TRANSVERSE IMPEDANCE DISTRIBUTION MEASUREMENT AT SSRF*

M.Z. Zhang[#], S.Q. Tian, B.C. Jiang

Shanghai Institute of Applied Physics, Shanghai 201204, P. R. China

Abstract

Since ore and more small-gap insertion devices (IDs), especially in vacuum undulators (IVUs), are installed in the SSRF storage ring, transverse impedance become larger and larger. Single bunch current threshold is reduced significantly. It's necessary to measure and understand the contributions of the small gaps and then optimizes the impedance distribution. Due to the beam sees the impedance as quadrupole whose strengths depend on the beam current. The impedance distribution is determined by the phase advances and their slopes using orbit response matrix analysis.

INTRODUCTION

The Shanghai Synchrotron Radiation Facility (SSRF) [1] is a dedicated third generation synchrotron light source with nominal energy of 3.5 GeV. In order to produce high photon flux and keep adjustability, lots of small gap IDs including IVUs are installed in the SSRF storage ring. In the project Phase-I, there are two IVUs and two wiggler. The minimum gap of both IVUs is 7mm, and the inner vacuum gap of two wigglers is 12mm. Another 3 IVUs and 1 EPU are installed in the SSRF storage ring last year. The minimum gaps of IVU are almost same as Phase-I. The inner gap of DEPU is 12mm. These small gaps and their tapers introduce transverse impedance. Combined with other factors, the single bunch current threshold reduces from 9mA to a little larger than 6mA. And also the instability of normal operation cannot be suppressed by transverse feedback system some times. By increasing the chromaticity, the single bunch current threshold and instability can be improved, but the injection efficiency decreases. A hybrid mode for timing experiments requires a single bunch more than 10 mA. So the impedance distribution measurement is necessary.

By measuring the transverse tune with single-bunch current changes, we can measure the combined transverse impedance. Conceptually, by measuring the combined transverse impedance before and after the installation of one or some new element, we can get the impedance of that element. But it is difficult to accurately measure or localize the impedance of one or several elements.

Since the beam sees the impedance as an additional defocusing quadrupole whose strength depends on the beam current [2]. Several methods have been attempted to measure the impedance distributions by this fact. 1) Phase advance measurements from beam position monitors (BPMs) turn-by-turn data. This is used at LEP [3], and also at APS using model independent analysis (MIA) [4]. We also have some attempts at SSRF. 2) Measuring the orbit deviations with single-bunch current change at the same local beta bump. The orbit bump method was done at BINP [5], APS [6], ESRF [7] and DIAMOND [8]. 3) Phase advance fitted by different single bunch current using orbit response matrix analysis. This method is used at APS [2] and BEPCII [9]. The accuracy of this measurement is better than the others. The efforts we have made are described in this paper.

ORBIT RESPONSE MARIX ANALYSIS

Orbit response matrix analysis tool named Linear Optics from Closed Orbit (LOCO) [10] is used for linear optics correction at the SSRF storage ring. Orbit response matrix is the data of BPMs response to correctors:

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

Where $M_{ij} = \frac{\sqrt{\beta_{cor}\beta_{BPM}}}{\sin 2\pi\nu} \times \cos(|\mu_{BPM} - \mu_{cor}| - 2\pi\nu)$, it contain not only the twiss parameters at BPMs but also at correctors. There are 140 BPMs and 80 correctors in the SSRF storage ring, the element number of the matrix is 140×80 in each plane, and the total number is 44800 if off diagonal term is included. It is much larger than the factors that influence the matrix (including quadrupole and skew quarupole strength, BPM gain and roll, corrector strength and roll), if we fit these factors to make the lattice model close to the measured matrix:

$$\chi^2 = \sum_{ij} \frac{(M_{\mathrm{mod},ij} - M_{meas,ij})^2}{\sigma_{ij}^2} \tag{2}$$

Where the σ is the BPM noise level. Using LOCO, one can get the quadrupole strength, beta function and phase advance and so on. Figure 1 shows twiss parameters in a quarter of the SSRF storage ring. The accuracy of beta function is estimated by taking several measurements and comparing the results. The rms difference between beta functions derived from different response matrix measurements was found to be about 0.3% [2].

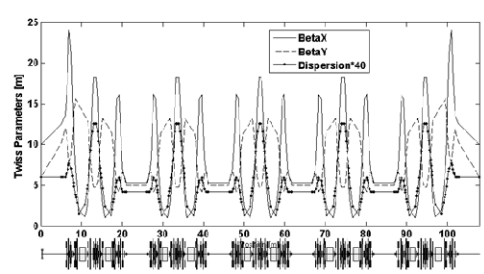

Figure 1: The twiss parameter in one quarter of SSRF.

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#zhangmanzhou@sinap.ac.cn

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Since the beam sees the impedance as an additional defocusing quadrupole whose strength depends on the beam current. We can measure the matrix at different currents and fit the quadrupole strength and phase advance varying with currents.

MEASUREMENTS

We measured 8 response matrices for different single-bunch current from 1mA to 6.4mA. In order to improve the BPM resolution, 25 bunches are filled in the ring originally. But due to temperature interlock of IVU15 (the temperature may come from the directly heated of sensor) bunch number is reduced to 8 when the single bunch current is larger than 5mA. The noises of most BPMs are less than 0.5 um and 0.2um at horizontal and vertical plane. Figure 2 shows the BPM noise at 1mA, 4mA and 6.4mA. Some BPMs become unstable at large single bunch current and must be removed from the response matrix analysis. The beam lifetime is less than 4 hours at large single bunch current. The response matrix measurement takes half hour, so we need reinjection when the response matrix is measuring. The bunch length is stretched with the single bunch current, figure 3 shows bunch length vs beam current. In order to keep bunch length constant, RF voltage is adjusted.

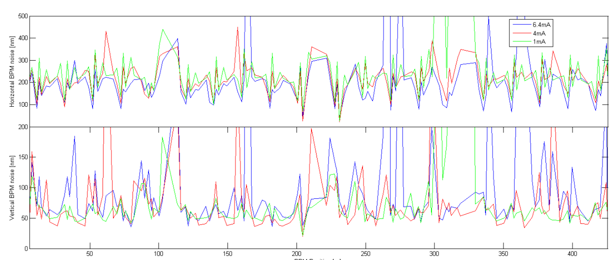

Figure 2: Noise of BPM at different single bunch current.

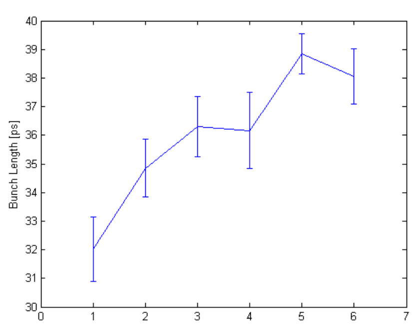

Figure 3: The bunch length vs single bunch current.

The defocusing effect leads to vertical phase advance shift. The phase advance is generated by the lattice model which is fitted by LOCO. A couple of quadrupoles at straight section center are added to the fit for the effect of local impedance. Then there are 220 quadrupoles, 140 skew quadrupoles at sextupole, 280 BPM gains and rolls, 160 corrector kickers and rolls in the fitting. Such a large number of fit parameters provide very accurate fit of the response matrix, betatron function and betatron phase. But it leads to some ambiguity in the resulting strength of quadrupoles and it does not allow using individual quadrupole strengths to represent impedance effects directly. Figure 4 shows the 220 quadrupole strength variances along with the single bunch current increasing. After the fits, phase advances between every two adjacent BPM and their slopes are calculated by linear fit. The fit results are very similar. Several tempt have done for the fit: with and without artificial quadrupoles, Gauss-Newton, Levenberg-Marquardt and Scaled Levenberg-Marquardt method.

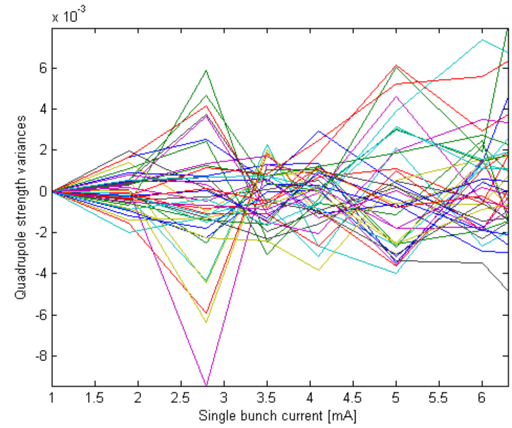

Figure 4: Quadrupole strength variances.

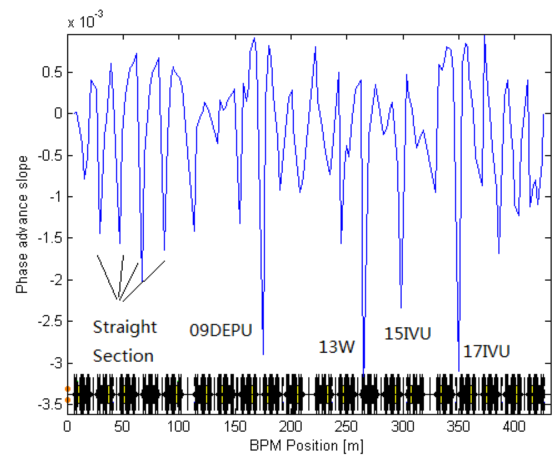

Figure 5: Phase advance slopes along the ring.

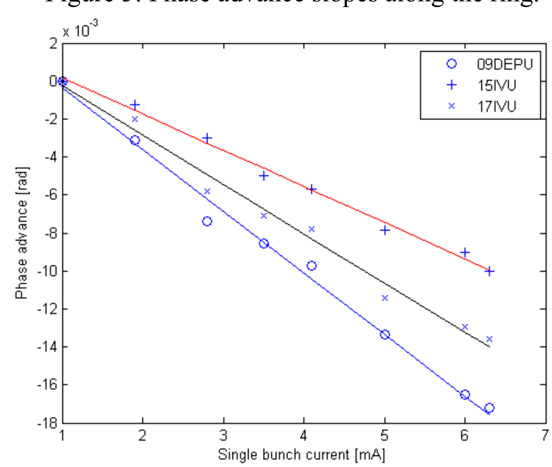

Figure 6: Phase advance at several positions. Constant phase offsets are removed.

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Figure 5 shows the phase advance slopes along the ring. The sharp down points are large local impedance. From the results we note that the straight section and small gap IDs are the main sources of impedance. 15IVU and 17IVU are the smallest gap in the ring. The local impedance at 09DEPU maybe comes from the scrap ion or small slits when we saw off the vacuum chamber to make more space for the shift mode of the ID. The beta function got by MIA also shows large variation when beam current increasing [11]. The reason of largest local impedance is still unknown. The other ones whose values around zero are due to the beta function mismatch, the phase advance oscillated in the ring. Figure 6 shows the phase advance at 09DEPU, 15IVU and 17IVU. The constant phase offsets are removed.

IMPEDANCE CACLUTION

The effective transverse impedance is the integral over the machine impedance, multiplied by the bunch spectrum squared. The phase advance shift slope is proportional to the local impedance [2]:

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

Where β_i is the local beta function of the impedance component, E is the electron energy, σ_s is the bunch, R is the radius of the ring, $\frac{d\mu}{dI}$ is the measured slopes of the phase shift divided by 2π. The energy of SSRF storage ring is 3.5GeV, and radius is 69m, the vertical beta function at short straight section is 2.5m, the bunch length is about 10mm. Table 1 shows the effective impedance results and total transverse impedance.

Table 1: Effective Impedance Results

	units	09DEPU	15IVU	17IVU	Total
$\frac{d\mu}{2\pi dI}$	(rad/A)	0.52	0.34	0.41	
Zeff	kΩ/m	47.5	28.9	39.1	1100

In order to verify the measurement results of the phase advance measurement, we also measured the local impedance at 09DEPU using bump method. The kick of local impedance can be written as [8]:

$$\Delta\theta = \frac{\Delta q}{E/e}k_\perp y_0$$

We make a 1.5mm orbit bump at 09DEPU, and measured the orbit before and after the orbit bump at 1mA and 6.4mA for several times to reduce the measurement error. The measurement of different current reduces the intensity effect on the BPM. Figure 7 shows the orbit changes at bump height of 1.5mm and the fit result. The fitted kick angle is 1.6 μ rad, the corresponding quadrupole strength $KL = 0.0011$, and the local impedance is [2]:

$$Z^i_{eff} = \frac{1}{2}\frac{E\sigma_s\beta_q}{R\beta_i}\frac{d(KL)}{dI} \quad (4)$$

The local impedance at 09DEPU is 20 kΩ/m, this value is 0.5 times smaller than the fit method. More work should be done.

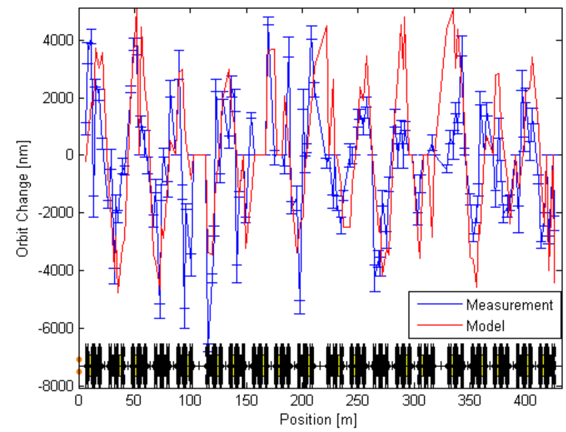

Figure 7: Orbit change due to impedance.

CONCLUSION

A transverse impedance measurement is tested at SSRF storage ring. The current-dependent phase advance and its slope are derived by response matrix analysis. The impedance is calculated by the slope. The measurement result shows the impedance at straight section is the main source, especially 09DEPU, 13W, 15IVU and 17IVU. Bump method is also used to confirm the measurement, but the result is not match. In the measurement there are still several problems to be solved, such as the match of two methods, the quadrupole strength for phase advance fitting, the unwanted phase advance increasing and not linear significantly at some position and so on.

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