THE VERTICAL IMPEDANCE DISTRIBUTION MEASUREMENT USING RESPONSE MATIRX METHOD AT BEPCII BPR*

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Abstract

In the last run of BEPCII, the single bunch current is limited to about 9mA by the beam-beam effect. To obtain the design luminosity, larger number of bunches are necessary. But higher total current may be limited by the collective effects. A good understanding of the transverse impedance distribution around the BEPCII storage ring is required. Response matrix method has been applied successfully in BEPCII to fit the quadrupole errors and restore the optics. We can also calculate the variation of betatron phase advance around the ring with different single bunch current using the response matrix method and the transverse impedance distribution is thus deduced. In this paper, the first measurement of transverse impedance in BEPCII is presented.

INTRODUCTION

BEPCII is an upgrading scheme of Beijing Electron-Positron Collider (BEPC). It is constructed for both high energy physics and synchrotron radiation researches (SR). The storage ring for collision consists of a positron and an electron ring. The two beams collide at the south IP with a cross angle of 11mrad×2, and the luminosity is optimized at 1.89GeV with $1\times10^{33}cm^{-2}s^{-1}$.

In the operation of 2011, we successfully moved the horizontal tune near the half integer. The peak luminosity reached $6.49E32cm^{-2}s^{-1}$ with 88 bunches each ring and the total beam current exceeded 750 mA. The single bunch current is limited to less than 9mA by the beam-beam effect. The higher current will induce the beam to blow up when colliding and is difficult to eliminate. The dynamic betatron effect causes the loss of luminosity. To achieve the design luminosity, we must overcome the instability, so as to increase the total beam current. On the other hand, the distributed impedance has never been measured in BEPCII before, only the simulation was presented. Some component was destroyed by the heating of HOM. For example, the ceramic plate of injection kicker was found broken and changed in 2010. And the feedback systems to suppress the multi-bunch coupling instability were installed in the storage. We need to realize the real impedance of these separate components and their influence on beam. Thus the study of the transverse impedance distribution is necessary.

The impedance works as a defocusing quadrupole whose strength is depend on the current. The phase advance will be reduced as the increasing of the current. At BEPCII, we use the Linear Optics from Closed Orbits (LOCO[1]) to correct the optics successfully. LOCO is based on response matrix method, and the distribution of focusing errors around the machine can be determined by fitting the orbit response. At the same time, LOCO can calculate beta functions and betatron phase along the ring. Since the impedance functioned as a current-dependent quadrupole, we measure the response matrix with different single bunch current, then fit betatron phase changes with the current, the impedance distribution can be deduced.

The first attempt to measure the transverse impedance is presented here. Because the BPM noise level in horizontal is worse than in vertical, only the vertical impedance distribution was measured.

RESPONSE MATRIX METHOD

The orbit response matrix is defined as:

$$\begin{pmatrix}\Delta x\\ \Delta y\end{pmatrix} = M\begin{pmatrix}\Delta\theta_x\\ \Delta\theta_y\end{pmatrix} \tag{1}$$

where $\Delta\theta_x$ and $\Delta\theta_y$ are the changes in strength of horizontal and vertical correctors respectively, Δx and Δy are the orbit perturbations at the BPMs. The response matrix M is an m×n matrix, and determined by the linear lattice of the ring, where m is the number of BPMs, and n is the number of horizontal and vertical correctors. M_{meas} is measured first, and the model matrix M_{model} which is calculate by accelerator modelling code such as AT[2] is fitted to the M_{meas}. By varying the parameters in model lattice, the difference between the measured and model response matrices are minimized [3]:

$$\chi^2 = \sum_{i,j}\frac{(M_{\mathrm{mod},ij} - M_{meas,ij})^2}{\sigma_i^2} \equiv \sum_{i,j} V_{ij}^2 \tag{2}$$

where the σ_i is the measured noise levels for the BPMs, V_{ij} is the function of the parameters. These parameters mainly determine the response matrix, including the quadrupole strengths, BPM gains, and corrector kicks.

In using LOCO, with the measured data and the initial parameters we calculate the initial V_{ij} and the derivative of the response matrix with respect to these paramters, then solve the changes of the parameters using singular value decomposition to minimize $\sum_{ij}(V_{ij}+\Delta V_{ij})^2$. M_{meas} and M_{model} converge to the noise level of BPM by iteration. With the parameters derived from LOCO, the model

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optics can predict the real machine optics, and the beta function and the betatron phase can also be calculated.

In each of the BEPCII storage rings, 34 horizontal correctors, which include 30 windings of bending magnets, 33 vertical correctors and 67 double-view BPMs are available. The Measurement of response matrix is done automatically, with corrector strengths changed one by one in bidirectional way. The BPM resolution of BEPCII is 10μm and the orbit shift is taken averaging over 8 times data to reduce the random error due to BPM resolution. It takes us about two hours to complete one measurement if all the correctors are revolved.

In the impedance measurement, to find the current-dependant phase changes, nearly 10 times response matrix should be measured with different current from 1mA single bunch current to 10mA, it would be very time-consuming. The limitation of the size of response matrix is required. We select 8 horizontal correctors and 8 vertical correctors whose betatron phase distributed evenly along the ring and the dispersion function there are relatively small. Therefore, in the uncoupled case, the response matrix contains (8+8)×67=1072 elements and depends on 219 parameters, including 69 quadrupole strengths, 134 BPM gains and 16 corrector kicks.

MEASUREMENTS

The double-ring geometric structure of BEPCII makes no symmetry in a single ring. The north part is RF region and south part is IR region. The Eastern and Western half-rings are different outer and inner ring. Each ring of BEPCII can be divided into four regions: the IR, the arc, the injection, and the RF regions. The arc region consists of 6 quasi-FODO cells except missing the fifth and eleventh bending magnets. The missing of two bending magnets forms two short straight sections. One injection kicker is installed in one of the short straight sections, and the other kicker is installed in the injection region.

The antechamber is adopted in the arc section to decrease PE instability. Its beam aperture is 120mm×54mm[4], and it is made of aluminium alloy. Two adjacent antechambers are connected by the RF shielding bellows. Considering the requirement of beam effective aperture and preventing the synchrotron radiation light from hitting the bellows, the flange and their welding, photon absorbers and synchrotron radiation masks are installed in front of the bellows. The dimensions of the absorbers are 71mm, 89mm and 104mm.

During the measurement, we changed the single bunch current from 1mA to 10mA, and measured the response matrix of different current. We fitted the betatron phase from response matrix using LOCO, and calculated the phase advance of two adjacent BPM along the ring. The defocusing effect of the impedance will be stronger as the increasing of the single bunch current, and leads to a more reduction of phase advance. Therefore comparing the phase advance of different current along the ring, we can find where the defocusing strength changes, corresponding to the local impedance. Because the bunch lengthening is more than 10 percent when the single bunch current exceeds 9.8mA, the data measured with 10mA is eliminated from the analysis. The phase advance between the response matrix measured with 9mA and 1mA in a single bunch is shown in Figure1. One can see sharp changes in the arc sections caused by changes in defocusing strength, and can by explained by the discontinuity of the antechambers installed at the ends.

Form figure 1, we can also notice that phase advance change is positive in some places, which can not be explained by impedance effect , may due to the accuracy of betatron phase fitting..

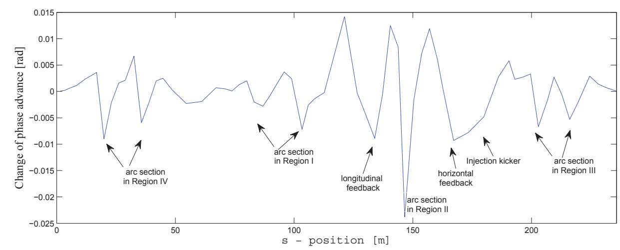

Figure 1: Phase advance difference between 9mA and 1mA along the ring.

The relationship between the advance phase and the beam current is linearity in the case that the bunch length keeping constant during the measurement by varying the RF voltage. Figure 2 shows the vertical phase advance slopes with current in the arc sectors.

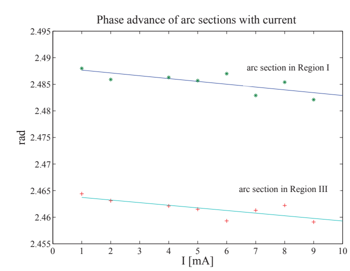

Figure 2: Vertical phase advance slopes of arc sections in different region.

We use a streak camera associated with a set of optical lenses put on a platform at the end of the synchrotron light extraction line, to measure the bunch length. At the beginning of the impedance measurement, the bunch length from streak camera was 55ps, and the noise level of the streak camera is 2ps. After changing the single bunch current, we measured the bunch length again and varied the RF voltage so that the bunch length was kept about 55ps. In the whole measurement, we changed the RF voltage from 1.3MV to 1.6MV as the current increasing from 1mA to 10mA.

According to the phase advance difference between 9 mA and 1mA, beside of the sharp changes in arc sections, we also find the sharp changes on the places where the injection kicker and the feedback system installed.

The two injection kickers of BEPVII are the cavity type. To meet the requirement on the field quality, the cross section of the kicker is slightly smaller than the standard vacuum chamber. Thus two tapers each at one end are needed. Figure 3 shows the phase advance between two BPMs which are installed at the both side of the kicker changes with the current, and the slop represents the impedance. In 2010, the ceramic plate of positron kicker was broken by the heating of HOM. This measurement helps us to study the real impedance of the kicker and understand the reason of the broken.

The transverse and longitudinal feedback systems are adopted in BEPCII to suppress the coupled bunch instabilities. Feedback kickers will introduce impedance. The stripline style longitudinal kicker like that in PEPII is installed in BEPCII. The transverse feedback kickers are of stripline pair design and two kickers are installed in each ring. The stripline is chosen to be 30 cm long. To determine the impedance of the feedback kickers, the phase advance between the downstream BPM and the upstream BPM of the kickers is calculated. The current-dependant phase advance is shown in Figure 3.

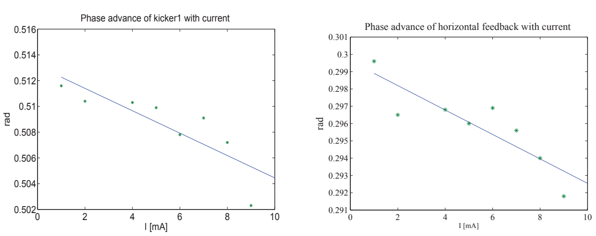

Figure 3: Vertical phase advance slop with current for Injection kicker (left) and horizontal feedback (right).

COMPUTATION

The effective transverse impedance is the integral over the machine impedance, multiplied by the bunch spectrum squared. For a particular impedance component, it can be presented by the measured slopes of the phase advance[5]:

$$Z^{i}_{eff} = \frac{E\sigma_s}{R\beta_i}\frac{d\mu}{dI}. \quad (3)$$

In the above equation, β_i is the local beta function of the impedance component. For the arc section, the beta function is averaged over the arc section. The bunch length is 55ps, and is maintained approximately constant. E is 1.884GeV when measurement, and the radius R of BEPCII storage ring is 37.6m. The calculated impedance values of arc section and some particular components are shown in Table 1. Form the results we note that the arc section contributes most to the impedance of the whole ring. The impedance of injection kicker is relatively large, may be correlated with the kicker broken in 2010. The design of the kicker should be studied carefully.

Table 1: Effective Impedance Results

		Arc	Kicker	HFB	LFB
$<\beta>$	m	7.48	11.36	17.96	11.26
$d\mu/dI$	Rad/A	-0.51	-0.87	-0.71	-0.23
Zeff	kΩ/m	56.5	63.4	32.6	16.8

CONCLUSION

This is our first experiment on the impedance distribution measurement. Because of the accuracy of the BPMs only the vertical impedance of BPR is performed. The current-dependant phase advance is derived by fitting the response matrix, then the impedance is deduced. The impedance of injection kicker and feedback system, which are not included in the old budget, are calculated for the first time. The results may provide some clues for explaining the broken of kicker and beam instability in colliding related to the feedback system. But there are still some problems in the measurement: The tune reduction with the current is not clear; In some places, phase advance increases slightly with the current and can not be explained by the impedance effect. The measurement is strongly dependant on the accuracy of the BPMs. More detailed measurement is necessary, and we should take some measures to improve the accuracy of BPMs, such as measure the response matrix with the same total current to avoid the thermal effect of BPMs, so as to improve the accuracy of phase fitting.

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