BEPC UPGRADES AND TAU-CHARM FACTORY DESIGN

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Abstract

The luminosity upgrades of the BEPC are briefly reviewed. The initial testing of the storage ring system and its present performance are described. The feasibility study on the Beijing Tau-Charm Factory is discussed.

1 INTRODUCTION

The Beijing Electron-Positron collider (BEPC) has been running smoothly for about 10 years since its first beam collision on Oct.16 1988[1]. The BEPC storage ring has a circumference of 240.4 m with two interaction points and mainly works in the tau-charm energy region for high energy physics. The Beijing Spectrometer (BES) has taken data at different energies for J/ψ, ψ', D_s and τ physics studies. About 9 million J/ψ and 3.5 million ψ' events were collected. A data sample at the C.M. energy of 4.03 GeV corresponding to an integrated luminosity of 22.3 pb^{-1} were accumulated. Several important experimental results such as the precise measurement of τ lepton mass and the confirmation of the existence of ξ(2230) have been obtained[2].

In order to further improve the performance of BEPC and to provide a significant improvement on luminosity, the plan of BEPC upgrades were carried out in recent years, consisting of the injector improvements, control system and luminosity upgrades. The latter will be mainly described in this paper and the others can be found elsewhere[3].

The BEPC luminosity upgrade program includes mini-β scheme and single interaction point (IP) operation. After finishing the hardware changes and a preliminary accelerator commissioning, we obtained the luminosity in excess of $4 \times 10^{30} cm^{-2}s^{-1}$ at the energy of 1.55 GeV.

As a next step to further develop the tau-charm physics research in BEPC, Chinese high energy community has proposed to build Beijing Tau-Charm Factory (BTCF) and a feasibility study on the BTCF has been finished at the end of 1996.

2 LUMINOSITY UPGRADES

The main efforts for the BEPC luminosity upgrades consist of adopting a mini-β insertion, shortening the bunch length to match the β_y^*, vertical β function at the interaction point, and running the machine with a single interaction point.

2.1 Proposed mini-β Scheme

In the original design of the BEPC mini-β insertion[4], a strong vertically focusing permanent quadrupole(QP) with an outside radius of 11.5 cm and a length of 0.56 m would be installed inside the BES with a distance of 1.27 m to the interaction point(IP). The insertion quadrupole Q1 would be moved from its the original distance of 2.5 m to 2.13 m from the IP.

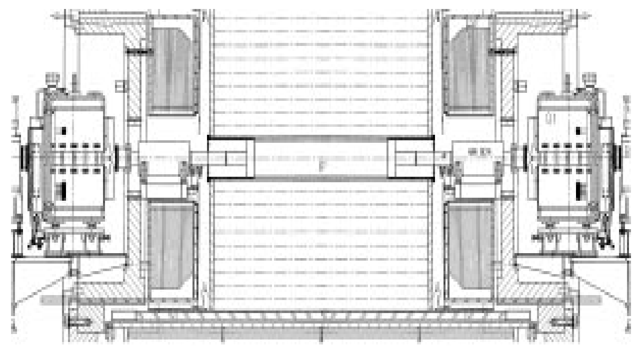

Figure 1: Interaction region of BEPC.

The major parameters between designed mini-β optics and 8.5 cm lattice are shown in Table 1.

Table 1: Main parameters of mini-β and normal lattice

Parameters	mini-β optics	8.5 cm optics
β_x^*/β_y^*(m)	0.9/0.036	1.3/0.085
ν_x/ν_y	5.785/6.710	5.85/6.82
ξ_x/ξ_y	0.04/0.04	0.04/0.04

The luminosity is given by:

$$L(cm^{-2}s^{-1})=2.17 \times 10^{34}\xi(1+r)I(A)E(GeV)/\beta^*(cm)$$

where r is the aspect ratio, others have common meaning. The expected luminosity gain from the mini-β scheme is mainly determined by the following factors:

- The experiences from the BEPC show that the luminosity was optimized when $\beta_y^* \approx 1.0 \sim 1.2\sigma_s$. This means a bunch length of σ_s=3 cm is needed to match β_y^*=3.6 cm.
- The most crucial factor for the mini-β optics in BEPC is how to reduce the bunch length.

2.2 RF System Improvements in BEPC

BEPC RF system was designed at a frequency of 200 MHz with two cavities and gave a bunch length about 6∼10 cm with available RF voltage at the energy of 2.0 GeV. To reduce the bunch length to a value of $\sigma_s \approx$3 cm, the BEPC RF system has been improved with the aim of providing higher RF voltage, which includes 1) two SPS retired cavities were added in the BEPC tunnel, 2) re-grouping the available RF power supplies for four cavities and 3) installing the HOM damper in the BEPC cavities and replacing the cavity tuner by a new version without contacts. Finally, two SPS style cavities, together with two BEPC cavities have been put into operation and provide a maximum RF voltage of more than 2.0 MV[5].

2.3 Attempts to Reduce Coupling Impedance

The phenomenon of current dependent bunch lengthening has been observed in BEPC. An early estimation of the impedance budget revealed a longitudinal broad band impedance of $|\frac{Z}{n}|_0 \approx 4.5\Omega$, and the main contributions came from kickers and bellows, etc. To reduce the bunch lengthening effects, a preliminary measure was made, such as removing the two idling kickers, a reduction of about 0.5Ω in the longitudinal coupling impedance was expected. Another effort came from shielding the bellows. There are 40 pieces racetrack shape bellows assemblies distributed along the BEPC ring. Each side of the assembly is connected by a flange in which a cavity structure exists. The status of flanges before and after shielding is depicted in Fig. 2.

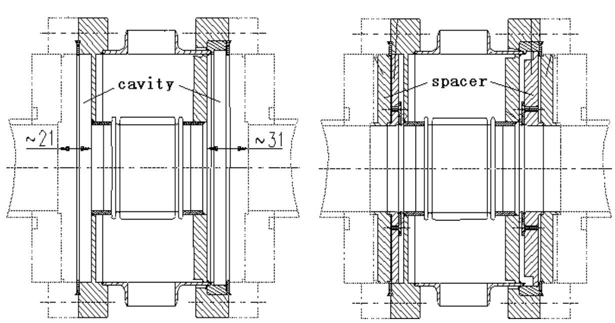

Figure 2: Flanges in BEPC before and after shielding.

The measurements show that the cavity between two flanges made a remarkable contribution to the impedance. To improve this structure of the assembly, spring contact spacers have been put into the cavities in each bellows assembly. These changes could be expected to reduce the impedance about 1.24Ω for the total 40 assemblies.

With the above efforts, a reduction of more than 10% in bunch length would be expected.

2.4 Measurements of Bunch Length with Higher Voltage

The measurements of bunch length with functions of beam current, RF voltage and beam energy have been performed with a streak camera and beam spectrum analysis method[6],[7].

The measurement results show that the data are well parameterized by the scaling law of $\sigma_z(cm)=0.651(\frac{I(mA)\alpha_p}{V_s^2 E(GeV)})^{1/3.49}$, showing in Fig. 3. The solid slope line describes the old scaling law which was measured before shielding the bellows.

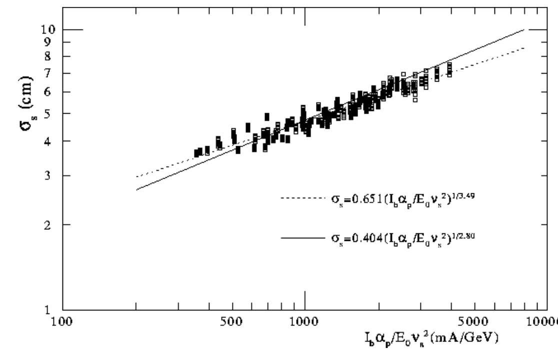

Figure 3: Scaling law of bunch lengthening.

Table 2: Main parameters of lower-β scheme

β_x^*/β_y^*(m)	1.3/0.05
ν_x/ν_y	5.82/6.82
ξ_x/ξ_y	0.045/0.04

The results also tell us that the bunch length reaches $\sigma_s \approx$ 4.2 cm for I_b=35 mA at E=2.015 GeV, V_{rf}=2.0 MV. which is longer than the required value of $\sigma_s \approx$3cm necessary for the mini-β scheme. On the other hand, the longitudinal coupling impedance $|\frac{Z}{n}|_0$ deduced from the measurements of the variation of betatron tunes with current before and after shielding the bellows are almost same. It can be seen that there are no distinct improvement for shortening the bunch length by shielding the bellows. The reason is not yet understood. It is evident that the bunch lengthening would limit the effective operation on β_y^*=3.6 cm. So the mini-β lattice has been modified from the original design.

2.5 Lower-β Design

Taking the operating experience of BEPC, the optimum ratio β_y^*/σ_s for the luminosity is about 1.2, with the $\sigma_s \approx$4.2 cm, the optimum value of β_y^* would be 5 cm.

Intensive studies showed that the lattice with β_y^*=5cm could be realized by moving the quadrupoles Q1,Q2 towards the IP by a distance of 35 cm and 45 cm respectively, without installing the permanent quadrupole QP. These changes would decrease the maximum β_y at the insertion quadrupole and natural chromaticities. The vacuum chamber in the interaction region (IR) have been rebuilt and the new one has larger aperture and smooth transition. Some main parameters for 5 cm β_y^* optics are listed in Table 2.

2.6 Commissioning with Lower-β Lattice

With the first priority given to physics experiments, only a fraction of operating time was spent on the machine experiments and studies.

During the commissioning, several different optical configurations (tunes and β^*) were tried with adjusting many other parameters such as orbit corrections, sextupole strengths and coupling corrections[8]. As a preliminary result, the luminosity of BEPC has increased by a factor of 1.5 and reaches a peak value of $4.38 \times 10^{30} cm^{-2}s^{-1}$ at the energy of 1.55GeV. A beam-beam parameter $\xi_y \sim$0.037 is also obtained. Fig. 4 draws the luminosity and the vertical beam-beam tune shift as functions of the beam current. Fig. 5 gives a picture of tune scan for the luminosity.

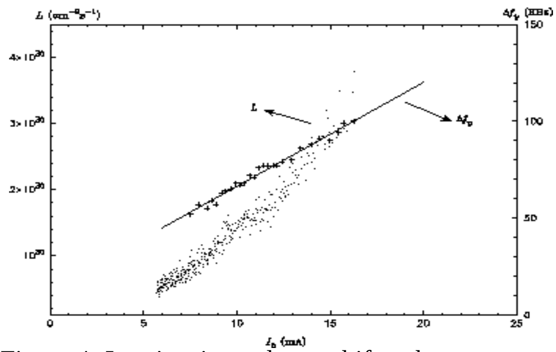

Figure 4: Luminosity and tune shift vs beam current.

Machine studies on the tune scan show that the working points at ν_x=5.805 and ν_y=6.800 yield a higher luminosity.

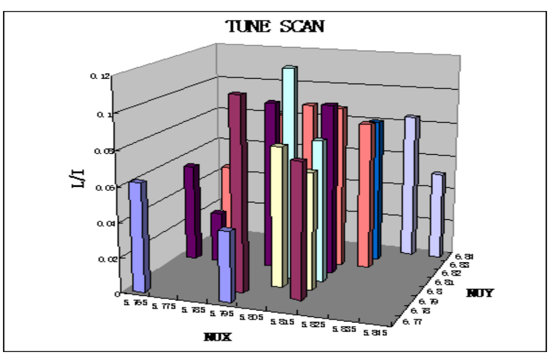

Figure 5: Tune scan for the luminosity.

In the machine study for optimum luminosity, an instability has been observed that the luminosity drops as the RF voltage is raised, while the β_y^* keeps unchanged. The studies show that luminosity dropping is caused by an enlargement of the vertical beam size due to beam-beam interaction. It seems that a synochro-betatron resonance excited by a residual vertical dispersion at the interaction points happens when beams collide with higher RF voltage. Some detailed studies and simulations are still under way.

2.7 Single Interaction Point (SIP)

A scheme to increase luminosity by running machine with only one collision per revolution has been testing[9]. Two beams are separated vertically at the north IP with separators since there is no detector there.

At beginning, we tried the SIP scheme on the base of high luminosity mode. But as the phase advance between two separators was not exact 180°, the orbit difference of two beams perturbed the collision in the south IP. Two trim separator supplies were used to eliminate such an effect. Even though, the early SIP experiments gave no positive results. The reason is considered to be the vertical orbit distortion created by north separators leakage to the active IP. With adding 4 new power supplies in the north insertion region, a new lattice with more favorable conditions to SIP operation has been designed:

- Larger beta functions β_x^*=0.65 m,β_y^*=4.62 m at the north IP.
- Exact 180° phase advance between two north separators.
- Different tunes ν_x=6.12,ν_y=6.62 from that in the two IP's mode, which are just above the integer horizontally and half integer vertically. The beam-beam shift for given beam-beam force would be minimized.
- Smaller natural chromaticities ξ_x=-11.2,ξ_y=-16.7 would reduce the perturbation due to sextupoles.

With the new lattice, the miscrossing in the experimental IP due to the perturbation of north separators has been eliminated, which makes the beams perfect collision. The present machine experimental studies with the new lattice of β_y^*=7 cm show that the beam-beam tune shift per revolution decreases significantly comparing with that in two IP's operation. In the meanwhile, both beam-beam parameter and maximum colliding beam current have increased, which results a higher luminosity. The further experiment with the β_y^*=5 cm lattice is under way.

Several hardware improvements including control system and magnet power supplies have been responsible for the luminosity upgrade. The next step in BEPC upgrades will include multi-bunch operation and micro-β scheme. Those will provide a further increase of luminosity and establish a solid technical basis for the Beijing Tau-Charm Factory design.

3 BEIJING TAU-CHARM FACTORY DESIGN

The design of BTCF[10] focuses mainly on the high luminosity mode and provides the possibility to realize polarization and monochromator operation with the priority order: high luminosity mode (1.5∼2.5 GeV), longitudinal polarization mode(∼2.0 GeV), and monochromator mode(1.55 GeV). According to the requirements of the physics, the design goals aim at:

- Maximum peak luminosity of $10^{33} cm^{-2}s^{-1}$ at the energy of 2.0 GeV.
- Rings capable of operating over the range 1.5≤E≤2.5 GeV and providing the potential up to 3.0 GeV.
- Basic design compatible with polarization mode and monochromator mode.

The strategy, adopted to achieve high luminosity, is common to the many other factory designs: micro-β, high current, multibunch, and separated rings.

The design approach is to maintain single-bunch parameters within currently achieved values but use a larger number of bunches and choose a small crossing angle collision optics as a main scheme.

3.1 Lattice Design and Layout

The lattice is designed with the emphasis on the high degree of flexibility of adjusting linear optics and the compatibility of different modes[10]. The schematic layout of the BTCF storage ring is shown in Fig. 6.

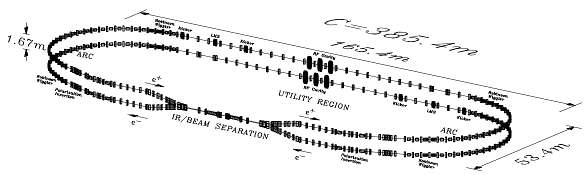

Figure 6: Schematic diagram of the BTCF storage ring

The two rings are vertically separated about 1.6 m. Each ring is 53.4 m wide and 165.4m long with a circumference of 385.4 m, and can be divided into four parts: interaction region, arc region, utility region, polarization region.

Two iron-free superconducting quadrupoles (Q1, Q2) are used as a strong doublet to reach the requirements of β functions at the IP. The quadrupoles Q1, Q2 lie completely within the detector. The two beams are separated with electrostatic separators and vertical bending magnets. Seven quadrupoles (Q3∼Q9) are arranged to match the beta and dispersion functions to the arc. Fig. 7 shows the beams separation in the IR region.

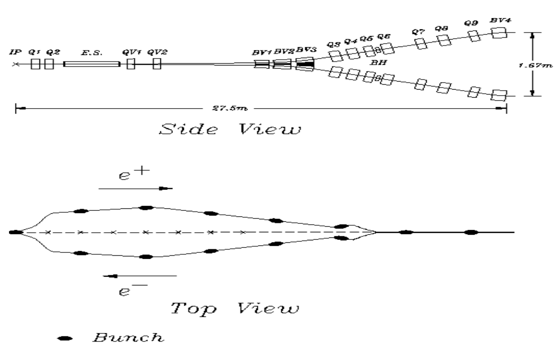

Figure 7: Beam separation and crossing angle scheme.

To compensate the effects of detector solenoid on the beams, an anti-solenoid with -3.0 T, 0.3 m long is located at 0.6m away from the IP to cancel the detector solenoid field between the IP and Q1. A shielding solenoid coil will be placed by surrounding the insertion quardrupole magnets to eliminate the detector solenoid field in the Q1, Q2 region.

Table 3: Main parameters of high lumi. scheme for BTCF

Crossing angle	$2\phi_c$=2.6×2 mrad
Bunch spacing	3.78 m
Bunch number	86
Natural emittance	ε_{x0}=140 nm·rad
Beam current	570 mA
β_x^*/β_y^*	0.65 m/0.01 m

Each arc consists of 2 dispersion suppressors and 10 standard FODO cells with more independent power supplies of quadrupoles for the lattice flexibility. The utility region consists of an injection insertion, 4 FODO standard cells and a transition section. There are enough straight sections for correctors, RF, injection kickers, wiggler systems and polarization elements.

The main scheme is chosen to use the collision with a small horizontal crossing angle created by a pair of horizontal dipoles BHs which located at the places where the horizontal phase advance from the IP is 180°. The main parameters for this scheme are listed in Table 3.

The polarized beam energy is required around 2.0 GeV, and the scheme with polarized electron only can meet the requirements of physics at beginning. The electron will be polarized transversely before filling the ring using the polarized electron gun. The current spin rotation schemes are considered to use solenoids and horizontal bends, located between the IR and the arc part[11].

For the monochromator scheme the polarity of quadrupoles Q1, Q2, Q6, QV2 will be changed and the magnets Q4, Q8 and BH will be switched off. The main parameters are chosen as: β_x^*=1.0 cm, β_y^*=15 cm, $D_y^* = \pm 0.45$ cm and the luminosity would expect 2×10^{32} $cm^{-2}s^{-1}$. The Robinson wigglers will be used to adjust the emittance and the energy spread.

3.2 Instability Control and Beam-Beam Effects

The bunch lengthening effect must be controlled in order to get $\sigma_z \leq \beta_y^*$. The criterion to avoid the microwave instability gives an impedance threshold requirement: $|Z/N|_{eff} \leq$ 0.51Ω (6.7 mA/bunch), and the present estimation for the impedance of ring components indicates: $|Z/N|_0 \sim 0.24\Omega$. Thus,we may expect a short bunch could be obtained.

The coupled-bunch instabilities in the τcF are a potentially serious problem due to large currents and short bunch spacing. It could be limited by reducing the number of cavities and their impedance, using HOM dampers to reduce external Q value lower than 100, and using the fast feedback system to suppress the instability[12].

The mechanism of the transient ion trapping and beam-photoelectron interaction are being investigated with simulation programs, and related machine studies are in progress in the BEPC and other laboratories. It would be expected that these instabilities in the BTCF should be much weaker than that in a B-factory. The studies of beam-beam effects with linear lattice has been carried out using simulation code, which gives a valuable guide for the choices of parameters[13].

3.3 *Superconducting Magnets and Supporting System[14]*

The insertion quadrupoles and compensation magnets are iron-free superconducting magnets. The maximum field gradients of Q1 and Q2 are 36 T/m and 20 T/m respectively with a length of 0.5 m. A common cryostat envelope contains Q1, Q2, anti-solenoids and shielding solenoids.

The cryostat provides a rigid structure to hold the coil windings to prevent them from moving during cooling down and exciting. It could be supported with a movable support table which can be moved along the beam line.

3.4 *RF System*

Choosing single-cell and deeply damped superconducting cavity (SC) with a frequency of 476 MHz has been considered based on: large gradient $\sim$10 MV/m, with large beam pipe, and small impedance.

The RF voltage is designed at 9 MV in maximum and operated at 6.8 MV with 3 SC cavities per ring. Each cavity delivers 50 KW to the beam.

3.5 *Vacuum System*

The BTCF storage ring requires that the operating pressure should be $\leq 1\times10^{-9}$Torr in the arc region and $\leq 5\times10^{-10}$Torr in the IR. Total pumping speed of 6.3×10^{-4}L/s with 110 sets of sputter ion pumps and NEG pumps are needed per ring to deal with the high thermal load and minimize the photo desorbed gas load.

The vacuum chamber will be made of extruded aluminum in the arc and stainless steel in the straight section with the inner dimensions: arc region (H$\times$V): 90 mm$\times$60mm , utility section: 90 mm, circular, and Q1, Q2: 130 mm, 150 mm respectively, circular.

The vacuum pipes at bending magnet region consist of two parts: the beam chamber and antechamber in which the copper absorbers are installed to intercept the synchrotron radiation flux.

3.6 *Injector*

The present BEPC linac is working at the energy of 1.55 GeV with a positron filling rate to the BEPC storage ring about 3 mA/min. It would be upgraded to serve as a full energy injector of the BTCF with an ability of finishing the injection in 5 minutes.

4 SUMMARY

The upgrades of BEPC stride on the road to higher luminosity and efficiency. After finishing the hardware changes, we have obtained some preliminary results from lower-β scheme and single interaction point in the machine studies, and in normal performance lower-β lattice is being adopted. Although a factor of 1.5 has been got in both peak and average luminosity, much time for machine study is needed. Some luminosity related phenomena such as instabilities and beam-beam interaction, observed in performance, are still being studied. And some other further upgrades like pretzel scheme for multi-bunch are also being carried on.

A reference design of the BTCF has been done. The study shows that the luminosity at the energy of 2.0 GeV is feasible on a rather conventional basis of multi-bunch and small crossing angle collision scheme together with a micro-β insertion.

5 ACKNOWLEDGEMENTS

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