THE PROGRESS OF BEPCII STORAGE RING DIAGNOSTICS SYSTEM

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Abstract

In this paper, we will present the progress of BEPCII storage rings beam diagnostics system along with the BEPCII commissioning. Tools such as Libera BPM had been used for the BPR first turn measurement and the injection residual orbit research of BER. COD_BPM can satisfy the resolution requirement for the beam-beam scan in the interaction region, and for the COD measurement, BCM (bunch current monitor) can help us on the different injection pattern. The TFB system is important to suppress the strong multi-bunch instabilities during the higher beam current running. The tune meters, the beam-loss monitors, DCCT and SLM (synchrotron light monitor) are also described in this paper.

INTRODUCTION

As the upgrade project of Beijing Electron Positron Collider (BEPC), BEPCII is still serving the purposes of both high energy physics experiments and synchrotron radiation applications [1]. The BEPCII is a double ring electron-positron collider and a synchrotron radiation (SR) source with its outer ring, or SR ring. It can work on collision mode or dedicated synchrotron radiation mode. The design goals of the BEPCII are shown in Table 1.

Table 1: The design goals of the BEPCII

Beam energy	1-2.1 GeV
Optimum energy	1.89 GeV
Luminosity	1×10^{33} cm^{-2}s^{-1} @1.89 GeV
Injector Linac	Full energy inj.: 1.55-1.89 GeV Positron inj. rate > 50 mA / min
Dedicated SR	250 mA @ 2.5 GeV

For the collision mode, the electron ring (BER) and positron ring (BPR) cross each other in the northern and southern interaction points (IP’s) with a crossing angle. In the northern crossing region, a vertical orbit bump is used to separate the two beams, while the southern IP is used for BESIII detector. When BEPCII works in the dedicated synchrotron radiation mode (SR), the electron beam circulates in the two outer half rings. A bypass in the northern IP is designed to connect two outer half rings. In the southern crossing region, a special pair of superconducting magnet complexes, mainly including quadrupole magnets (SCQ) and bending magnets (SCB), are used for 1.5 cm β function in the y direction at the IP on colliding mode and to serve as the bridge connecting two outer half rings for SR operation, respectively. Because the construction schedule of the cryogenics system and superconducting magnets was little delayed compared to the other systems, it was decided to install conventional magnets in the interaction region (IR) as the backup scheme, so that we can provide beam to SR users as early as possible, and accumulate the beam commissioning experience on the colliding mode. The backup lattice is similar to that of the original design.

Two phases of commissioning of the BEPCII rings have been completed: collision mode commissioning, and providing beam to beamline users in the dedicated synchrotron radiation mode. Phase one commissioning started on Nov. 13, 2006 by using conventional magnets instead of SC magnets in the IR. Phase two commissioning started on Oct. 24, 2007 by using SC magnets (without the BESIII detector). In the two phases, the beam diagnostics system played important roles, such as using the Libera BPM for first-turn beam circulating and for injection residual orbit research on the BER, and transverse bunch-by-bunch feedback (TFB) system to suppress the strong multi-bunch instabilities in higher-beam-current running, and so on.

LIBERA BPM

In the storage rings of BEPCII, a total of 16 units of Libera BPM are used. Libera control platform is located in Central Control Room. We can implement the control of Libera and data acquisition through the local-area network. BEPCII event timing system provides the trigger signal through an event receiver (EVR) module. Then we use clock splitter to synchronize data acquisition in different Liberas.

The Libera BPM played an important role during the commissioning of the first-turn and first-several-turns beam-circulating in BER and BPR (Figure 1) We only took 3 hours and one day to realize the beam accumulation in BER and BPR, respectively.

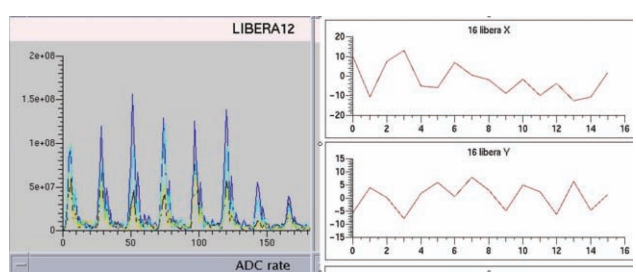

Figure 1: Libera BPM signal for first several turns of beam in the BER

Another important role Libera played is the optimization of timing delay of injection kickers and minimization of residual orbit oscillation in BER. The BEPCII includes two injection kickers and a Lambertson magnet for each

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ring. The injection layout of two rings is the same. Both kickers would kick the beam in the horizontal plane. The phase advance in the horizontal plane between two kickers is designed to be exactly 180° to decrease the disturbance to the circulating beams during the injection. During the beam injection in BER, we found the injection kickers frequently cause beam loss when the voltage intensities of two kickers are set almost the same. We use the Libera BPM to measure the turn-by-turn beam position data by changing the difference of two kicker intensities and try to analyze the residual orbit oscillation. When the difference of two kicker intensities becomes smaller, we observed that the amplitude of residual orbit oscillation becomes smaller in the X direction but bigger in the Y direction. We suspected a coupling between X and Y direction in the injection region. Later we finally found a short circuit in the R1OQ16 quadrupole magnet in the injection region. Before this problem was found and solved, we had to optimize the injection efficiency. We adjusted the voltage intensity and timing delay of two kickers to reduce the residual orbit oscillation, and the injection efficiency was improved. With a small residual orbit oscillation, we cold keep the two-beam colliding condition during injection [2]. Figure 2 gives the measurement results of residual orbit oscillation before and after optimizing the injection efficiency of BER.

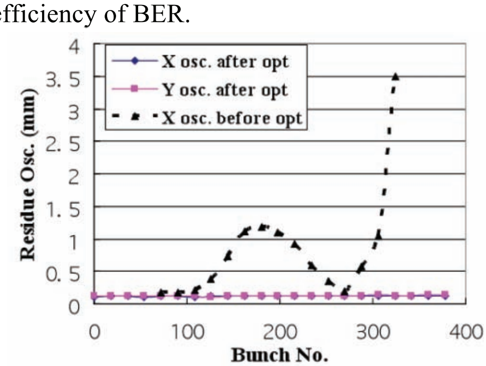


Figure 2: The measurement results of residual orbit oscillation in BER.

MX_BPM

In the BEPCII double rings with 240 m circumference, there are 67 BPMs in each ring (total 132 BPMs, two are for common) for the COD measurement and correction. A set of low loss coaxial cables brings up the pick-up signals of each detector to the local control room where the DAQ system is located. The lengths of cables vary from 60 to 90 meters depending on the locations of the detectors in the storage rings. Table 2 shows the main BPM and BEPCII parameters.

The COD BPM system consists of Bergoz MX_BPM, VME64x and ADC boards. Among various analog signals from a MX_BPM board, only the beam position (x and y), Σ and A, B, C, D (four buttons) signals are digitized for the regular operational database [3].

There are twenty 32-channel 60-kHz 16-bit ADC boards in each ring. The resolution of the position measurement is improved by averaging 30 raw BPM data in the microprocessor. It gives the 2 Hz data refreshing rate for double rings. Figure 3 shows the DAQ structure of the BPM system.

Table 2: Main parameters of BPM and BEPCII

Parameters	Unit	Value
BPM Accuracy	mm	0.1
BPM Resolution	mm	< 0.01
RF Frequency	Mhz	499.8
Harmonic Number	Colliding mode	396
Harmonic Number	SR mode	402
Bunch Current	mA	9.8
Total Beam Current	mA	910
Bunch Length	cm	~1.5
Crossing Angle	mrad	±11

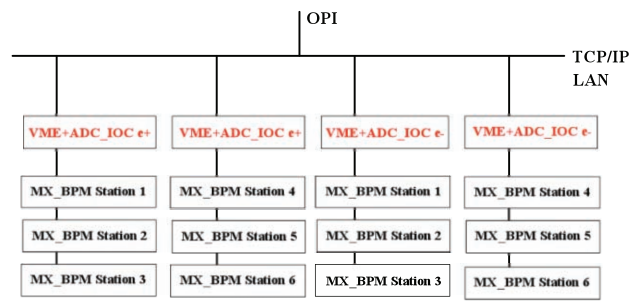


Figure 3: The DAQ structure of the COD BPM system.

Resolution

Normally, the main performance parameters of the BPM system are accuracy and resolution. The accuracy mainly depends on the alignment. This can be compensated by the BBA. By taking 16-bit ADC and averaging the raw BPM data, the system resolution is less than 2 µm in Y, within a measuring range of ±5 mm, and 4 µm in X within a measuring range of ±10mm. Figure 4 shows the BPM resolution during one standard shift (7 hours).

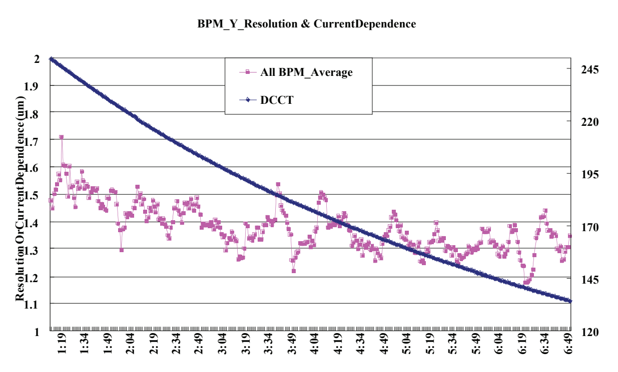


Figure 4: The BPM resolution in the Y direction over 7 hours.

For Beam-beam Scan

The vertical β function at the IP is one of the key parameters for luminosity. The small beam size means that the BPM system should have good resolution to satisfy the requirement for beam-beam scan (BBS) on collision tuning. The first beam-beam scan with SCQ at IP was done by 2 μm steps on Nov. 18, 2007. For this purpose, an orbit bump around the IP in one ring is used to scan the beam position at the IP, while observing the beam orbit variation in the other ring due to the beam-beam deflection. Fig. 5 is a typical BBS result.

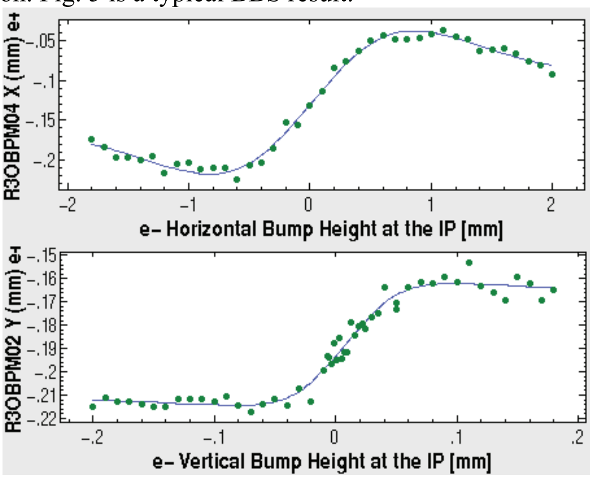


Figure 5: Positron beam orbit variation due to beam-beam deflection. The lines are the fitted curves for Gaussian bunches.

BUNCH CURRENT MONITOR

There are at least these two reasons for filling each ring with an equal charge in all bunches: to optimize the beam-beam tune shift and to control the stability of individual bunches.[4] The bunch current monitor (BCM) system consists of three parts in the hardware layer: the front-end circuit, the DAQ and the bucket selection system. The front-end circuit is located near the storage rings; the DAQ is in the local station of the beam instrument. The key component of DAQ is a FADC board with model of ECAD-1-081500-1 (1.5 GSPS, 8-bit VME board). Here the analog bunch current signal sent from the front-end circuits is processed by FPGAs and then the digital signal is sent to the shared memory board. The bucket selection system in the central control room reads the bunch current data from the shared memory board, then controls the beam pulse from the linac to be injected into the required bucket within 20 ms, which is the repetition period of the linac. Figure 6 shows the system structure with a dedicated optical communication system.

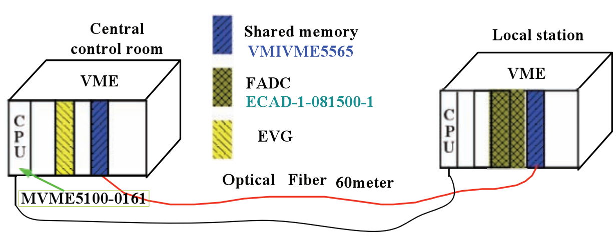


Figure 6: The BCM system structure.

In the software layer, the VME computer MVME5100-0163 in the local station of beam instrumentation runs real-time VxWorks program for the DAQ, while the same type VME computer in the central control room runs program based on standard EPICS I/O. For an 8-bit ADC with maximum input of 500 mV, the resolution of BCM system can reach 50 pC for an injection beam pulse. Figure 6 gives a measurement result from a 300 mA·300 mA multi-bunch collision.

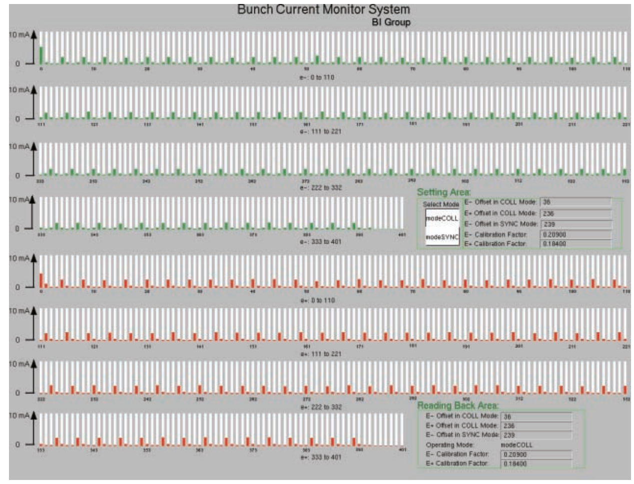


Figure 6: BCM measurement result on 300mA·300mA multi-bunch collision.

TRANSVERSE FEEDBACK SYSTEM

BEPCII is designed to operate with every other 4-bucket filled, with a bunch spacing of 8 ns (62.5-MHz bunch frequency) and high beam current (about 1 A) as shown in Table 2 in the colliding mode. Each ring has 93 and 99 bunches, with and without a small ion clearing gap, respectively. According to estimations of the growth time of most dangerous coupled bunch modes (4.3 ms for resistive wall and 0.5 ms for electron cloud) are shorter than the radiation damping time of 25 ms in the transverse direction. The design goal of the feedback damping time is set to 0.5 ms in the transverse direction.

Because the storage rings are small and the budget is limited, the transverse feedback system (TFB) is analog. To increase shunt impedance, the damping kicker length matches the 125-MHz bunch frequency. Two kickers were installed in the outer ring so the system can work in both colliding and SR modes. The front-end electronics, phase shifter, one-turn delay unit, notch filter and power amplifiers are shared by both modes.

The TFB system successfully operated in the phase two commissioning of BEPCII, including colliding mode and SR mode. Figure 7 gives the measurement results of synchrotron light monitor with the TFB system turning on and off during BEPCII operated in the SR mode.

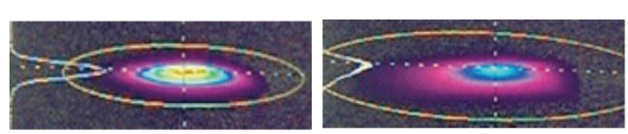


Figure 7: TFB turn on (left) and turn off (right)

In most cases of operation without TFB, a threshold of beam current often appeared when injecting beam into rings to over 200 mA. The capability of suppressing betatron sidebands can reach to 40 dB in both horizontal and vertical directions in the designed 125MHz system bandwidth. Figure 8 shows another beam spectrum measurement results in BPR when BEPCII operated in the colliding mode with 93 bunches and 243mA beam current.

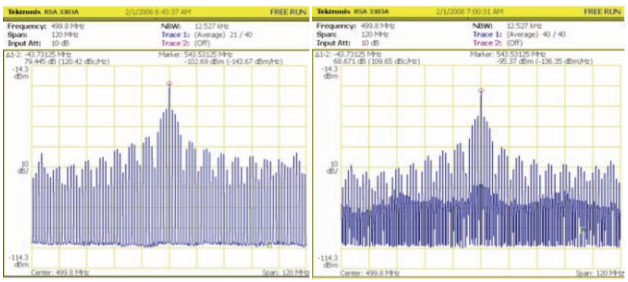
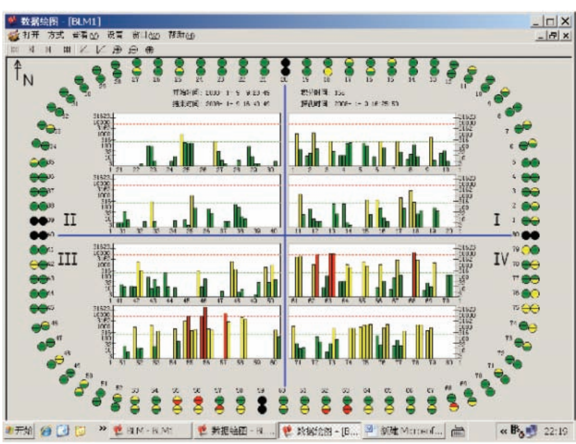


Figure 8: TFB turn on (left) and turn off (right)

BLM AND TUNE

The beam loss monitor (BLM) and tune measurement systems also played an important role for the first beam circulating in the outer ring for the dedicated SR mode (BSR) in phase one commissioning. They were also important for background study on BESIII (Figure 9 is an example of the beam loss measurement during the electron beam injection), tune-tune shift measurement for the luminosity estimation, and so on. By using the BLM and BPM, we found a wrong connection of a power supply to the R1OQ09 quadrupole magnet.



Figures 9: The beam loss measurement during electron beam injection.

Background study

The beam loss monitor (BLM) system usually is used for detecting or locating any possible excessive beam loss with the injection process, beam instabilities, bad vacuum, ion trapping, etc. This system is a useful supplement to the beam diagnostic system for the trouble-shooting. The detector is produced by Bergoz Company. It is the PIN diode type and not sensitive to photons. We try to use the BLM system for the BESIII detector background study. From the BLM measurement results, we found that:

- The electron beam injection brings more beam loss than positron beam injection.
- The collimators at present locations in the electron ring didn't show obvious effects to reduce the background, but the collimators at transport line show obvious effects to reduce the background during the electron beam injection.
- On the SR mode, the beam loss in IR is small.

Because BEPCII doesn't have a dedicated abort system for dumping the beam, so the beam abort became a problem. Similarly, according to the BLM measurement results, the new abort method was decided by using injection kickers and local orbit bump and it can obviously reduce the background in IR.

Tune-tune shift

The beam-beam tune shift can be used to evaluate the collision luminosity. Before the dedicated luminosity detector can offer the measured luminosity data for the accelerator commissioning, the sweep frequency method was used for the tune measurement while the transverse feedback kicker serving as the shaker to excite the beam oscillation. The perturbed tunes of each ring corresponding to the so called high tune (H) and low tune (L) modes have been observed with spectrum analyzer [1]. Figure 10 is a typical tune spectrum observed during two-single-bunches collision.

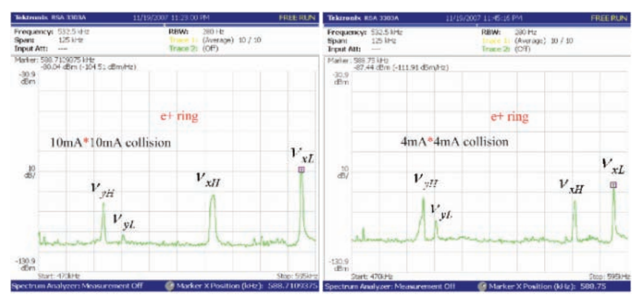


Figure 10: Measured tunes due to beam-beam effects.

SLM AND DCCT

Comparing with other diagnostics devices, like BCM, TFB, BLM and so on, synchrotron light monitors (SLM) just keep the same optics structure with BEPC used, only first mirror and its vacuum chamber were replaced by new one. It is used for the measurement of beam size, bunch length and to monitoring the beam instability. The calibration of the transverse magnification of the imaging optics had been done with beam by using the method of sliding the lens. The measurement error of beam size including chromatic error, depth of field error, diffraction error and curvature error are also analyzed.

The DCCT will be introduced in detail in the ref. [5]. Here only introduces the issues related to the high beam current. Along with beam intensity growth, particularly when the beam current is higher than 500mA in colliding mode, the heating effect due to HOM appeared clearly in the DCCT. The temperature rise shows sensitivity to the bunch current. This problem had been considered in the shielding design, e.g., a copper layer to bridge the image current rerouting on the ceramic gap was adopted for RF shielding, but its capacity seems too small for some low frequency part of the image current. Therefore some capacitors will be connected during machine shutdown to improve the RF shielding.

SUMMARY

Two phases of BEPCII commissioning have been completed. Various beam instrumentation systems played important roles during each commissioning stage. However, there is still much work to do, such as eliminating the sporadic jitter in BCM, carefully tuning the phase to keep the TFB stable, solving the heating problem in DCCT, developing more functions for Libera in order to get more beam information, and so on.

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