INTERACTION REGION DESIGN AND REALIZATION FOR BEPCII

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Abstract

The BEPC (Beijing Electron Positron Collider) is being upgraded as a double-ring factory-like collider (BEPCII). A New and compact interaction region (IR) has been designed to afford a peak luminosity of $10^{33}cm^{-2}s^{-1}$ with an equal beam energy of 1.89 GeV, a cross angle of ±11 mrad, 93 bunches and maximum beam current of 0.91 A. All the components of the IR have been fabricated successfully. During the commissioning of BEPCII the operation experience shows that the IR components have excellent performance and meet the design requirements. The design and realization of the interaction region for the BEPCII will be introduced in detail.

LAYOUT OF THE IR

The central part of the BESIII detector is a cylindrical drift chamber surrounded by electromagnetic calorimeters. The geometry of the drift chamber has a direct bearing on the IR design. It requires that the accelerator components inside the detector must fit within a conical space with an opening angle of 21.5˚. The first accelerator element can only approach to 0.55m on each side of the IP.

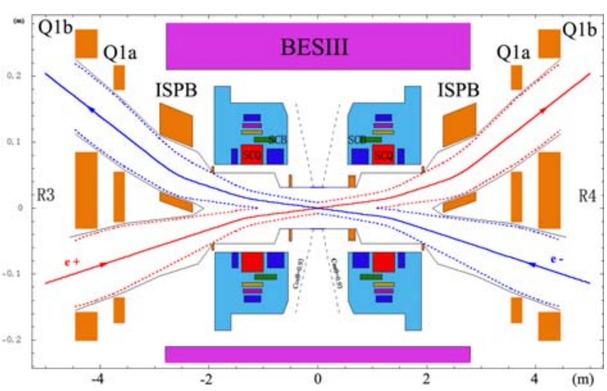

Figure 1: The layout and beam separation scheme in the IR for the colliding mode.

To ensure adequate quantum lifetime, the beam stay clear is defined to accommodate at least 14σ+2 mm in the IR [1]. The beam line layout in the central part of the IR is shown in Fig. 1. On each side of the IP, a doublet of quadrupole is used to provide the focusing optics at the IP. The first vertical focusing quadrupole, SCQ, connects the outer and inner rings, which are shared by both beams. Two beams collide with a horizontal crossing angle of 22 mrad at the IP. A horizontal bending magnet ISPB, which is located just beyond the vertical focusing quadrupole, will enhance the separation between electron and positron beams. ISPB is a septum magnet which acts on the outgoing beam-line only. The second element of the doublet is horizontal focusing quadrupoles Q1a and Q1b. In order to achieve the aims of keeping the symmetrical structure of two rings and saving space, the quadrupoles Q1a and Q1b are designed as a two-in-one type. Two separate beam channels for the incoming and outgoing beams have same field strength.

BEPCII will be operated not only for high energy physics (colliding mode) but for synchrotron radiation application (SR mode). The switch of two modes is to control the power supplies of SCQ and SCB. The bending dipoles SCB which are only used for the synchrotron radiation mode connect the outer-ring. During the SR mode operation two SCQs are turned off.

SUPERCONDUCTING MAGNETS

The superconducting magnet [2] has a multi-function coil pack. As shown in Fig. 1, it consists of independent quadrupole (SCQ), horizontal dipole (SCB), vertical dipole (VDC), skew quadrupole (SKQ) and three anti-solenoid (AS1, AS2, AS3) windings. The cryostat has a warm bore with an inner diameter of ϕ132mm and outer diameter of ϕ326mm. The endcan of cryostat has an outer diameter of ϕ640mm.

The main mechanical work of superconducting magnets was completed in China and the main coils were wound at BNL laboratory in U. S.

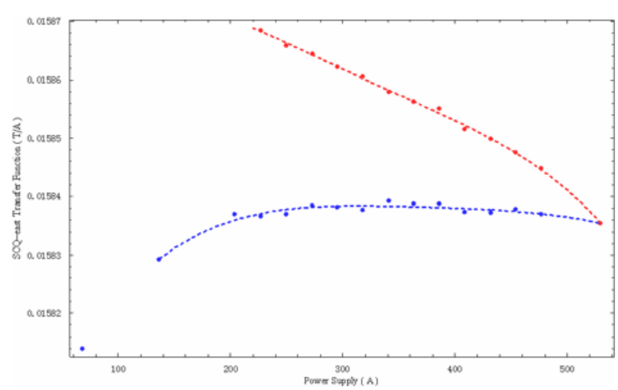

Figure 2: The measurement transfer function of SCQ.

The field measurements of the superconducting quadrupoles and dipoles have been performed at IHEP. The transfer function of SCQ is shown in Fig. 2. The harmonic components were measured by the rotating coil system. The integral gradient, offset and tilt angle were measured by SW system. Furthermore, the characteristics of each magnet have been studied in detail according to various performance possibilities.

The harmonic requirements for SCB and SCQ at the reference radius are SCB (R=38mm) $B_n/B_1<5\times10^{-4}$ and SCQ (R=50mm) $B_n/B_2<3\times10^{-4}$. Field measurement results show that there is a larger sextupole component of 7.0×10^{-4} in the superconducting quadrupole which is located in the east region. Other components of this quadrupole satisfy the requirements. The field quality of the other superconducting quadrupole and both superconducting bending magnets can satisfy the requirements.

COMPENSATION OF SOLENOID FIELD

For the colliding mode, the detector solenoid has an effective length of ±1.8m around the IP. The maximum field strength of solenoid is 1.0T so that the particle motion between the horizontal and vertical planes will be coupled strongly. It's impossible to meet higher luminosity without the dedicated coupling compensation of solenoid field. According to the requirements of high energy physics, the collider will be operated at the energy range from 1.0GeV to 2.1GeV, so the compensation system should be powerful enough to work perfectly for particles within the relevant momentum range. For this purpose a special anti-solenoid system has been designed to realize the local compensation of solenoid.

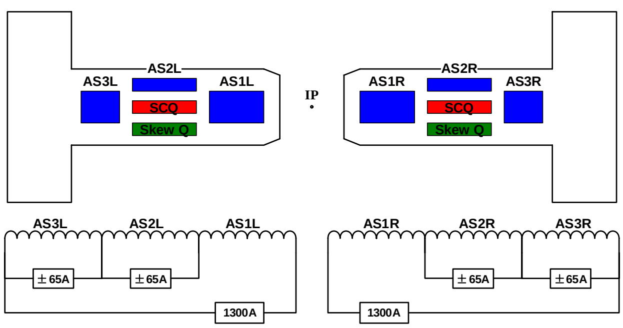

Figure 3: The wiring schematic diagram of anti-solenoids.

This system consists of three anti-solenoids AS1, AS2 and AS3 and a skew quadrupole SCSKQ which are all inside the superconducting cryostat. AS1 locates between the IP and the superconducting quadrupole (SCQ). AS2 and the skew quadrupole SCSKQ overlap the SCQ, while AS3 locates after the SCQ.

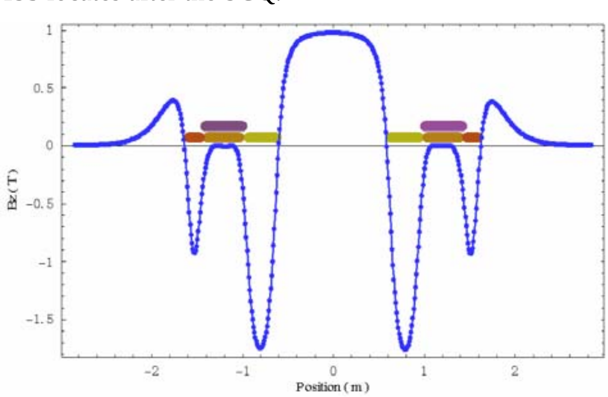

Figure 4: The combination magnetic field Bz along the axis of BESIII detector after compensation.

The local compensation layout of BEPCII and wiring schematic diagram are shown in Fig. 3. AS2 and AS3, which have their own independent trim circuits to allow fine tuning of the anti-solenoid compensation scheme, are in series with AS1. Since the compensation of longitudinal field within the SCQ region is a key to control the vertical beam size at the IP, the skew quadrupole SCSKQ is used to make fine tuning of longitudinal field over the SCQ region instead of the mechanical rotation method.

With this local coupling compensation scheme, the integral field $\int B_z ds$ between the IP and the SCQ is zero. The longitudinal field over the SCQ is nearly zero and the integral field $\int B_z ds$ between the SCQ and the first horizontal focusing quadrupole is zero too. The field measurements of the detector solenoid, anti-solenoid and the combination field have been finished. The distribution of the combination magnetic field B_z along the axis of the BESIII detector after compensation is shown in Fig. 4.

SEPTUM BENDING MAGNET ISPB

Figure 5: The shape of ISPB.

Two ISPB [3] magnets shown in Fig. 5 have been successfully fabricated. The field measurements show that its performance meets the requirements of beam dynamics with $B_n/B_1 < 5 \times 10^{-4}$.

SPECIAL QUADRUPOLES Q1a AND Q1b

The separation between two beams is about 185 mm at the inboard face of Q1a [3] and 231 mm for Q1b while the beam stay clear (BSC) is 95mm and 102mm respectively. The space for the design of septum is very limited. The following accelerator elements are quadrupoles Q2, Q3 and Q4 where the separation of two beams is large enough to allow them to be installed side by side into the two rings.

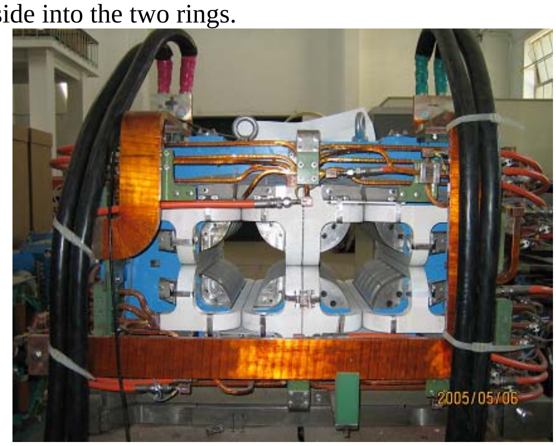

Figure 6: The shape of Q1a/Q1b.

The fabrication of Q1a and Q1b were completed at the IHEP workshop with the shape shown in Fig. 6. The measurements of the magnetic field were finished. After being shimmed by the method of edge harmonic compensation developed by IHEP, all the components of higher order magnetic fields of Q1a and Q1b are less than the design requirements 4×10^{-4} (R=53.5mm)and 3×10^{-4} (R=61.5mm) respectively.

SYNCHROTRON RADIATION

The colliding and SR modes have different synchrotron radiation sources and different synchrotron radiation fan distributions.

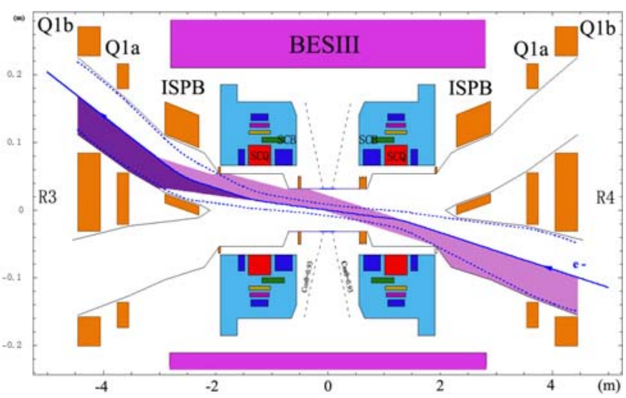

Figure 7: The SR fan of e- beam of colliding mode.

The colliding mode will be operated at the energy range of 1.0GeV to 2.1GeV. However, the case with maximum SR power distribution is 1.89GeV, as well as beam current of 0.91A. For the e- beam, synchrotron radiation fans of the IR shown in Fig. 7 are mainly generated from the final bending magnet R4OWB and from the IR quadrupoles due to the crossing angle trajectory. As the e- beam travels through the final bending magnet R4OWB (13.4m from the IP) and enters the IR, it generates SR fan with the total power 396W (Ec=0.7keV). The SR fan of center beam passes through the IP and spreads horizontally up to 0.5m from the IP. It contributes about 3.0W of SR power on the 0.5m~0.7m beam pipe. There are 6 quadrupoles between R4OWB and the IP. Among them R4SCQ magnet is the largest radiation source due to its off-axis installation. The total SR power generated by the R4SCQ magnet is 95.2W (Ec<1.2keV). About 19.2W of SR power from R4SCQ can strike on the 0.5m~0.7m beam pipe. The rest of SR fans travels out of the near IR and is absorbed on the surface at 3m~4m. Most of the synchrotron radiation power (521.3W) generated by R3SCQ and ISPB magnets hits the beam pipe at 3.0m~4.4m from the IP.

The SR mode will be operated at energy of 2.5GeV. The maximum beam current is 250mA. The SR powers are mainly generated by the final bending magnet R4OWB, the superconducting bending magnets R4SCB and R3SCB nearby the IP. For the SR mode, only e- beam is employed. As the e- beam travels through the final bending magnet R4OWB and enters the IR, it generates SR fan with the total power 333W (E_c = 1.7 keV). The SR fan of center beam passes through the IP and spreads horizontally up to 0.5m from the IP. It contributes about 2.5W of SR power on the 0.5m~0.7m beam pipe. The total power of the SR fan generated by R4SCB is 223W (E_c = 2.3 keV). About 25.3W of SR power from R4SCB can strike on the region of 0.5m ~ 0.7m of the beam pipe. The rest of the SR fan from R4SCB travels out of the near IR and is absorbed on two surfaces, one is a mask placed in front of the ISPB septum, and the other is the beam pipe at 3m ~ 4m. About half of the SR power 223W generated from R3SCB hits the mask placed in front of the ISPB septum. The remainder mainly strikes the beam pipe between the R3Q1a and R3Q1b

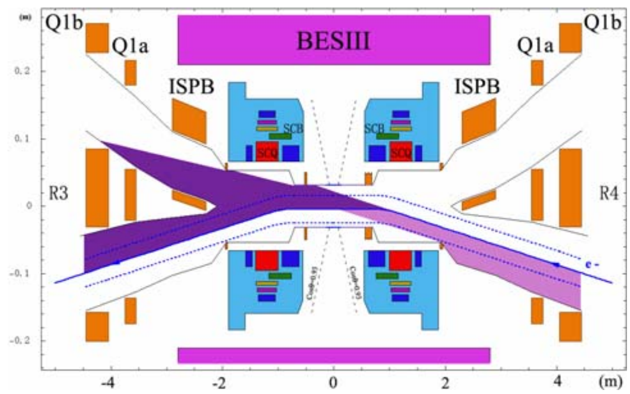

Figure 8: The SR fan of SR mode.

For the present IR design, it's very difficult to stop both direct and once-scattered photons emitted within $10\sigma_x$ of beam size at all magnets hitting on the detector beryllium pipe. The critical energy of photons is less than 0.7keV during the operation of colliding mode. The simulation results show that the SR background level is acceptable.

IR VACUUM CHAMBER

The central part of the beam pipe is a double-wall beryllium structure with a 1mm gap of cooling channel. It is ± 0.15 m long around the IP with the ID of 63 mm. The inside wall of Be pipe will be coated by gold. The Be pipe is welded to a copper cylinder which is connected to the SCQ chamber through a special CF63 bellows [4].

The SCQ chamber is about 1.24 m long with an inner diameter of 111 mm. It is connected to the Y-Type chambers through special CF100 flange. The Y-type chamber is about 0.3 m long in which a bellows, one NEG pump, and two BPMs are installed. At the end of the Y-type section the vacuum chambers are completely separated for each beam. Both Q1a and Q1b chamber have an inner diameter of 104 mm. After Q1b the vacuum chamber has a transition to the standard chamber.

The water cooling structure have been designed in the beam pipe 0.5~0.7m away from the IP, the crotch beam pipe, the SCQ beam pipe and the beam pipe 3.0~4.0m away from the IP, to avoid the heat problem in these region. Except for the Be pipe, copper was chosen for the vacuum chamber within ±3.5m as its low coefficient of photon-induced gas desorption, large photon absorption coefficient and high thermal conductivity [5].

There are 132 thermocouples in the IR to monitor the temperature raise and SR fans behavior. During the operation of both colliding and synchrotron radiation modes, the temperatures of vacuum chambers were controlled effectively.

COLLISION TUNNING MONITORS

The beam-beam deflection technique [5] is adopted in the BEPCII to find and maintain the collision conditions.

For the consideration of phase advance and beta function, the BPMs between Q1a and Q1b are set to measure horizontal beam-beam kicker angle. The BPMs on the crotch beam pipe are set to measure vertical beam-beam kicker angle. The measured signals of beam-beam kicker during collision tuning are shown in Fig. 9.

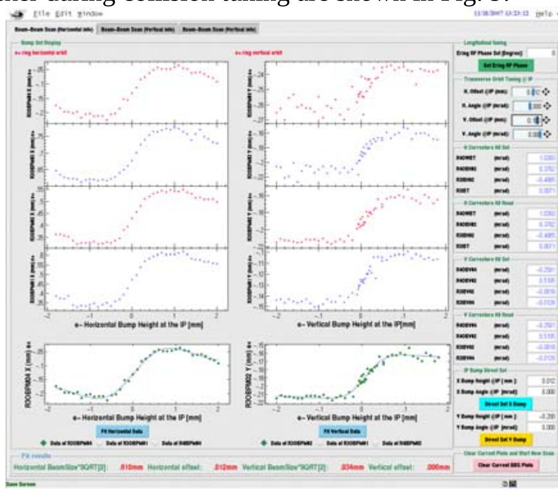

Figure 9: The measured signals of beam-beam kicker

A pair of Cherenkov luminosity detectors which measure the radiative Bhabha photons are installed to monitor positron and electron beam, respectively. They worked well during the last collision tuning operation.

SUPPORTING SYSTEM

The cryostat of superconducting magnet, transfer line, service cryostat and ISPB, Q1a, Q1b etc. are supported by a movable stage. This movable stage could move along the beam line by approximately 3m. With this motion the superconducting magnets could be pulled out and pushed into the detector [7]. The drawing of the supporting system of IR is displayed in Fig. 10.

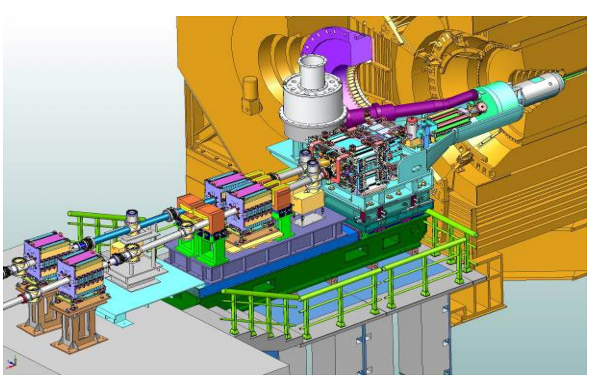

Figure 10**:** The supporting system of IR.

The measurements of ground vibration in the IR have been finished. The results of data analysis indicate that the average rms displacement is about 10nm. The IR is a good place with a low cultural noise. The inherence frequency of supporting system has been optimized to avoid the resonance from noise frequency [8]. The power spectral density of ground motion is shown in Fig. 11.

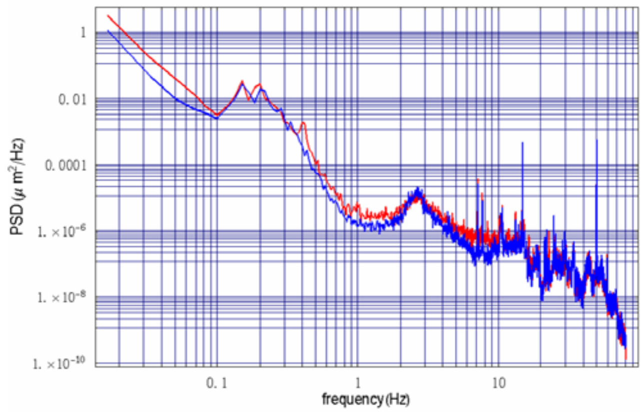

Figure 11**:** Power spectral density of ground motion.

DISCUSSIONS

The design and realization of interaction region for the BEPCII have been introduced in detail. The detector will be rolled into the interaction point this summer. Coupling compensation, background issues, radiation dose, etc. will bring new challenges for the commissioning of the BEPCII.

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