose rate D (Gy/h) in the forward direction (for energies ranging from 100 MeV to 1 GeV and straight section lengths of 1 to 50 m) is given by

$$D = 2.5\times10^{-27}\left(\frac{E_0}{m_0c^2}\right)^{2.67}\frac{L}{d(L+d)}I\frac{P}{P_0} \qquad (2)$$

where

E_0 : the primary beam energy (MeV);

m_0c^2 : the rest-mass energy of the electron/positron (MeV);

L : the length of the straight section (m); d is the distance from the end of the straight section to the point of interest (m);

I : the stored beam current (e–/s);

P : the pressure in the straight section (Pa);

P_0: 1.33 x 10–7 Pa (10-9 torr).

d: the object distance

Since gas bremsstrahlung becomes more forward peaked as the primary beam energy increases, this expression was derived using different scoring areas at different energies. For E_0 > 500 MeV, a scoring area of 0.0059 cm2 was used.

(2) The gas bremsstrahlung was calculated by the formula for the linear section of the BEPC's storage ring and the BES area. The dosage are calculated for BEPC and BEPCII, as listed in Table 1 and Table 2, respectively:

Table 1: The dose of the BEPC in two modes

BEPC	E_0 (GeV)	I (mA)	L (m)	P (Pa)	d (m)	D (Gy/h)
Beam collide mode	1.55	100	13.5	1.064 x10^7	12	0.11
			13.5		23	0.40
			29.6		8	0.24
			29.6		15	0.11
Synchrotron radiation mode	2.2	137	13.5	1.064 x10^7	12	0.38
			13.5		23	0.14
			29.6		8	0.85
			29.6		15	0.38

Table 2: The dose of the BEPCII in two modes

BEPC II	E_0 (GeV)	I (mA)	L (m)	P (Pa)	d (m)	D (Gy/h)
Beam collide mode	1.89	910	13.5	1.064 x10^7	12	1.68
			13.5		23	0.62
			29.6		8	3.76
			29.6		15	1.69
Synchrotron radiation mode	2.5	250	13.5	1.064 x10^7	12	0.98
			13.5		23	0.36
			29.6		8	2.18
			29.6		15	0.98

THE CALCULATE RESULT AND THE SCALE RESULT

In the BEPC, we set two detectors (detector1and detector 2) at the short-wall of the synchrotron radiation hall and the entrance of the synchrotron radiation light, and set the third detector at the east entrance of the synchrotron radiation hall. The data from the three detectors is shown in Table 3.

Table3:The dose of the synchrotron radiation hall

Detect area	2002.1-6 data (mSv)	2002.7-12 data (mSv)	2002 data (mSv)	2003.1-6 data (mSv)
Detector 1	14.6313	2.9463	17.5776	2.5250
Detector 2	8.8746	2.3539	11.2285	10.2762
Detector 3	0.6891	0.8091	1.4982	0.7490

It can be found from Table 3, the dose increase obviously at the short wall connected to the synchrotron radiation hall. Compared with other places in the hall, it is not enough to consider only the influence of the average dose in the tunnel. So we should include the gas bremsstrahlung from the linear section.

At the same time, we can easily find that the dose of the gas bremsstrahlung is majorly from the linear section in the storage ring vacuum chamber, which would be more serious. When the energy increases, the dose will increase too. So we should take it into account when designing the shielding of the BEPCII.

From the above data, we can easily find that the dose of the gas bremsstrahlung is high enough to be considered. In the BEPC's storage ring , the cross section of the electron beam is a ellipse. By the Eq(1), we could assess the radius of the electron beam:

$$R_1 \approx 1350 \times \tan((0.511/1550) \times (360/3.14)) \approx 0.89 \text{ (cm)}$$
$$R_2 \approx 2960 \times \tan((0.511/1550) \times (360/3.14)) \approx 1.95 \text{ (cm)}$$

The radius of the electron beam is accord with the trim size observed. That mean the gas bremsstrahlung concentrates in a very small range.

SHIELD DESIGN CRITERIA AND MEASURE

Shield Design Criteria

Based on National Standards of P.R.China recommendations, the shielding for the BEPCII beam lines is designed to keep the equivalent integrated dose at the shot-long wall shield surface less than 20 mSv in 5 years, and less than 50 mSv in one year. In the design for the BEPCII, the annually integrated dose is equivalent to 10 mSv. For a 2000-h operating year, this corresponds to 5 μSv/h.

Shield Design Measures

With the correlative data, the lead (ρ=11.34g/cm^3) decay coefficient is λ=25g/cm^2, and concrete (ρ=3.7g/cm^3) decay coefficient is λ=49 g/cm^2 .Therefore, to decay the bremsstrahlung to the reasonable dose level with one kind of material, we need 23 cm lead or 141 cm concrete at least. But now in the reform project of the long-short wall, we plan to add 15 cm lead on the 50 cm concrete wall at some parts along the light beam, so the work can meet the requirement of shield design. In the BEPCII, with increase of the beam energy and the radiation, we need 27 cm lead or 161 cm concrete at least. We are going to add a number of lead blocks or firebricks to meet the shied design's requirement.

SUMMARY

- The dose of the radiation from the gas bremsstrahlung.should not been ignored and should been taken into account in shielding design for the BEPCII.
- The dosage of the gas bremsstrahlung is severely influenced by the residual gas molecules. It is important to keep high vacuum of the storage ring vacuum chambers to decrease the radiation.
- Some shielding measures should been taken when the light beams are lead out of storage ring. Normally we install beam stopper at the beam entrance, which is made up of some metals such as tungsten. There should been the shielding wall around the beam stopper and the flanges could been set at the short parts acting as the labyrinth.

REFERENCES

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