APPLICATIONS OF THE TUNE MEASUREMENT SYSTEM OF THE HLS-II STORAGE RING*

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Abstract

During the commissioning phase of the HLS-II storage ring, the betatron function, the natural chromaticity, the corrected chromaticity and the central RF frequency were measured using the Swept-Frequency-Exitation based tune measurement system. The betatron function was measured using the quadrupole modulation method. The natural chromaticity and the corrected chromaticity were measured using the dipole modulation method and the RF modulation method respectively. In addtion, the central RF frequency was measured using the sextupole modulation method, which can be viewed as a direct measure of the ring circumference. This paper describes the measurement details and presents the measurement results.

INTRODUCTION

The 800 MeV electron storage ring is the major part of HLS-II. It has been running well since commissioning was completed in late 2014. The HLS-II storage ring consists of four DBA (Double Bend Achromatic) cells, which not only significantly decreases the beam emittance but also increases the lengths of the achromatic straight sections for IDs [1]. The main parameters of the HLS-II storage ring are shown in Tab. 1. The theoretical emittance is lower than 40 nm-rad.

Table 1: Main Parameters of the HLS-II Storage Ring

Parameter	Value
Circumference	66.13 m
Energy	800 MeV
Beam current	300 mA
RF frequency	204 MHz
Harmonic number	45
Emittance	40 nm−rad
Tune	0.44/0.36

The principle block diagram of the Swept-Frequency-Excitation based tune measurement system of the HLS-II storage ring is shown in Fig. 1. Such a system consists of the hardware construction and the software structure [2]. The spectrum analyzer is the excitation generator and the signal processor. The generated swept-frequency signal is preprocessed by a excitation circuit and then is transferred to the transverse dipole kicker on the storage ring. The signal of the BPM is processed by a processing circuit to generate the difference signal. Then the difference signal is performed a down-conversion and is analyzed by the spectrum analyzer. For the consideration of the safety of the equipments and the commissioning operators, the equipments are placed in the experimental area. Thus long cables must be adopted to transfer the signals across the shielding wall. After the completion of the system hardware construction, the control of the spectrum analyzer is integrated into the central control system of HLS-II through the EPICS softwares.

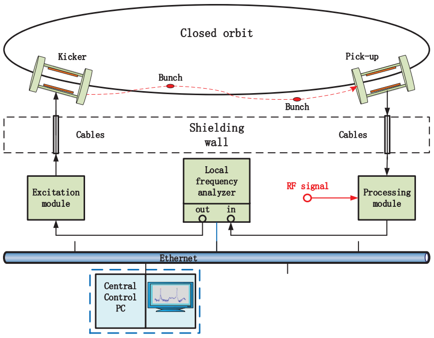

Figure 1: Layout of the Swept-Frequency-Excitation based tune measurement system of the HLS-II storage ring.

BETA FUNCTION MEASUREMENT

With the thin-lens approximation, the tune shift as a function of quadrupole error is

$$\bar{\beta}_{x,y} \approx \pm 4\pi \frac{\Delta\nu_{x,y}}{\Delta k \ell}, \qquad (1)$$

where $\beta_{x,y}$ is the local beta function in either horizontal or vertical direction, $\nu_{x,y}$ is the corresponding tune, Δk is the gradient error of the quadrupoles and ℓ is the quadrupole length. The results obtained from Equ. 1 can be viewed as the average betatron function inside the corresponding quadrupoles.

The measurement was performed by self-compiled Matlab script under the EPICS frame work. The data interaction were based on MCA (Matlab Channel Access) toolbox which provided interfacing between Matlab and EPICS [3]. The measurement was started at the beam current of 5.47 mA. The collective effects were supposed to have a relatively small impact on the measurement in this mode.

Using Equ. 1, the measured value of the average betatron function inside the 32 quadrupoles can be obtained. The comparison between the design batatron function and the

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measured value is shown in Fig. 2. The ideal curve is the design value calculated by Accelerator Toolbox of MATLAB, while the dots represent the measured value [4]. It can be seen that the measured value agrees well with the design value.

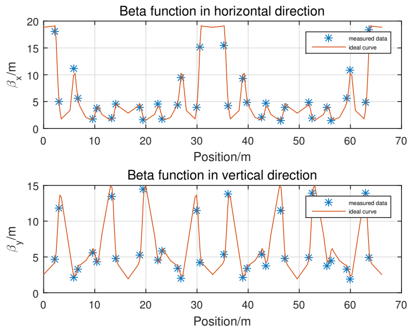

Figure 2: Measured and design betatron functions of the HLS-II storage ring.

NATURAL CHROMATICITY MEASUREMENT

One of the chromatic abberation effects induced by quadrupoles is referred as to the natural chromaticity. According to the definition of the chromaticity, the actual natural chromaticity can be achieved by measuring the variation of the tune with the beam energy without the consideration of sextupoles. A common solution is to measure the tune shift with the strength of the bending magnets . The natural chromaticity can be obtained through

$$\xi_{x,y}^{nat} \approx \frac{\Delta\upsilon_{x,y}}{\Delta B/B} = \frac{\Delta\upsilon_{x,y}}{\Delta I_B/I_B}, \qquad (2)$$

where $\xi_{x,y}^{nat}$ represents the natural chromaticity in either transverse direction, B is the strength of the bending magnets and I_B is the excitation current of the bending magnets.

The measurement was started at the beam current of 3.36 mA. The variety of the tunes as a function of the excitation current are shown in Fig. 3. The top figure shows the measured results and the fitting curve in the natural chromaticity

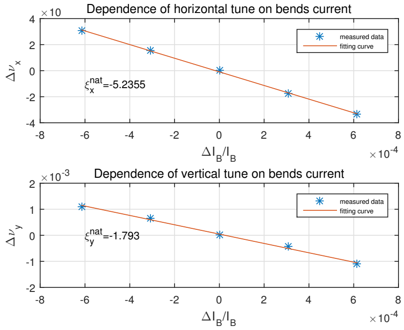

Figure 3: Measured tunes as a function of the excitation current of the bending magnets.

measurement in the horizontal direction. From Equ. 2, the measured value of the natural chromaticity is -5.2355. The bottom figure shows the measured tunes and the fitting curve in the vertical direction, and the measured chromaticity is -1.739.

CORRECTED CHROMATICITY MEASUREMENT

Two groups of sextupoles (denoted by S3 and S4 respectively) are used to correct and control the chromaticity of the HLS-II storage ring. The corrected chromaticity measurement is based on the relationship of

$$\xi_{x,y}^{cor} = -\alpha_c \frac{\Delta\upsilon_{x,y}}{\Delta f_{RF}/f_{RF}}, \qquad (3)$$

where $\xi_{x,y}^{cor}$ represents the corrected chromaticity in either horizontal or vertical direction, α_c is the momentum compact factor and f_{RF} is the RF frequency.

The measurement was started at the beam current of 9.72 mA, which reduced the collective effects on the measurement. The variety of the tunes as a function of the RF frequency are shown in Fig. 4. The top figure is the measured tunes with RF frequency and the fitting curve in the corrected chromaticity measurement in the horizontal direction. Using Equ. 3, the measured value can be calculated as 2.1242. The bottom figure shows the measured tunes with the RF frequency and fitting curve in the vertical direction, and the measured corrected chromaticity is equal to 2.9051.

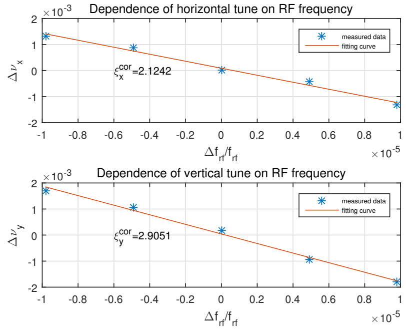

Figure 4: Measured tunes as a function of the RF frequency.

CENTRAL RF FREQUENCY MEASUREMENT

Central RF frequency is a direct measure of the circumference of the storage ring. The central RF frequency can be used to estimate the deviation of the ring circumference from the design value after the completion of the storage ring installation. Using the relation between the RF frequency and the length of the beam orbit for relativistic particles, the central RF frequency f_{RF}^C is defined as

$$f_{RF}^C = h\frac{c}{C_C}, \qquad (4)$$

where h is the harmonic number, C_C is the length of the central orbit and c is the speed of light.

The tune value will not vary with the different sextupole settings if the RF frequency is adjusted to be equal to the central RF frequency. Therefore, the measurement of central RF frequency of a storage ring is to find out the RF frequency point at which the chromaticity curves cross, or put another way, to find out the frequency point at which the tune does not rely on the sextupole strength. The methods to find out this RF frequency point can be classified into two categories: RF shaking and sextupole modulation [5]. Although the two methods to obtain the data differ, there is no essential distinction between the results. In order to obtain stable and reliable results, the sextupole modulation method, which is faster and more robust than the RF shaking method, was adopted for the central RF frequency measurement of the HLS-II storage ring [6].

The measurements were started at the beam current of 3.62 mA. The RF frequency and strength of S3 (or S4) were respectively swept 5 times as a predefined function. Fig. 5 shows the different chromaticity curves in the S3 modulation. As mentioned above, the frequency at the crossing point of the different chromaticity curves can be viewed as the central RF frequency. Due to the existence of the various error sources, the different chromaticity curves do not cross at a same point. The average frequency with corresponding rms value of the crossing points is 204.027005±0.000762 MHz, while the obtained central RF frequency is 204.027546±0.000148 MHz. Similarly, the measurement results in the S4 modulation are shown in Fig. 6. The central RF frequency is 204.027322±0.000119 MHz taking the horizontal plane as reference, and the central RF frequency is 204.027342±0.000030 MHz taking the vertical plane as reference.

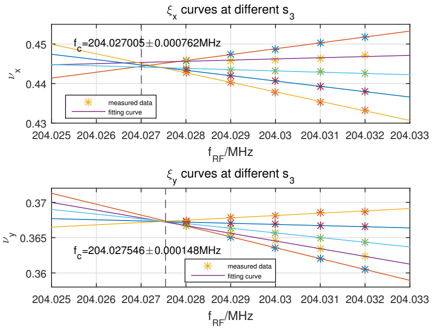

Figure 5: Chromaticity curves at different strengths of S3.

The result obtained in vertical plane in S4 modulation is taken as a credible value of the central RF frequency of the HLS-II storage ring since the uncertainty is the lowest and this value is also covered by other results. Using Eq. 4, the relative deviation of the circumference from the designed value after the installation of the ring is 1.3027×10^{-5}. The circumference deviation is 8.6151×10^{-4} m.

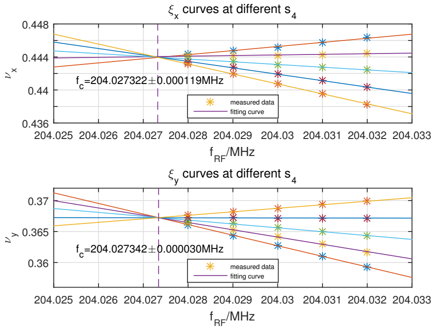

Figure 6: Chromaticity curves at different strengths of S4.

CONCLUSION

During the commissioning phase of the HLS-II storage ring, the betatron function, the natural chromaticity, the corrected chromaticity and the central RF frequency were measured using the Swept-Frequency-Exitation based tune measurement system. The betatron function was measured using the quadrupole modulation method which shows that the real beta function values are accordance with the desigh values. The natural chromaticity and the corrected chromaticity were measured using the dipole modulation method and the RF modulation method respectively. The measured natural chromaticity are -5.2355/-1.793, while the corrected chromaticity are 2.1242/2.9051. Moreover, the central RF frequency was measured using the sextupole modulation method, which can be viewed as a direct measure of the ring circumference. The relative deviation of the circumference from the designed value after the installation of the ring is 1.3027×10^{-5}, which means that the circumference deviation is less than 1 mm.

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