BEAM DYNAMIC ISSUES IN THE BEPCII LUMINOSITY COMMISSIONING*

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Abstract

As a τ-charm factory like collider, the upgrade project of the Beijing Electron Positron Collider (BEPCII), has reached 1/3 of the design luminosity. During the luminosity commissioning, beam optics recovery, machine parameters measurement, detector solenoid compensation, and instability cure are main problems we met. Besides commissioning the machine, beams were delivered to the users from high energy physics and synchrotron radiation. This paper summarizes the accelerator physics issues in the BEPCII luminosity commissioning from 2009.

INTRODUCTION

BEPCII was designed as a factory-like collider with a design luminosity of $1\times10^{33}cm^{-2}s^{-1}$ at the beam energy of 1.89GeV. It is characterized as "one machine, two purposes", which means to provide beam not only for high energy physics experiment, but also for synchrotron radiation (SR) users in parasitic or dedicated mode. Using the BEPC tunnel, BEPCII keeps the linac and two transport lines same as BEPC, but was upgraded as two rings in parallel to store e^- and e^+ beams, respectively, and named as BER and BPR. The two halves of the outer rings are connected as an SR ring, the third ring named as BSR, with 9 beam lines extracted from 5 wigglers, and other 6 beam lines from bending magnets. To save the budget, all the beam line extraction ports are kept the same as BEPC. The layout of BEPCII is shown in Fig. 1.

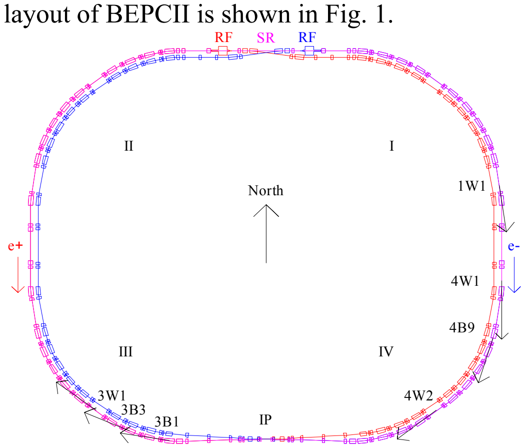

Figure 1: Layout of the BEPCII storage rings.

The commissioning of the storage rings were carried out in three phases, as already described in [1] and [2]. In Phase III, the detector, upgraded BEijing Spectro-meter (BESIII), had been rolled in the tunnel in 2008, and was commissioned together with the collider. Table 1 lists the main design parameters of BEPCII.

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Table 1: Design parameters of the BEPCII collision mode

Energy for collision	GeV	1.89
Circumference	m	237.53
Beam current in collision	mA	910
Injection energy	GeV	1.89 – 2.5
Injection rate (e^+, e^-)	mA/min	50, 200
Luminosity	$cm^{-2}s^{-1}$	1×10^{33}

In this paper, the beam dynamics issue during the luminosity commissioning of the BEPCII storage rings, mainly the Phase 3 of commissioning in 2009 and 2010, are reviewed and discussed.

LATTICE AND ITS REALIZATION

The BEPCII storage rings are composed of 4 arcs, 1 interaction region, 1 RF region and 2 injection regions. The Twiss functions in the arcs are similar as that of BEPC, which is a kind of quasi-FODO structure. In the lattice design, the two rings have the exact same Twiss functions, but the inner and the outer half ring are different. The β and dispersion functions of the ring are shown in Fig. 2.

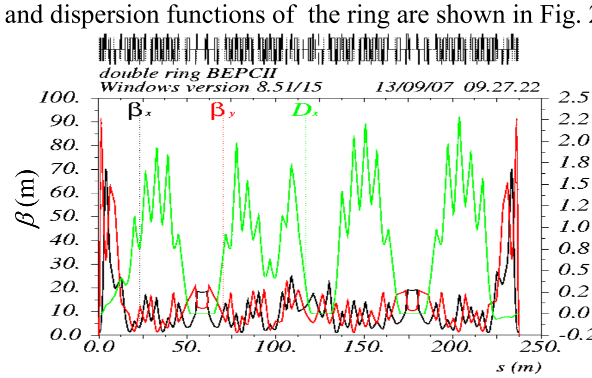

Figure 2: β and D_x around the BER or BPR.

To realize the linear lattice, which means to have the Twiss functions and tunes of the whole ring to be as close as to the theoretical model, the method of response matrix was applied, and all the quadrupoles' strengths were corrected. Closed orbit distortions were also corrected with the method of SVD, based on the measured response matrices. To understand the reason of fudge factors, a ratio of real quadrupole strength to theoretical value, some models of magnets were set up and analyzed together with the magnet measurement. The details can be found in [3] of this proceedings. After the correction, the measured β functions are approached to the theoretical ones, with a maximum relative error of ~10% in two directions. The tunes thus are also get close to the design values.

LUMINOSITY COMMISSIONING

The luminosity commissioning contains longitudinal beam position tuning by RF phase, collision offset determination by orbit scanning, single bunch luminosity tuning including tune scan, coupling optimization, IP β-waist tuning, etc., as well as multi-bunch luminosity optimization. Figure 3 shows the tuning of vertical angle of two orbits at the IP with the RF phase scanning. Figure 4 demonstrates the scan of the IP β-waist.

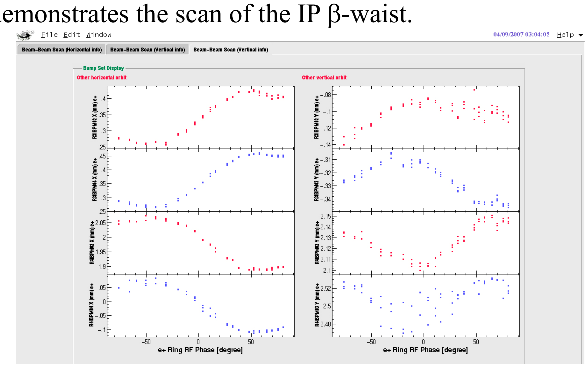

Figure 3: RF phase scanning to get vertical crossing angle.

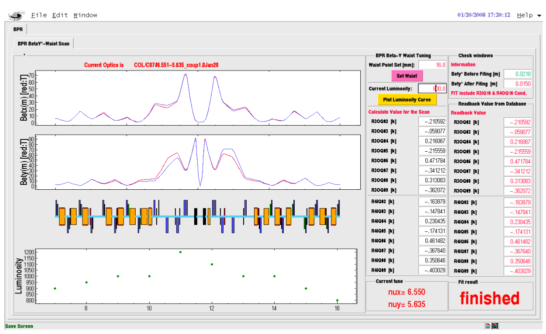

Figure 4: IP β-waist scanning.

All the above processes need to be iterated to get a better luminosity. By the beam-beam scanning, we also got the bunch sizes at the IP as ~0.4mm in horizontal and 5µm in vertical, respectively. A luminosity of near 5×10^{30} $cm^{-2}s^{-1}$ at 8mA×8mA bunch currents was achieved during commissioning. However, when in multi-bunch collision, the luminosity didn't increase as linearly as expected.

Beam instability observations

In September 2008, as the beam current in the multi-bunch collision exceeded 400mA for each beam, a luminosity reduction along the bunch train was observed, as shown in Fig. 5.

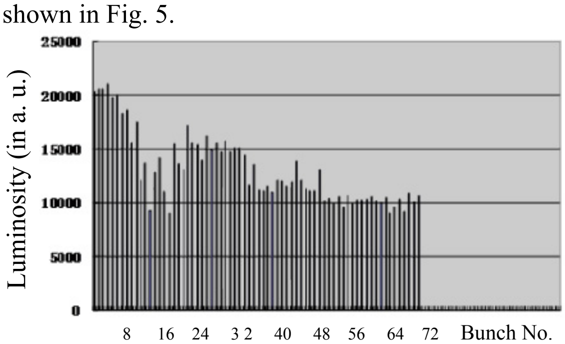

Figure 5: Bunch-by-bunch luminosity along bunch train

To identify which ring had the problem, experiments were designed to collide one beam with a bunch train to another beam with two short bunch trains, observing the change of luminosity. From the signals of the common BPMs for the two beams, and the bunch size measurement with streak camera, a kind of longitudinal quadrupole oscillation was clearly observed, and thus a bunch lengthening along the bunch train was induced by this oscillation in the BPR, as described in [2].

A temporary screen monitor with two cavity-like slots at the BPR was found to be responsible to this quadrupole oscillation. The calculations in analytical formulae and MAFIA estimation show that a kind of medium R/Q impedance at ~2GHz contributes an equivalent inductance, which is about 1/4 of the low frequency impedance of the whole ring [4], [5].

This impedance and the instability it can invoke were simulated too. Equation (1) is the map in longitudinal used in the simulation [6]:

$$\begin{pmatrix}\Delta E\\ \Delta t\end{pmatrix} = \begin{pmatrix}1-2\frac{U_0}{E_0}s & 0\\ \frac{\alpha T_0 s}{E_0} & 1\end{pmatrix}\begin{pmatrix}\Delta E\\ \Delta t\end{pmatrix} - \begin{pmatrix}U_0 s\\ 0\end{pmatrix} \quad , \qquad (1)$$

where ΔE and Δt are the conjugated variables in longitudinal phase space, U_0 the radiation energy loss per turn, T_0 the revolution period, α the momentum compaction factor, and s the position of cavity in a ring. The beam-cavity interaction was thus simulated with the mapping of [6]

$$\begin{pmatrix}v_m(t)\\ i_m(t)\end{pmatrix} = \exp(-\alpha_m t)\times \begin{pmatrix}\cos(\beta_m t)-\frac{\alpha_m}{\beta_m}\sin(\beta_m t) & -\frac{\omega_m R_{sm}}{\beta_m Q_m}\sin(\beta_m t)\\ \frac{\omega_m Q_m}{\beta_m R_{sm}}\sin(\beta_m t) & \cos(\beta_m t)+\frac{\alpha_m}{\beta_m}\sin(\beta_m t)\end{pmatrix}\begin{pmatrix}v_m(t)\\ i_m(t)\end{pmatrix} . \qquad (2)$$

Here, we use the conjugated variables $v_m(t)$ and the current in inductance $i_m(t)$ to represent the behaviour of the induced wake voltage for each mode "m". With the impedance source of the screen monitor, the bunch lengthening can be simulated for multi-turn, and the results of longitudinal oscillations are shown in Figs. 6 and 7. From these figures, one can see that a clear quadrupole longitudinal oscillation exists along the bunch train, and therefore the bunch lengthening in different turns is illustrated, which caused a luminosity reduction.

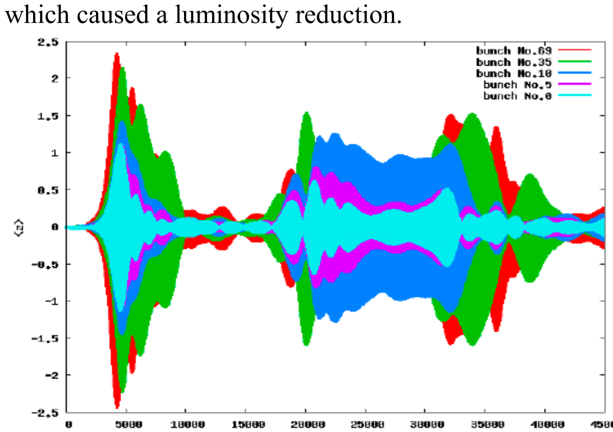

Figure 6: Longitudinal oscillation of in different turns along the bunch train

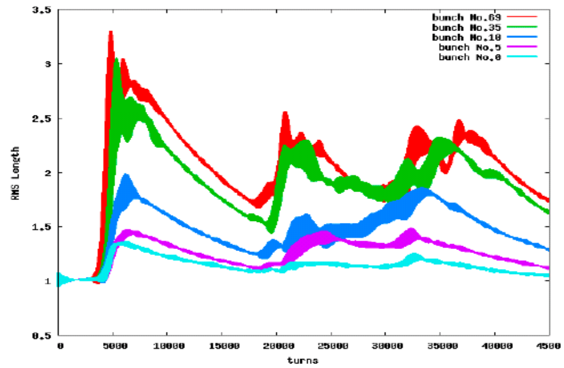

Figure 7: Evolution of bunch length along bunch train.

Luminosity recovery

In February 2009, the screen monitor was removed, and the luminosity was commissioned again. The bunch-by-bunch luminosity was recovered a lot, but the reduction still exists. It was believed that the dipole longitudinal oscillation of two beams caused this luminosity reduction. With the longitudinal feedback system, which was installed this January, the luminosity reduction disappeared, as discussed in [7], reached $3.3\times10^{32}cm^{-2}s^{-1}$.

Beam-beam issues

When the transverse tunes were moved to half integers, say (6.508, 5.587) for the measured tunes, the luminosity of BEPCII was increased about 20%, as shown in Fig. 8. Figure 9 shows the beam-beam parameters we got in the luminosity commissioning.

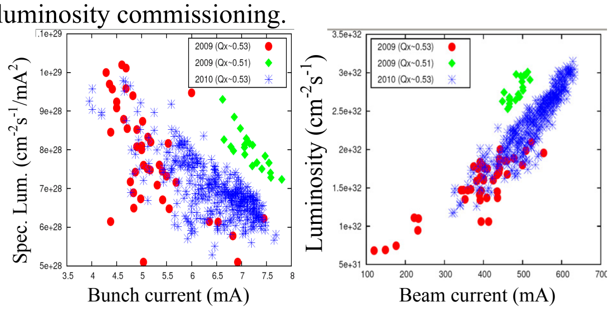

Figure 8: Luminosity at different tunes and time.

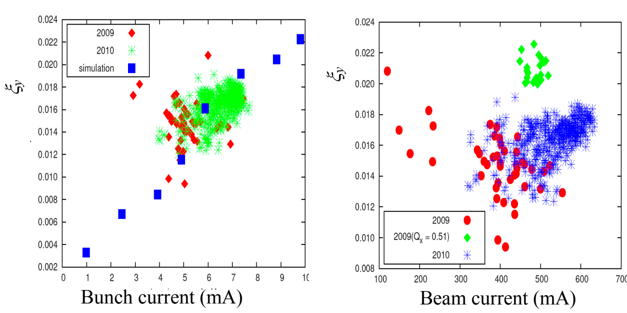

Figure 9: Beam-beam parameters got in luminosity tuning.

The beam-beam simulation also gives the similar luminosity and beam-beam parameter as the real results. At the design value of the single bunch current, the simulated beam-beam parameter is less than 0.04 due to the crossing angle at the IP. This is confirmed with the measured luminosity values. In the future running, we need to increase beam current, and the bunch current as well to get a higher beam-beam parameter.

BEAM LIFETIME

The beam lifetime of both BER and BPR at single and multi-bunch cases were observed, and calculated in detail [8]. In the recent operation, with 86 bunches in BPR, the beam lifetime was 2.2 hours at 650 mA, when the maximum vacuum pressure was 2.3nTorr. The e^- beam has a longer lifetime than the e^+ beam, since the vacuum in BER is better than BPR. With the measurement of beam lifetime, we deduced the longitudinal acceptance.

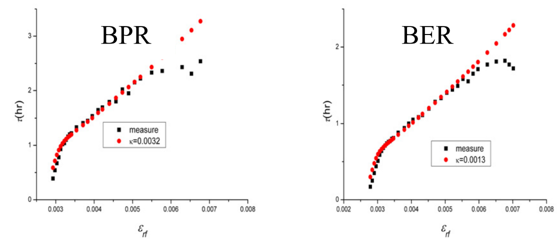

Figure 10: Longitudinal acceptance measurement

The longitudinal acceptances of BER and BPR are 0.47% and 0.45%, respectively, shown as Fig. 10. This might be the reason why the measured lifetime was always smaller than the theoretical value. Beam dynamic apertures are also needed to be optimized, which might be another effect of the beam lifetime.

CONCLUSION

During the luminosity commissioning and the routine operation of the machine, we realized the beam optics, corrected the beam orbits, and measured other beam parameters. The instabilities occurred along with the beam current increase was studied experimentally and analytically, and finally the impedance source was found and overwhelmed by removing the screen monitor and applying the longitudinal feedback. The luminosity recovered and was enhanced further by moving the tunes close to half integers. But still, the beam-beam parameter was only half of the design value, due to the effect of crossing angle at IP and the low bunch current we have now. The beam lifetime looks lower than expected. From the measurement, we can conclude the longitudinal acceptances of two rings, and this perhaps is the reason of low beam lifetime. Further beam studies are going to be carried out, together with the luminosity upgrade in the near future.

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