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SIMULATION OF THE EFFECTS OF TRANSVERSE FEEDBACK SYSTEM ON BEAM PERFORMANCE AT BEPCII

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Abstract

In the operation year of 2022-2023, BEPCII has made an excellent achievement being able to routinely operate above the design luminosity of 1×10^{33} cm^{-2}s^{-1}. On the way to operate above design luminosity, we found the transverse feedback system played such an important role in improving the collision luminosity. To understand what exactly the effects of transverse feedback system are on the luminosity, we carried out a series of simulations. In this paper, we try to summarize the simulation results of the effect of the transverse feedback system on beam performance and luminosity, and also try to compare the simulation results with the measurement results.

INTRODUCTION

The Beijing Electron Positron Collider II (BEPCII) [1] is a two-ring eletron positron collider running in the tau-charm energy region. The design luminosity of BEPCII is 1×10^{33} cm^{-2}s^{-1} at the optimal beam energy 1.89 GeV. The commissioning of BEPCII started at 2007, and the designed luminosity has been achived at 2016 [2]. However, to operate at design luminosity remained challenging during the daily operation by then.

In Jan. 2023, BEPCII reached the design luminosity in operation mode, and managed to routinely operate above the design luminosity in the 2022-2023 run. During commissioning, we found the transverse feedback system played such an important role in improving the collision luminosity. The luminosity improvement is made by change the feedback status of the positron ring (BPR) from optimizing at injection mode to optimizing at collision mode during data taking process, while the feedback status of the electron ring (BER) is kept always optimizing at injection mode. The comparison of luminosity before and after the change of BPR feedback work status is shown in Fig. 1. We can see that, a gain of 20% in luminosity was obtained after the change of feedback status been made.

So after the designed luminosity been reached during daily operation, we started to do machine study and simulations trying to understand why and how the transverse feedback impacts on luminosity, and at the same time, trying to find out if it is possible to further improve the beam performance in BEPCII.

The transverse feedback system at BEPCII is using the iGp feedback system, which is a commercial digital bunch-by-bunch feedback system that provides a maximum 32-tap FIR filters. Each ring has one feedback kicker. The feedback kickers each has four stripline electrodes, with a bandwidth of 250 MHz. One 75 W-amplifier is used for each port of feedback kicker [3].

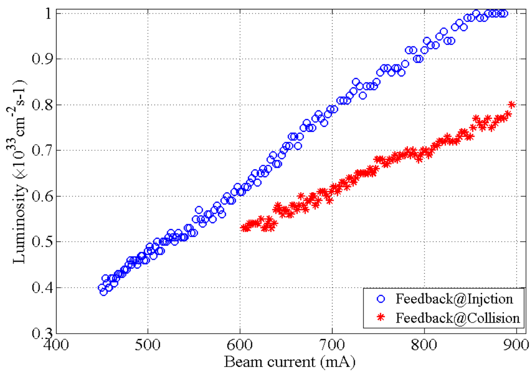

Figure 1: Measured luminosity before and after the change of BPR feedback work status from injection to collision mode.

The simulation of beambeam interaction is carried out with the code IBB [4, 5], which has been developed during the design period of BEPCII and then extended to support large Piwinski angle collision. The coupled bunch instability is modelled with a dipole kick in each turn, which is represented by the following map,

$$\begin{pmatrix} \delta\bar{x} \\ \delta\bar{p} \end{pmatrix}_i = (e^{1/\tau} - 1) \begin{pmatrix} \langle\bar{x}\rangle \\ \langle\bar{p}\rangle \end{pmatrix}, \tag{1}$$

where τ is the growth time of the most unstable coupled-bunch mode, $\bar{x}$ and $\bar{p}$ are the normalized coordinates. Each macro-particle i receives the same kick which is related with the dipole moment of the bunch.

The feedback systems are modelled with pickup/kicker and corresponding N-tap FIR filter, the kick from the feedback kicker is applied once for each turn,

$$\delta x'(n, s_{\mathbf{kicker}}) = K \sum_{i=0}^{l} c_i x(n - l + i, s_{\mathbf{pickup}}), \tag{2}$$

where n is the turn number, l is the tap length of FIR filter and K represents the strength of the feedback which is determined by the feedback damp rate. The FIR filter coefficients c_i is

$$c_i = \cos(i * 2\pi\nu + \phi), \tag{3}$$

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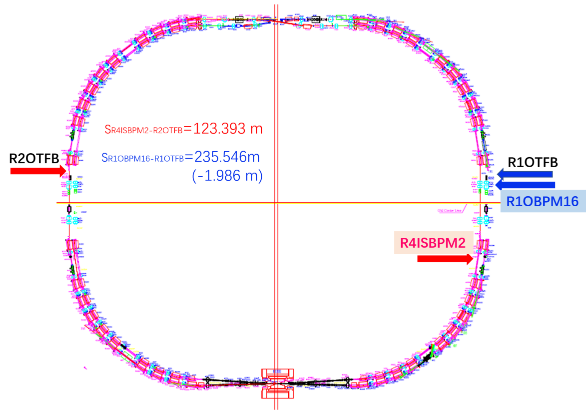

Figure 2: The positions of feedback kickers and pickups in BEPCII electron and positron ring.

Table 1: Beam Parameters at Feedback Kickers and Pickups in BEPCII Rings

	BPR		BER	
Parameters	kicker	pickup	kicker	pickup
β_x (m)	9.67	3.65	9.66	18.79
α_x (rad)	-1.26	0.95	-1.26	-6.59
β_y (m)	19.5	11.7	19.5	15.25
α_y (rad)	0.27	-1.83	0.28	4.71
η_x (m)	0.0	0.35	0.0	0.0
η'	0.0	-0.17	0.0	0.0
ϕ_x (2π) (from IP)	5.5839	1.6473	5.5836	5.6089
ϕ_y (2π) (from IP)	4.0615	1.4167	4.0661	4.0831

where ν is the optimized working point, and ϕ is the phase which could be tuned.

MACHINE PARAMETERS

The positions of feedback kickers and pickups in BEPCII electron and positron ring are sketched in Fig 2.

The beam parameters at the feedback kickers and pickups are shown in Table 1.

To better characterize machine status, we measured the horizontal and vertical tunes at different beam currents, the results are shown in Fig. 3. The bunch number is 118 in the measurement. We can see from Fig. 3 that, the decimal part of horizontal tune is 0.509 and 0.571 at the maximum beam current of 900 mA. These measured tunes will be used in the following simulations.

We have also measured the instability increasing time and the feedback damping time in each ring at different beam currents [3], the results for beam current at 900mA is listed in Table 2. The other beam parameters will take the theoretical value generated by the code SAD [6] in the follow simulations. The main beam parameters used in the simulation are summarized in Table 1.

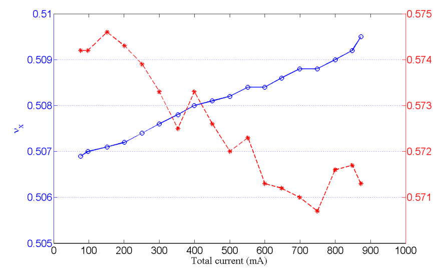

Figure 3: The measured horizontal and vertical tune at different beam currents at BEPCII.

Table 2: Beam Parameters used in the Simulation

Parameters	BPR	BER
Beam energy (GeV)	1.89	1.89
Emittance (nm· rad)	108	108
β_y^* (cm)	1.35	1.35
ν_x	7.5090	7.5090
ν_y	5.5712	5.5712
$1/\tau_{instability-x}$ (ms^{-1})	2.94	0.98
$1/\tau_{feedback-x}$ (ms^{-1})	5.11	5.83

SIMULATION RESULTS

In simulations, we use the measured beam instability growth rate and feedback damping rate to characterize the effects of feedback system on beam performance. While the feedback phase is set so as to optimally suppress the working point tune(ν=0.509 in Eq. (3)) — the so-called injection mode, and to optimally suppress the π-mode of collision (ν=0.529 in Eq. (3)) —the so-called collision mode, respectively, in order to reproduce the feedback work status change in operation.

Figure 4 shows the simulated beambeam parameters of collision at different bunch currents with BER feedback optimized at injection mode, while BPR feedback optimized at injection (blue circles) and collision (red stars) modes, respectively. From the simulation results we can see that, when the BPR feedback is optimized at injection mode, the beambeam parameter saturates at a bunch current of 6 mA,

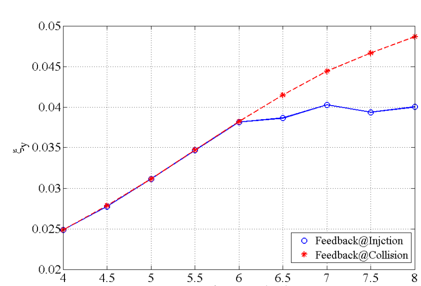

Figure 4: Comparison of simulated beambeam parameter ξ_y of collision at different bunch currents with BPR feedback optimized at injection and collision modes, respectively.

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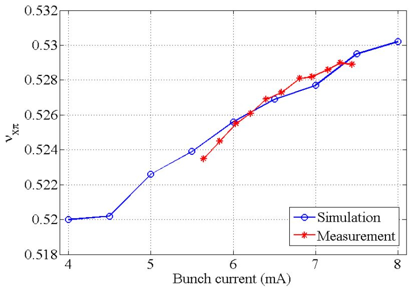

Figure 5: Comparison of simulated horizontal π-mode position of collision with horizontal instability at different bunch currents for the case that BPR feedback system is optimized at collision mode.

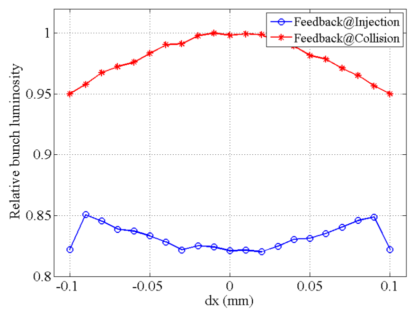

Figure 6: Simulated luminosity variation as the offset at IP changes for bunch current of 8 mA and BPR feedback working at injection mode and collision mode,respectively.

while no saturation is observed when the BPR feedback is optimized at collision mode. A gain of 20% in beambeam parameter is achieved by changing the work mode of BPR feedback from injection to collision mode at a bunch current of 8 mA, which agrees with the operation experiences shown in Fig. 1.

Figure 5 shows the simulated horizontal π-mode position of collision with horizontal instability at different bunch currents for the case that BPR feedback system is optimized at collision mode as listed above. For the measurement data, the beam current is taking as the average of electron and positron beam currents. It is shown that the simulation results agree well with the measurement.

In operation, we also found that the horizontal offset at IP had to be tuned to have a higher luminosity as the beam current decays before switching the BPR feedback from injection mode to collison mode during data taking. So we also simulated the luminosity variation as the offset at IP changes for BPR feedback working at injection mode and collision mode. The result is shown in Fig 6.

We can see from Fig. 6 that when the BPR feedback is optimized at collision mode, the collision luminosity maximize at zero horizontal offset. While when the BPR feedback is optimized at injection mode, the horizontal offset has to be adjusted to achieve maximum luminosity. The simulation results agree well with the operation experiences at BEPCII.

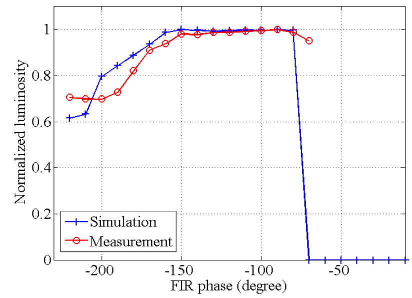

Figure 7: Comparison of measurement and simulation results of luminosity change as the BPR feedback FIR phase been varied at 700 mA beam current.

From Fig. 6 we can also see that, the luminosity of BPR feedback working at collision mode is always higher than BPR feedback working at injection mode, within a reasonable tuning range of the horizontal offset. The luminosity gain at zero offset of feedback working at collision mode in regard to injection mode is ~ 20%, which again agrees with the previous simulation results shown in Fig. 1

To illusatrate how much the feedback phase could affect the luminosity, we also simulated the luminosity variation as the feedback phase varies. Also, we did measurement of luminosity variation as the feedback phase varies in order to compare the simulation and measurement results. The comparison of measurement and simulation results of luminosity change as the BPR feedback FIR phase been varied in shown in Fig. 7, at an beam current of 700 mA. In the plot, the FIR phase in measurement is shifted to compare with the simulation results. We can see from Fig. 7 that, the luminosity has a flat top in a FIR phase range of 70 degrees in measurements, and the simulation agrees well with the experiment results. When the BPR feedback phase change exceeds the flat top area, an degradation in luminosity occurs.

SUMMARY

In this paper, we presented the simulation and measurement results of the feedback system effects on the luminosity at BEPCII. It shows that the simulation results agree well with the measurement results. It also proves that, different work mode of feedback system could greatly affect the collision luminosity. The simulation helps us to understand the phenomenon encountered during the recent commissioning of BEPCII.

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