BEPCII: THE SECOND PHASE PROJECT OF THE BEIJING ELECTRON-POSITRON COLLIDER

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Abstract

The status of second phase construction of the Beijing Electron-Positron Collider (BEPC), i.e. the BEPCII, is reported. The design luminosity of the BEPCII is 1×10^{33}cm^{-2}s^{-1} @1.89 GeV with a double-ring scheme. The performance of the BEPC as a synchrotron radiation source will also be improved with the expected beam current of 250mA at 2.5 GeV. Some key technologies are being developed in order to achieve the goal of the BEPCII.

1 INTRODUCTION

The BEPC was constructed for both high energy physics (HEP) and synchrotron radiation (SR) researches [1]. The BEPC-accelerators consist of a 202 m long electron-positron linac injector, a storage ring with circumference of 240.4 m, and in connection with each other, 210 m transport lines. 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 beam lines and 12 experimental stations, is flanking the east and west of the southern areas of the storage ring. Figure 1 illustrates the layout of the BEPC

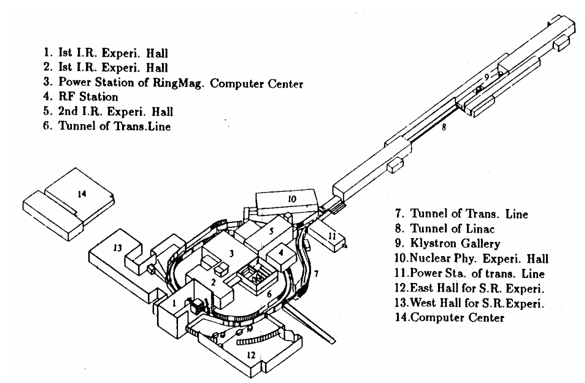

Figure 1: Layout of the BEPC

As a unique e^+-e^- collider operating in the τ/charm region and a first synchrotron radiation source in China, the machine has been well operated for 13 years. The performance of the BEPC is described elsewhere in this conference [2]

The physics opportunity in the charm-τ region calls higher luminosity. The BEPCII, with a luminosity goal of two orders of magnitude higher than the present BEPC, is its natural extension. The detail design can be found in the reference [3].

2 BASIC DESIGN

2.1 Luminosity from BEPC to BEPCII

As a measure of the event production rate, luminosity is one of the most important parameters in colliders. The luminosity of an e^+-e^- collider is expressed as

$$L(\mathrm{cm^{-2}s^{-1}}) = 2.17\times10^{34}(1+r)\xi_y \frac{E(GeV)k_b I_b(\mathrm{A})}{\beta_y^*(\mathrm{cm})} \qquad (1)$$

where $r=\sigma_y^*/\sigma_x^*$ is beam aspect ratio at the interaction point (IP), ξ_y the vertical beam-beam parameter, β_y^* the vertical envelope function at IP, k_b the bunch number in each beam and I_b bunch current. BEPCII will operate with beam energy E=1–2 GeV. Table 1 describes the strategy of luminosity upgrading from the BEPC to the BEPCII.

Table 1: The luminosity strategy of BEPCII (E=1.89 GeV)

Parameters	BEPC	BEPCII
Beta function at IP β_y^* (cm)	5.5	1.5
Bunch number k_b	1	93
Beam-beam parameter ξ_y	0.04	0.04
Current per bunch I_b (mA)	35	9.8
Luminosity gain L_{BEPCII}/L_{BEPC}	1	95

2.2 Main Parameters

Based on the strategy of luminosity upgrading of the BEPCII, its design study for is worked out. Table 2 summarises the main parameters of the BEPCII.

Table 2: The main parameters of the BEPCII

Optimized Beam Energy E	GeV	1.89
Circumference C	m	237.53
Bunch Number k_b		93
Beam Currents per Ring I_{beam}	A	0.98
RF Frequency f_{RF}	MHz	499.8
RF Voltage per ring V_{RF}	MV	1.5
Beta Function at IP β_x^*/β_y^*	cm	100/1.5
Emittance $\varepsilon_x/\varepsilon_y$	m·mrad	0.14/0.0021
Bunch Length σ_{z0}/σ_z	cm	1.3/1.5
Bunch Spacing S_b	m	2.4
Tune $\nu_x/\nu_y/\nu_z$		6.57/7.61/.034
Damping Time $\tau_x/\tau_y/\tau_z$	ms	25/25/12.5
Beam-beam Parameter ξ_x/ξ_y		0.04/0.04
Crossing Angle ϕ_c	mrad	11×2
Luminosity L	cm^{-2}s^{-1}	1×10^{33}

2.3 The Double-ring Structure

Figure 2 shows the layout of the double ring arrangement in the BEPC tunnel. The inner ring and the outer ring cross in the northern and southern IP's. A bypass connects the outer ring in the northern interaction regions (IR) and a pair of bending coils in SC magnets serves this purpose in the southern IR, so that electron beams can be circulated in the outer ring for dedicated SR runs of the BEPCII. The design beam currents for dedicated SR operation are 250 mA at 2.5 GeV.

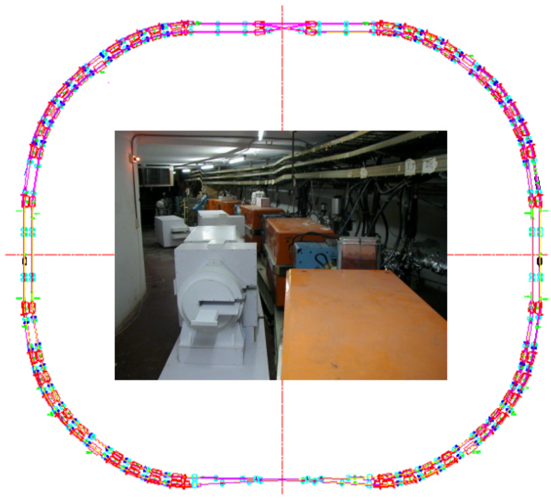

Figure 2: The layout of the double ring of the BEPCII

A substantially higher performance could be reached with the double-ring option for much more bunches are allowed to be collided, as seen in eq.(1). However, the space for the two rings in the existing BEPC tunnel needs to be carefully checked. The mock-up test was carried out to examine the feasibility of the double ring installation. Figure 2 also pictures the wooden "magnets" installed in the existing BEPC tunnel as a part of the inner ring. The conclusion of the mock-up test is as follows.

- No showstoppers are found for the transportation, installation, mounting and dismount of the magnets.
- The inner ring magnets will cover some of the existing monuments for survey and alignment. New monuments will be fixed on the wall of the tunnel.
- The antechamber of the positron ring needs to be carefully designed to fit the crucial space between two rings;
- The cable system, the cooling-water system, the pressure-air system and others need to be rearranged.

2.4 Impedance and Collective Effects

Control of the bunch length and impedance is one of crucial issues for the success of the micro-β scheme in the BEPCII. There are experimental and theoretical evidences that the bunch length in a collider should be smaller or comparable to the β-function at IP. The bunch length in the BEPC is about 5 cm in the operation condition of I_b ~20 mA, V_{rf}~0.6 MV at 1.55 GeV. In order to operate the collider with micro-β scheme of $\beta_y^* = 1.5$ cm, the bunch length σ_l in the BEPCII should be less than 1.5 cm. With the 500 MHz superconducting cavities of $V_{rf} = 1.5$ MV, the natural bunch length $\sigma_{l0} = 1.3$ cm. However, the finite impedance due to the discontinuity of the vacuum pipes in the storage rings will make the bunch lengthening with its intensity. The bunch length will increase due to potential well distortion and microwave instability. The threshold of microwave instability is expressed as

$$I_{th} = \frac{\sqrt{2\pi}\,\alpha_p \frac{E}{e}\sigma_{e0}^{\,2}\sigma_{l0}}{R\left|\frac{Z}{n}\right|_{eff}}, \qquad (2)$$

where α_p is the momentum compaction factor, E the energy of the beam, σ_{e0} and σ_{l0} the natural rms energy spread and natural rms bunch length respectively, R the mean radius of the ring, $|Z/n|_{eff}$ the effective longitudinal effective coupling impedance. Equation (2) implies the limit of $|Z/n|_{eff}$<0.97Ω for I_b=0.98 mA is under the threshold of the microwave instability.

In order to make the impedance $|Z/n|_{eff}$ smaller, all the vacuum components such as bellows, kickers, separators, BPM's, masks, connectors, valves, pumps, Y shape chambers, and SR beam ports must be carefully checked and studied. The computer code of MAFIA is applied to compute the impedance of vacuum components in comparison with measurements. According to the above impedance budget, the total inductance of BEPCII is about 25.5 nH, corresponding to Z/n ~0.2Ω. This shows that it is possible to control the impedance under the threshold impedance of the microwave instability if the vacuum chamber is rebuilt by adopting the state of art technology in the BEPCII[4].

The coupled bunch instabilities due to the beam-cavity interaction is estimated based on the high order mode (HOM) data of KEKB superconducting cavities. The dangerous modes of the coupled bunch instability with N_b= 99, I_b = 9.8 mA are τ_{rise} = 6.3 ms (longitudinal m = 0) and τ_{rise} = 26.6 ms (transverse m=1), which are shorter than the SR damping time of the BEPCII at 1.55 GeV of ($\tau_x/\tau_y/\tau_z$ = 44/44/22 ms). A bunch feedback system can be applied to cure the instability.

The real part of the impedance may cause the resistive wall instability. The major part of the vacuum chamber of the BEPCII is made of aluminium. The computation with the code of ZAP indicates that the most dangerous mode of the resistive wall instability in the BEPCII has the growth time of 4.3 ms with N_b = 99, I_b = 9.8 mA and ν_x/ν_y=6.6/7.6 at the present design tunes. It can be handled with a feedback system.

The electron and positron beams will circulate in the individual rings in the BEPCII, the foreign particle caused instabilities, such as ion trapping, fast ion instability, dust effect and electron cloud instability (ECI), are studied. Antechamber with TiN coating will be applied in the positron ring in order to get ride of the ECI in the BEPCII.

The head-on beam-beam parameter of 0.04 is demonstrated in the BEPC. A finite-crossing angle of ±11 mrad is adopted for the IP of the BEPCII. Beam-beam simulation for BEPCII has shown that the beam-beam parameters and crossing angle are acceptable.

The beam lifetime determines the duty factor of the storage ring operation. Many coherent and incoherent effects will influence the beam lifetime. In the BEPCII, the major effects are considered as beam-gas interaction, beam-beam bremsstrahlung, Touschek effect and quantum effect. The overall beam lifetime is estimated as about 2.7 hours, and then the optimized collision time is calculated as 1.0 hours with the maximum average luminosity $<L>_{max}=0.6\times10^{33}$ $cm^{-2}s^{-1}$.

3 KEY TECHNOLOGIES

Number of key technologies and hardware systems need to be developed for the BEPCII, including injector upgrading, superconducting RF system, superconducting insertion quadrupoles and IR design, low impedance vacuum chambers and some others.

The BEPCII requires the injector in two aspects. One is the full energy injection to the storage ring, i.e. E_{inj} = 1.55−1.89 GeV, the other is that the positron intensity satisfies the required injection rate of 50 mA/min. In order to realize the full energy injection for E = 1.55−1.89 GeV, 2−8 present-used 34 MW klystrons will be replaced with the new 50 MW devices.

The BEPC has been operating with 200 MHz normal conducting cavities. In order to meet the luminosity goal with shorter bunch length, one needs to increase RF frequency and voltage. Normal and superconducting RF cavities are compared for the BEPCII. The later is adopted for its larger accelerating gradient, smooth structure and large beam port, transmitted-out of HOMs and low RF power consuming. Two superconducting cavities will be used in the BEPCII providing 2×1.5 MV RF voltage. The cavities will be powered with two 180 kW RF transmitters. The refrigeration capability of 300W is required for two SC cavities.

A pair of quadrupoles will be inserted in the BESIII detector to squeeze the β function at IP. For the tight space in the interaction region, two types of insertion quadrupoles are considered, one is the permanent magnets and other the superconducting magnets. The permanent magnets are compact and no power supply required. However, it is difficult to satisfy the wide operation range of the beam energy in the BEPCII using this type of magnets. The superconducting magnets can provide a strong and adjustable magnetic field. A special pair of superconducting IR magnets is being designed with main and skew quadrupole and dipole coils. Figure 3 shows its structure.

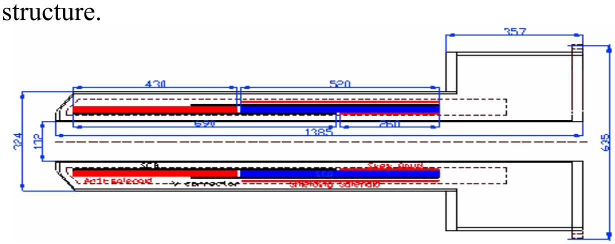

Figure 3: The superconducting IR magnet

The support, installation, background, synchrotron radiation shielding, parasitic energy loss and its cooling, vacuum pumping and many other issues in the interaction region of the BEPCII are carefully studied. Figure 4 shows the sketch of the IR.

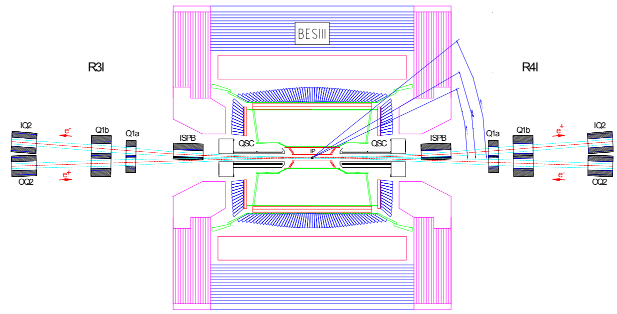

Figure 4: The sketch of the interaction region

The BEPCII poses two challenges to the vacuum system, one is the vacuum pressure, and the other is the impedance. The dynamic vacuum at a high beam current should satisfy the requirements of the sufficient beam lifetime, as well as the background in the detector. The design vacuum pressure of the BEPCII is 8×10^{-9} Torr in the arc and 5×10^{-10} Torr in the IR. The heating due to the synchrotron radiation is studied. Masks will be placed in order to prevent the vacuum components from the synchrotron radiation. To reduce the impedance, the vacuum chamber should be as smooth as possible.

The upgrades also involve injection, magnets and their power supplies, instrumentation, control, utilities and other subsystems.

The project is scheduled to complete by the end of 2006 with the budget of 80 MUSD .

4 SUMMARY

- The BEPC has been well operated with many exciting HEP and SR results for 13 years.
- The BEPCII is designed with micro-β plus multi-bunches and double ring structure. The luminosity is two orders of magnitude higher than the present BEPC in the τ/charm energy region.
- Some key technologies need to be developed in order to achieve the goal of the BEPCII.
- The international collaboration and contribution will be promoted in order to accomplish this challenging and exciting project on the schedule and the budget.

5 REFERENCES

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