ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-THPMK129

LATTICE TWEAKING USING A TUNE KNOB BASED ON GLOBAL MECHANISM*

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Abstract

The transverse tunes are important parameters for a storage ring and tune knobs are used to adjust the tunes in a specific range. Usually for large rings, a set of quadrupoles is set on the straight sections for the use of tune knob. A tune knob has been designed for the HLS-II storage ring without affecting the twiss parameters of the injection section. This paper introduces the design and online test of this tune knob. The quadrupoles are adjusted according to the simulation results and the tunes are measured and calibrated. The online test results show that the tune knob design works well on the HLS-II storage ring and can be applied for various machine studies.

INTRODUCTION

In electron storage rings, the betatron tune is the scaled one-turn phase advance of the transverse oscillation. For a storage ring, the betatron tune should stay away from critical resonance lines to ensure a stable operation. Also, a certain range of tune adjustment is needed for machine study requirements. To fulfill this task, a tune knob is developed for the HLS-II storage ring. This tool can also be used for compensating the tune variations caused by various dynamic processes.

The tune knob is originally inspired by a work at the Duke FEL Lab [1]. A previous work of the tune knob design for the HLS-II storage ring has already been reported in an IPAC paper [2], which adopts all the quadrupoles in the HLS-II storage ring. In this paper, an alternative tune knob scheme is adopted. This tune knob does not affect the twiss parameters of the injection section and is suitable for compact storage ring. This paper reports the corresponding design, simulation results and online tests of the new-scheme tune knob.

TUNE KNOB DESIGN

For a storage ring, the injection process is essential and has been well designed in the lattice. A tune knob without affecting the injection is considered. This goal is achieved by constraining the twiss parameters at the two ends of the injection section. The quadrupoles inside the injection section will not be adopted by the tune knob. From the transfer matrix it can be seen that the twiss parameters of the whole injection section will be unchanged. For the HLS-II storage ring, only quadrupole families labeled from K5 to K8, as shown in Fig.1, are adopted by the tune knob. The tune knob adjustment is based on quadrupole families, thus preserving the lattice symmetry. An optimization program in MAD-X [3] is used and the optimization constraints are set accordingly. The optimization program is designed with a step-by-step method, i.e. each time the tune is adjusted by only a small step $\Delta\nu = 0.001$, and the adjusted lattice is set as the starting point for the next optimization run. After a

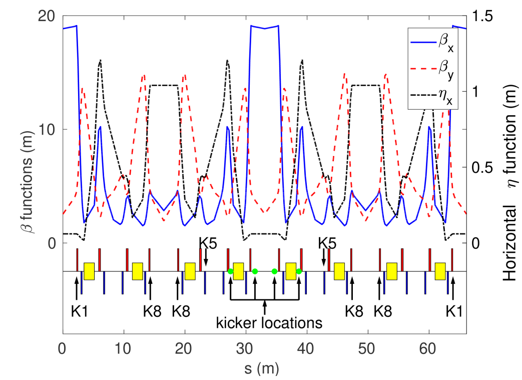

Figure 1: The lattice of the HLS-II storage ring.

whole optimization program is completed, the relations of the adjusted quadrupole strengths with respect to the tune changes are plotted in Fig. 2. They are fitted with respect to the tune change by a polynomial function up to 5th order:

$$\begin{aligned} \Delta K_{ix} &= a_{i5}\Delta\nu_x^5 + a_{i4}\Delta\nu_x^4 + a_{i3}\Delta\nu_x^3 + a_{i2}\Delta\nu_x^2 \\ &\quad + a_{i1}\Delta\nu_x + a_{i0}, i = 5,\dots,8 \\ \Delta K_{iy} &= b_{i5}\Delta\nu_y^5 + b_{i4}\Delta\nu_y^4 + b_{i3}\Delta\nu_y^3 + b_{i2}\Delta\nu_y^2 \\ &\quad + b_{i1}\Delta\nu_y + b_{i0}, i = 5,\dots,8 \end{aligned} \tag{1}$$

If ν_x and ν_y are both adjusted, the required quadrupole adjustment can be achieved by a combination of Eq.(1) as

$$\Delta K_i = \Delta K_{ix} + \Delta K_{iy}, i = 5,\dots,8. \tag{2}$$

These fitted relations are used to test the tune knob both by simulation and by online experiments.

SIMULATION AND RESULTS

Impacts on Chromaticities

The chromaticities of the nominal HLS-II lattice are pre-corrected to about 1 and 3 in horizontal and vertical directions, respectively. When the tunes are adjusted by the tune

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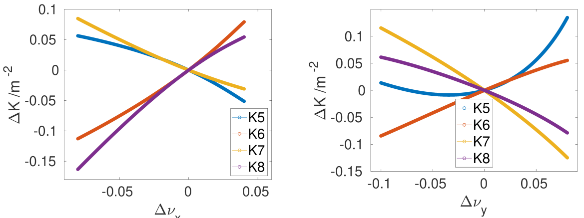

(a) (b)

Figure 2: Quadrupole strength adjustments with respect to the tune change. (a) ν_x is adjusted and ν_y remains unchanged. (b) ν_y is adjusted and ν_x remains unchanged.

knob, the chromaticities are also affected due to the adjustment of the quadrupole strengths. From Fig. 3 it can be seen that when ν_x is adjusted, the horizontal chromaticity C_x varies from about 0.7 to 1.2 and C_y varies within the range of 2.6 to 3.0. When ν_y is adjusted, the corresponding range is about from 0.5 to 1.5 for C_x and from 1.6 to 3.8 for C_y. This shows the chromaticities do not decrease to minus values in the designed tune knob range. Thus there is no big impact on the stability due to chromaticity change.

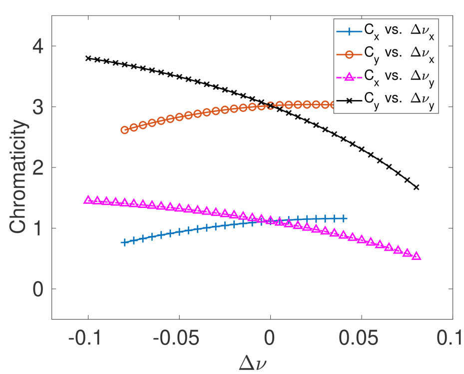

Figure 3: Chromaticity changes with respect to the tune change.

Impacts on β functions

The β functions are also affected when the tunes are adjusted by the tune knob. From Figs. 4 and 5 it can be seen that the β functions corresponding to the injection sections are unchanged. The maximum β function change is about $\Delta\beta_x$ =1 m and $\Delta\beta_y$ =3 m. Although the maximum β function change is not small, the injection is almost unaffected by β function changes. The lattice symmetry is also preserved, thus the impact on the beam dynamics is small.

ONLINE TEST AND CALIBRATION

The tune knob is tested on the HLS-II storage. The quadrupole strengths are set through the HLS-II control system based on Experimental Physics and Industrial Control System (EPICS). The tune spectral is read from the spectrometer and the Lorentzian function is used to fit the transverse tunes [4]. The Lorentzian function is expressed

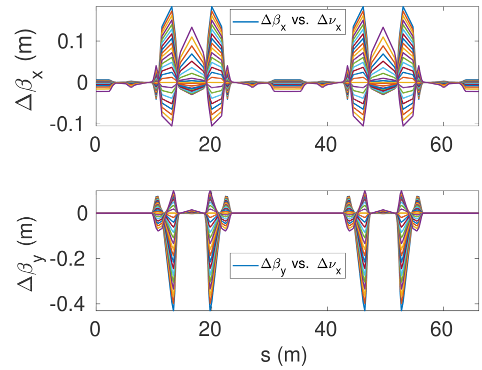

Figure 4: Theoretical β function changes with respect to nominal ones when ν_x is adjusted and ν_y remains unchanged.

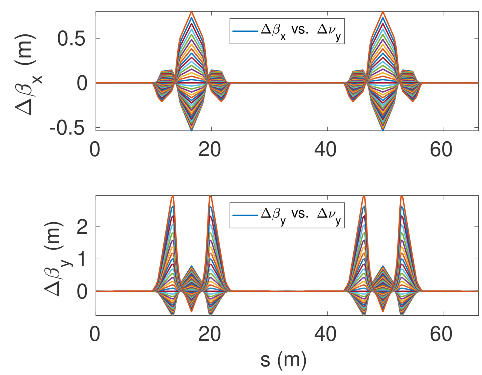

Figure 5: Theoretical β function changes with respect to nominal ones when ν_y is adjusted and ν_x remains unchanged.

by

$$L(x) = \frac{1}{\pi}\frac{\frac{1}{2}\Gamma}{(x-x_0)^2 + (\frac{1}{2}\Gamma)^2}, \tag{3}$$

where Γ is the FWHM when the Lorentzian function is normalized.

For the online experiment, the tune knob is set according to the fitted quadrupole strength relations in Eq. (1). The step length $\Delta\nu$ for measurement is set to 0.005. The tested adjustment range is from -0.07 to 0.04 for $\Delta\nu_x$ and from -0.08 to 0.07 for $\Delta\nu_y$. The range is set to avoid approaching the half-integer resonance and difference resonance. To test the validity of the tune knob, only ν_x or ν_y is adjusted at the single-bunch mode with a bunch current of about 5 mA. This aims at avoiding the impacts from coupled bunch instabilities. For each measurement turn, the tune is adjusted from lower bound to upper bound step by step. The measured result is shown in Fig. 6. From the figure it can be seen that the relation between the measured and the preset tunes is linear.

A calibration can be performed by a change of the tune knob coefficient. To fulfill such a task, the tune knob relations in Eq. (1) can be reset by

$$\Delta\nu_{x,\mathrm{cali}} = \frac{\Delta\nu_{x,\mathrm{set}}}{0.9723}, \quad \Delta\nu_{y,\mathrm{cali}} = \frac{\Delta\nu_{y,\mathrm{set}}}{0.9721} \tag{4}$$

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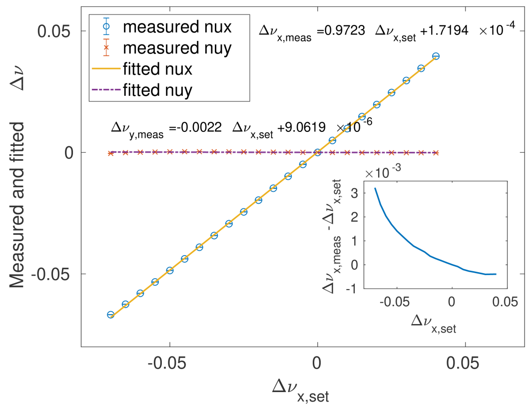

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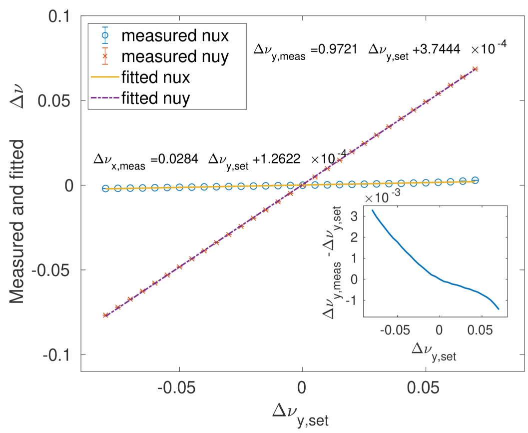
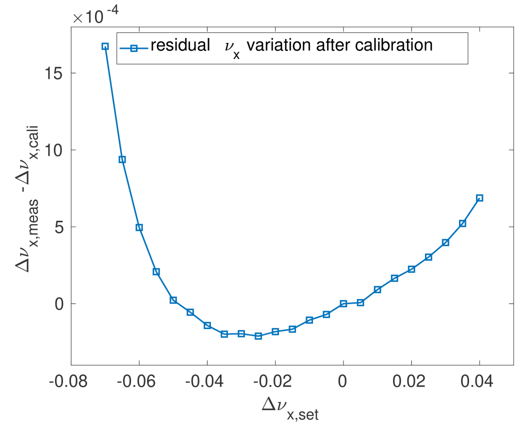
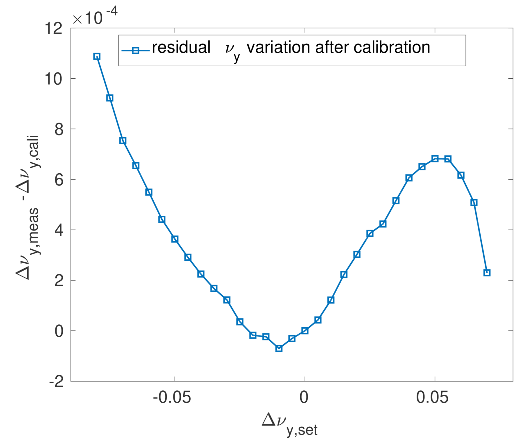


(b)

Figure 6: The relation between the measured tune changes and the preset tune adjustment. (a) ν_x is adjusted and ν_y set to remain unchanged. (b) ν_y is adjusted and ν_x set to remain unchanged.



(a)



(b)

Figure 7: The relation between the measured tune changes and the preset tune adjustment. (a) knobing ν_x. (b) knobing ν_y.

according to the fitted linear coefficients in Fig. (6). The calibrated tune knob is also tested on-line with the same measurement condition and steps. After the calibration, the main relations between the measured and preset tunes are fitted to be

$$\begin{aligned} \Delta\nu_{x,\mathrm{meas}} &= 0.9981\Delta\nu_{x,\mathrm{set}} + 1.6361\times10^{-4} \\ \Delta\nu_{y,\mathrm{meas}} &= 0.9994\Delta\nu_{y,\mathrm{set}} + 3.6670\times10^{-4}. \end{aligned} \quad (5)$$

It can be seen that after the calibration, the fitted linear coefficients almost equal 1, which means the real tune change well matches the preset tune adjustment.

The deviation of the measured tune change from the preset tune change is shown in Fig. 7. The largest deviation is estimated to be of order 10^{-3}, which shows the tune can be adjusted linearly in the designed range with an acceptable accuracy.

SUMMARY

A tune knob without changing the lattice symmetry and the twiss parameters of the injection section has been designed for the HLS-II storage ring. Simulation results show that the impact on the beam dynamics is small. Online tests show that the tune knob works well in a specific adjustment range. This tune knob design scheme can be applied for compact storage rings and it can be used for various machine studies.

REFERENCES

[1] H. Hao *et al.*, "Characterizing betatron tune knobs at Duke storage ring", *Proc. of IPAC 2015*, Richmond, Virginia, paper MOPMA053.

[2] S. Wang *et al.*, "Development of a tune knob for the HLS-II storage ring", *Proc. of IPAC 2017*, Copenhagen, Denmark, paper MOPIK087.

[3] H. Grote *et al.*, "MAD-X — an upgrade from MAD8", *Proc. of PAC'03*, Porland, Oregon, paper FPAG014.

[4] X. Wei *et al.*, "A betatron tune measurement system based on bunch-by-bunch transverse feedback at the Duke storage ring", *Chinese physics C* **37**(7), p. 077006, 2013.