The BEPC Storage Ring – Status and Prospects

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Abstract

The present status of BEPC storage ring is briefly described. The plans for future development are discussed.

Introduction

The project of Beijing Electron-Positron Collider (BEPC) began in October 1984, and the first electron beam was stored on December 17, 1987. Since May 1989, the BEPC storage ring has been operated mainly for J/ψ physics experiments at the c.m. energy of 3.1 GeV.

The design and operating characteristics of the storage ring have been described in several publications[1].

The maximum luminosity of $2.6\times10^{30}cm^{-2}\ s^{-1}$ is reached with beam current of 2×22 mA at J/ψ energy. Integrated luminosity of (60∼70) nb^{-1} per day is obtained on the average, with peaks exceeding 90 nb^{-1} per day.

It is believed from the viewpoint of machine physicists that the even higher luminosity could be reached, while problems are encountered with increased background in detectors which make it difficult to take data. At present, the routine operation luminosity is limited by experiments around $1.3\times10^{30}cm^{-2}s^{-1}$ and the average luminosity is $(7\sim8)\times10^{29}cm^{-2}s^{-1}$. Up to now, about $6\times10^{6}\ J/\psi$ events are obtained , 2/3 of which are made into DST (Data Standard Tape) after calibration, reconstruction and sorting, and some $J/\psi\rightarrow\rho\pi$, $K^{*}K$, $\omega\pi\pi$, $\gamma\ K^{+}\ K^{-}$, $\gamma\ K_sK_s\cdots$, are analyzed. A dedicated synchrotron radiation (SR) mode was tested successfully with an emittance of $7.6\times10^{-8}m\cdot rad$ at 2.2 GeV.

The main parameters of the storage ring are given in Table 1, and Fig. 1 shows the layout of the ring.

Table 1. Main Parameters of the Storage Ring

	Design Value	Operating Value
Energy (GeV)	1.55-2.8	1.55∼2.2
Injection Energy (GeV)	1.1-1.4	1.11
Circumference (m)	240.4	240.4
Bending Radius (m)	10.35	10.35
Energy Spread	$2.66\times10^{-4}E$	
SR Loss per Turn (keV)	$8.59\ E^4$	
Critical Energy of SR (keV)	$0.214\ E^3$	
RF Frequency (MHz)	199.53	199.53
Harmonic Number	160	160
Peak RF Voltage per Cavity	675	400
Current (mA) Single Beam	130	150
Two Beams	66 × 2	(20 ∼ 30) × 2
β_x^*/β_y^* (m/m)	1.3/0.1	1.3/0.085
Luminosity ($10^{30}cm^{-2}s^{-1}$)	$17\times(E/2.8)^4$	2.6 ∼ 7.0
No. of Bending Magnets	40	40
No. of Quads	60	60
No. of Insertion Quads	8	8
Length for Experiment (m)	5	5

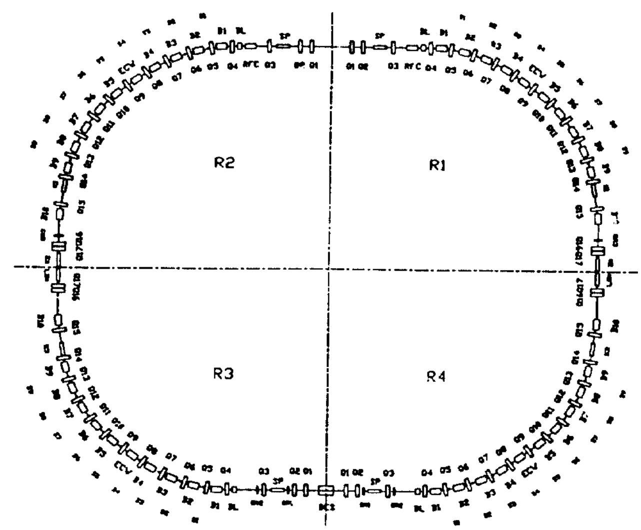

Fig. 1 Schematic Layout of Storage Ring Lattice

The storage ring ran for about 5400 hours during the period of March to the end of 1990. And 59.7% of the time was devoted to high energy experiments and SR experiments, 23.5% to filling, tune-up and machine study, and 16.8% down time due to failure of the linac, the ring and others.

One half of the BEPC storage ring downtime was due to leaks of the distribution pumps, vacuum valves and breakdown of ceramic windows in RF cavities which led to vacuum loss about 1/4 of the ring. The process of finding, fixing and recovering from the leaks was laborious and time consuming.

With first priority given to high energy physics experiments, only a fraction of the operating time was spent on machine studies and the dedicated SR operation. Fig. 2 shows the beam time for Beijing Spectrometer (BES) in the last two months of 1990.

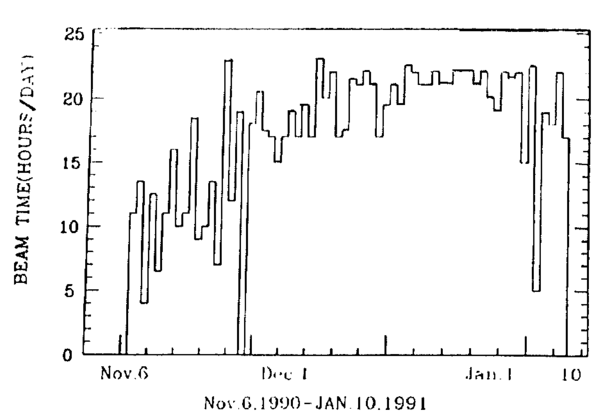

Fig. 2 Data Acquisition Time of BES

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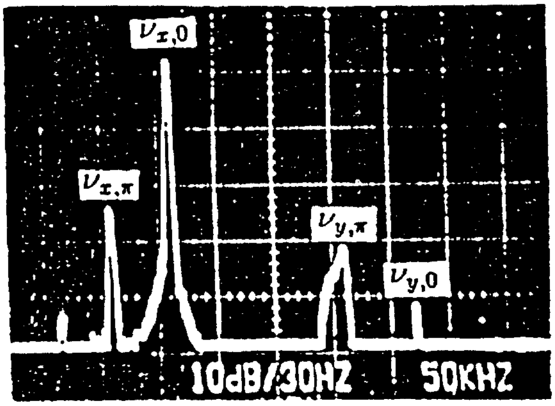

Fig. 4 Eigen-frequencies of the Bunches

An instability is observed in BEPC. Sometimes one of the beams or both of them blow up vertically and luminosity drops about 20% of normal value and in the meantime significant coherent longitudinal oscillations can be observed. The spectrum analysis of signals from a BPM electrode reveals a sideband structure which suggests a strong longitudinal dipole instability with small mixtures of high order modes. The reasons leading to such instability are not yet well understood, and it seems to be related to higher order modes of RF cavities excited by out of temperature control in the cavities.

Future Improvement

The near future and long-term machine improvements in BEPC aim at an increase of luminosity and reliable operation at higher energy. More photon beam lines will be constructed to enhance utilization of synchrotron radiation.

1. Single IP operation

A scheme to increase luminosity by running machine with only one collision per revolution will be tested. The beam will be separated at the northern IP with separators since the northern IP is still spare at present. Higher colliding beam current is expected in this way.

2. RF system improvements

Because of the rich physics interest in the J/ψ region, BEPC normally operates well below its maximum design energy now with rather low RF power requirements. However, serious tuner sparking of the RF cavities due to poor contact and RF window failure problems are troublesome obstacles to efficient operation of BEPC. The structure of the tuner will be modified and the RF window fabrication technology will be improved in order to couple more RF power to the cavities.

3. Mini-β insertion

The experiences from the existing colliders show that one of the most efficient methods to raise the luminosity is to adopt mini- β or micro-β schemes[4]. Therefore we have started to design the mini-β insertion for BEPC since 1984 and kept the necessary space for using this scheme in the design of BES[5].

According to the structure of BES, a strong vertically focusing iron-core quadrupole magnet can be placed inside BES. The first vertically focusing quadrupole Q1 of the existing lattice would be removed. The front face of this mini-β quadrupole (MQ) is 1.27 m away from the IP. Since MQ has to be built into the BES its outer dimensions must be limited to about Φ600 to fit the available space in BES. The first horizontally focusing quadrupole magnet Q2 should be moved towards the detector to give a strong doublet as close as possible to the IP, whereas all other magnets are unchanged.

The mini-β optics design for BEPC provides a vertical β function of β_y^*=0.036m at the IP and horizontal β_x^*=0.9m, without increasing the maximum β functions. Assuming that the beam-beam tune shift for the mini-β optics is the same as low-β optics, an increase of a factor of 3.85 in the luminosity would be expected. The main parameters for mini-β optics are given in Table 3.

Table 3. Major Parameters for Mini-β Optics

β_x^*/β_y^* (m/m)	0.9/0.036
ν_x/ν_y	5.8/6.8
α	0.0376
ϵ_x (mm·mrad)	0.65 (2.8 GeV)
Chromaticity ξ_x/ξ_y	-12.74/ -21.07

The main problem to adopt mini-β insertion for BEPC is how to reduce the beam length. The present BEPC RF system operates at a frequency of 200 MHz which gives the bunch length about 6~7 cm with RF voltage of 300 kV at 1.6GeV. To operate with β_y^*=0.036m, β_x^* =0.9m and keep $\beta_y^* \sim 1.2\sigma_s$, σ_s must be reduced to $\sim$ 3cm. Two methods provide short bunches in BEPC have been considered. One is to use much higher RF voltage of about 1.3 MV for low energy operation with the BEPC existing RF system. The higher RF voltage leads to larger synchrotron tune. It might be necessary to control the dispersion and COD in the RF cavity to avoid the excitation of synchro-betatron resonance. The second is to design a new RF system using higher frequency above 400 MHz which gives twofold increase in harmonic number in BEPC. This also enlarge the synchrotron tune. Furthermore the short bunch length achieved in this way will decrease the injection time acceptance and the requirements on the injector beam are considerably more stringent. A new 7 A electron gun is being developed in order to increase the production of the positrons and then decrease the injection time. The injection energy will be increased from 1.1 GeV to 1.4 GeV, and the repetition rate can also be increased from 12.5 to 25 Hz. All of those will keep the filling time to present level.

4. Construction of new synchrotron radiation beam lines

In order to improve the quality of the photon beam, especially brightness and intensity, it has been proposed to install an undulator and new multipole wigglers in the storage ring, which would be operated in dedicated SR mode. Several new photon beam lines from bending magnets will be built to provide more utilization of synchrotron radiation in parasitic mode.

References

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Machine Performance

1. Injection

In BEPC storage ring a single bunch per beam is used for collision at two interaction points (IP's). The beam is injected at 1.1 GeV. The operation sequences of the storage ring are as following. Prior to each filling, the magnets are run through a hysteresis cycle to injection field. Positrons are then injected into the ring. With separators on, electrons are injected. During the filling period, the lattice is detuned to have a larger β function at the IP's in order to make easier filling. After energy ramping the lattice is set to luminosity mode. Normally the injection process takes half an hour.

The difficulty of second beam (e^-) troubled us for a long time. Sometimes the electron beam was very difficult to be injected when the positron beam had been stored. The studies showed that one of the reasons was multibunches of the stored positron beam. With carefully watching the beam signals from the beam position monitor (BPM) electrode in the ring we found that 2~3 small bunches accompanied the main positron bunch. The injected electron was then disturbed by these unexpected bunches, which makes it difficult for electrons to be accumulated. The situation has been improved by getting rid of the extra pulsed beams from the linac.

2. Beam Position Monitor and Orbit Control

The orbit correction system in the ring consists of 32 BPM's, 4 horizontal dipoles (BH), 28 trim coils in bending magnets (BT), and 30 vertical dipoles (BV). The typical rms closed orbit distortion (COD) after correction is X_{rms} and $Y_{rms} = 1 \sim 2$ mm with 3 correctors. It was found that a small COD as indicated by BPM might not work as well as it was expected, and some BPM's showed poor repetition of measurement. Those mean there would be some errors in BPM reading which make orbit control difficult. After correcting some hardware failures of BPM and calibrating the attenuate factor of BPM cables, the orbit repetition seems to be improved. The offset errors of BPM have been corrected and a self-consistency check software of BPM has been added to the orbit measurement program. All of those improvements reduce the reading errors of BPM and increase the accuracy of COD measurements.

3. Luminosity and Beam-Beam Tune Shift

The dependence of the luminosity on various machine parameters and their optimization at BEPC have been studied preliminarily by using usual methods such as optimization of tunes, increasing emittance, decreasing β functions at IP's and adjusting beam height.

Because the arc lattice of BEPC storage ring was designed as non-standard cell structure and more independent power supplies have been used to control the quadrupoles, the BEPC lattice has a high degree of flexibility to adjust beam dynamic parameters over a wide range, which is important in optimizing the performance of the storage ring.

It is indicated by preliminary scanning of the tunes that the better working points for higher luminosity are in the region around ν_x=5.8 and ν_y=6.8 which does not agree to the theoretical predication and experiments of most existing colliders[2]. A research on such unusual results is under way. Table 2 shows the typical configurations with different working points.

BEPC has been operated with the maximum current approaching to the beam-beam interaction limitation. In order to increase the luminosity without raising the tune shift attempts have been made to increase the beam emittance and intensity. Table 2 shows that with emittance increasing from 0.15 mm·mrad to 0.4 mm·mrad at 1.55 GeV, the maximum beam current and luminosity increase to 2×22 mA and 2.6× $10^{30} cm^{-2}s^{-1}$ respectively.

Table 2. Typical Configurations

	M62717	M5868	M583669	M938518**
E (GeV)	1.6	1.6	1.549	2.2
ν_x/ν_y	6.2/7.17	5.8/6.8	5.83/6.69	9.38/5.18
β_x^* (m)	1.3	1.3	1.3	5.0
β_y^* (m)	0.1	0.085	0.085	7.0
$\epsilon_x(mm{\cdot}mr)$	0.22	0.22	0.40	0.076
$I_{max}(mA)$	2×8	2×14	2×22	150
ξ_{ymax}	0.025	0.035	0.028	
L_{max} ($10^{30}cm^{-2}s^{-1}$)	0.7	2.0	2.6	

** SR dedicated configuration

When the beam current is lower than 2×10 mA during a collision cycle, the emittance can be adjusted smoothly from 0.4 mm·mrad to 0.2 mm·mrad keeping tunes constant, and the luminosity increases by 30%. In this way the average luminosity reaches 60% ~ 70% of the peak luminosity during a physics run.

Attempts were made to reduce β_y^*, but it might result an increased background in detectors. At the current below 2× 9 mA at 1.55 GeV, the luminosity for $\beta_x^* = 1.0$m and $\beta_y^* = 0.075$m was measured 20% higher than that of $\beta_x^* = 1.3$m and $\beta_y^* = 0.085$m.

The beam height is one of the most important parameters for the luminosity in BEPC and is mainly determined by a vertical dispersion caused by machine imperfections, misalignment of magnets and vertical closed orbit displacements, and also by the contribution of the solenoid and the beam-beam interaction. The perturbation effects of the solenoid on the luminosity in BEPC have been compensated with one pair of skew quadrupoles near the injection region[3]. The other two pairs of adjustable skew quadrupoles in the ring are not effective to control horizontal- vertical coupling without disturbing β functions at IP's. Experiments show that the luminosity in BEPC sensitively depends on the vertical dispersion which increases the beam height. By careful adjusting the vertical closed orbit the luminosity can be increased by about 15%. The luminosity as a function of current for M583669 is plotted in Fig. 3.

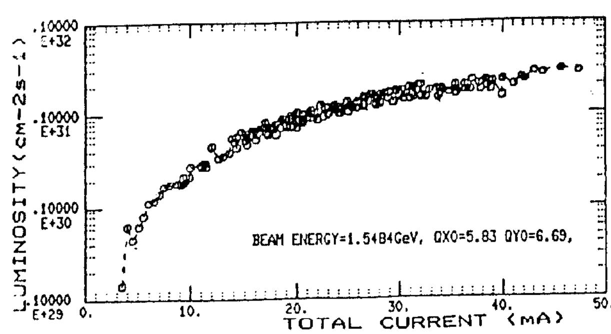

Fig 3. Luminosity vs. Current of M583669

The tune shifts due to beam-beam interaction have been measured directly. Fig. 4 shows the two eigen-frequencies of the two bunches which are coupled by the beam-beam interaction force. The difference in the frequencies is the coherent tune shift per ring.