LINEAR OPTICS COMPENSATION OF THE SUPERCONDUCTING WIGGLER IN HLS *

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Abstract

Hefei Light Source is a dedicated VUV light source. A superconducting wiggler magnet, whose peak magnetic field is 6 T, was installed on the storage ring to generate hard X-ray radiation. With the compensation of tune shift due to superconducting wiggler, beam was successfully stored, while the beam lifetime was degenerated much. In order to cure the beam lifetime, some simple hardware improvement was made and linear optics compensation scheme was intensively studied by two calculation methods. Calculation results showed that focusing perturbation from wiggler can't be eliminated completely for HLS and a new scenario of compensation, whose purpose is to remove tune shifts and to suppress large beta-function distortions, was brought forward. Experimental result has demonstrated the effectiveness of this new compensation scheme and the beam lifetime was recovered to original level without wiggler.

INTRODUCTION

Hefei Light Source is a second generation dedicated VUV radiation light source. It is composed of 200MeV linac and 800MeV storage ring. The characteristic wavelength of the bending radiation was 2.4 nm. In order to meet the requirement of hard X-ray synchrotron radiation users, a superconducting wiggler magnet was installed at storage ring of HLS. The characteristic wavelength of wiggler radiation was 0.485 nm and its usable wavelength was extended to 0.097nm, which lies in hard X-ray range. The main parameters of the HLS storage ring are listed in table 1. And the beta-functions of HLS storage ring are plotted in figure 1.

Table 1: Main Parameters of HLS Storage Ring

Injected Beam Energy(MeV)	200
Stored Beam Energy(MeV)	800
Circumference(m)	66.1
Lattice Type	TBA
Number of Dipoles	12
Number of Quadrupoles	32
Natural Emittance(nm • rad)	133
Betatron Tunes	3.54/2.60
Betatron Functions at Location of Wiggler(m)	21.5/3.6
Peak Magnetic Field of Wiggler(T)	6.0

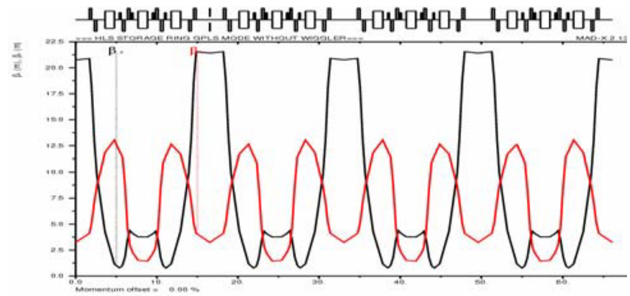

Figure 1: Beta-functions of HLS storage ring without wiggler.

The superconducting wiggler in HLS storage ring is a high field insertion device, which has single period composed of three poles, and the peak magnetic field strength of central pole and the poles in either side is 6T and 4.3T respectively[1]. Strictly speaking, this is a wave length shifter. During injection process, excitation current of wiggler is set to zero and the wiggler hasn't obvious effects on beam injection and accumulation. After beam energy ramping, magnetic field strength of wiggler was increased slowly to the maximum in 6 minutes. For HLS storage ring, the vertical focusing from wiggler produces two leading deleterious effects. The first effect is that large vertical tune shift produced by focusing perturbation from wiggler would lead to beam loss without optics compensation. The second effect is beam lifetime degeneration due to large beta-function distortions. Tune shift and beta-beating, can be simply estimated by following formulae [2],

$$\Delta\nu_y \approx \frac{\beta_y L_{wiggler}}{8\pi\rho^2}, \qquad \Delta\nu_x \approx 0 \tag{1}$$

$$\left(\frac{\Delta\beta_y}{\beta_y}\right)_{\max} \approx \frac{\beta_y L_{wiggler}}{4\rho^2 \sin(2\pi\nu_y)}, \qquad \frac{\Delta\beta_x}{\beta_x} \approx 0 \tag{2}$$

For HLS, ignoring horizontal focusing effect is an acceptable approximation for the large pole-width of wiggler. The vertical tune shift and maximum beta-beating for HLS are about 0.2252 and 240% respectively according to (1) and (2).

At early stage, a simple tune compensation scheme was found experimentally. There are 8 families of quadrupoles in the ring, each contains 4 quadrupoles and is powered in series by one supply. One family adjacent to wiggler was chosen to compensate vertical tune shift, then another family was adjusted a little to remove horizontal tune shift produced by the change of first quadrupole family. Adopted this method, beam was successfully stored and hard X-ray was produced. At the same time, beam

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lifetime was decreased much and some synchrotron radiation users expect to improve the beam lifetime.

CALCULATION METHOD AND RESULTS

According to our analysis, degeneracy of beam lifetime is the result of imperfect linear optics compensation of superconducting wiggler. Some efforts were made to optimize linear optics with the wiggler.

Hardware Improvements

According to alpha matching ideas, quadrupole doublets at the each end of straight section where wiggler was installed should be more effective in compensation. Four power supplies were paraxially connected to these four quadrupoles, which belonged to different families and located around the wiggler. As the actions of new power supplies, the gradients of these four quadrupoles can be varied quasi-independently and can be stronger than that of others in same family.

Hard-Edge Model of Wiggler

To obtain available compensation scheme, it is important to describe lattice model and vertical focusing effect from wiggler exactly.

Firstly, in terms of re-measured magnetic field data of a spare quadrupole and dipole, more accurate focusing strength of quadrupole and fringe field integral value of dipole were obtained. Compared with the previous measured data, systematic error of magnetic measurement system was eliminated. The tune measurement at different lattice configurations demonstrated that, the lattice model based on new measured data is basically agreement with the real storage ring. On the other hand, linear optics calibration of storage ring by LOCO is underway and should provide more accurate focusing information.

Secondly, a simple hard edge model was employed to describe vertical focusing effect from wiggler and was constructed grounding on the magnetic-field measurement data of wiggler. The relations between parameters of hard edge model and real wiggler are as the following [3],

$$\rho_{hard-edge} = \frac{4}{\pi}\rho_0 \tag{3}$$

$$l_{hard-edge} = \frac{2}{\pi^2}\lambda_p \tag{4}$$

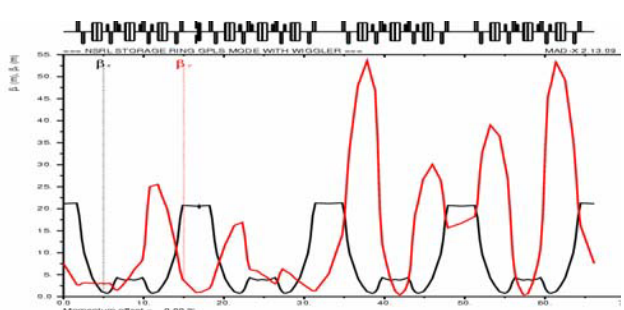

Figure 2: Beta-functions of the tune compensation scheme for HLS storage ring.

Also, we have experimentally checked that the tune shift introduced by superconducting wiggler is nearly identical with that computed by hard edge model.

Using calibrated lattice model and hard edge model of wiggler, we calculated the simple tune compensation scheme, whose beta-functions are drawn in figure 2. Obviously, the distortion of vertical beta-function is too large and should be responsible to poor beam lifetime.

Calculation by MAD-X

The new compensation scheme, whose aim is to restore the unperturbed optics parameters, is studied by code MAD-X [4]. To begin with, we set the unperturbed parameters obtained from lattice model without wiggler as matching constraints, including beta-functions, dispersion functions at some locations of the ring and global tunes. Then, lattice model with wiggler was used and focusing strengths of the four quasi-independent quadrupoles were chosen as variables. Unfortunately, after some iteration it is seemed that the goal is reachless. And then, strengths of 8 quadrupole families are also added as variables. During matching process, it is found that to recover the unperturbed linear optics parameters exactly is very difficult for HLS storage ring. Finally, priority was given to the compensation of tune shifts which is a more stringent requirement than the correction of beta-functions for machine operations. At same time, large beta-function distortion should be avoided. We have found a new compensation scheme, in which the tunes were exactly restored, and the maximum beta-functions are similar to the unperturbed ones, while the periodicity of beta-functions is not as good as unperturbed case. The beta-functions are shown in figure 3. The relative changes of quadrupole strength, whose maximum value is ~120%, are somewhat large and are displayed in figure 4.

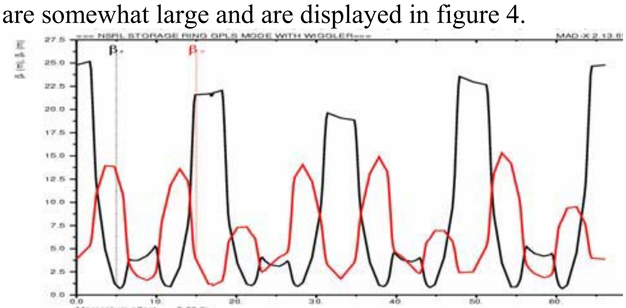

Figure 3: Beta-functions of the new compensation scheme obtained by MAD-X.

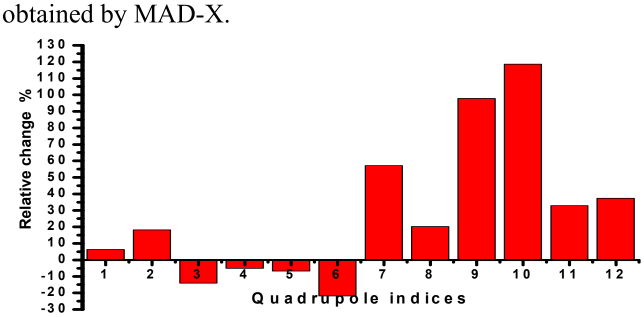

Figure 4: Relative change of quadrupole strength in the new compensation scheme obtained by MAD-X.

Calculation by Response Matrix Fitting

We also use other method to study the compensation scheme. The response matrix fitting method [5, 6], which was demonstrated as an effective technique in linear optics correction, was also used in compensation calculation for wiggler of HLS. The definitions of orbit response matrix are wrote out in expressions (5) and (6),

$$\vec{r_k} = R \cdot \vec{\theta}_k, \qquad k = x \quad \text{or} \quad y \tag{5}$$

$$R_{ij} = \frac{\sqrt{\beta_i \beta_j}}{2 \sin \pi\nu} \cos(\left|\phi_i - \phi_j\right| - \pi\nu) \tag{6}$$

For horizontal direction, a small correction term due to energy change was ignored in (6). All information of beta-functions and betatron phase advance of storage ring are included in response matrix. For HLS, the response matrices used in fitting are uncoupled matrices for horizontal and vertical direction respectively, whose size is 24×16. If we can restore the response matrix, the linear optics parameters would be also recovered exactly.

The MATLAB-based LOCO code was used in calculations [7]. Firstly, we computed the response matrix R_1 of unperturbed lattice and set it as the matching goal. Secondly, lattice model with wiggler was used to calculate perturbed response matrix R_2 and was varied automatically by code to match the goal. In order to find most efficient remedy, we have not set any limitation on quadrupole gradients, so that strength of each quadrupole can be varied independently in the fitting process. The rms difference between response matrices R_1 and R_2 is a good indicator of iteration process. When further iterations would not reduce this difference, the new compensation plan, whose response matrix is closest to the unperturbed one, was obtained directly from the fitting parameter values. Calculations also showed that, for HLS storage ring, the perturbation effects from wiggler can't be removed completely, and the minimum rms difference between R1 and R2 is about 0.40 mm/mrad. Beta-functions of the final iterations are plotted in figure 5. Compared with figure 1, the maximum horizontal beta-function was controlled to acceptable level and vertical beta-function distortion was confined to limited range beside wiggler.

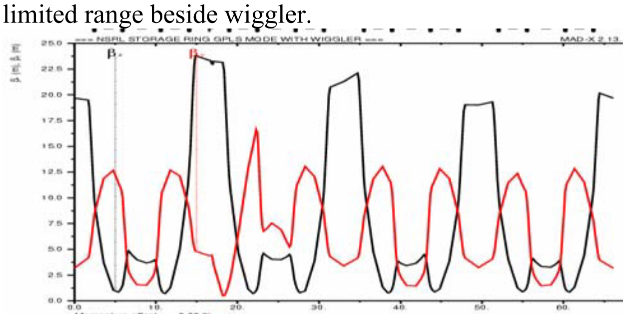

Figure 5: Beta-functions of the new compensation scheme obtained by response matrix fitting method.

And the figure 6 illustrated the relative change of each quadrupole. Some quadrupoles, whose relative change is larger than others, should be more efficient in compensation of focusing from wiggler. Unfortunately, as seen in figure 6, it is required that strength of these quadrupoles should lower than that of others in same family and is impractical for the present hardware limitations of HLS described in 2.1. We also have tried to find new practical scheme applicable to HLS by response matrix fitting and failed due to the same reason or unsatisfactory results.

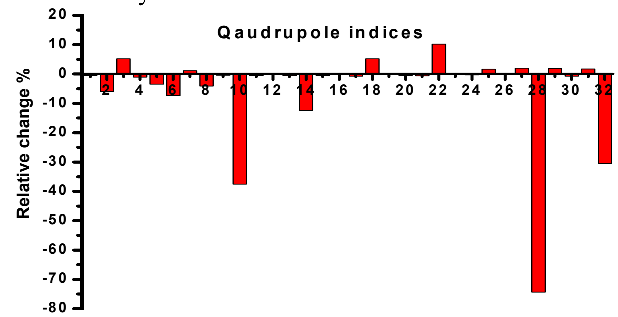

Figure 6: Relative change of quadrupole strength in the new compensation scheme obtained by LOCO code.

CONCLUSIONS

Calculations of new wiggler compensation scheme by MAD-X and MATLAB-based LOCO showed that, it is very difficult to eliminate perturbation from wiggler completely and to restore unperturbed beta-functions exactly for HLS storage ring. Then, a new compensation scheme, in which betatron tunes were exactly recovered and large beta-function distortions were avoided, was brought forward and is more appropriate for present layout of HLS. Applying new compensation scheme to machine operation, beam lifetime with wiggler was restored to the normal level without wiggler, which is above 8 hours.

REFERENCES

[1] Liu N.Q., Zhang W., "Development report of 6T superconducting wiggler in NSRL", 1999.

[2] A. Ropert, "LATTICES AND EMITTANCES", CAS CERN Accelerator School: Synchrotron Radiation and Free Electron Lasers (edited by S. Turner), GENEVA, 1998, p.91.

[3] Helmut Wiedemann, "Particle Accelerator Physics II (second edition)", Springer, 1999, p.64.

[4] HTTP://mad.home.cern.ch/mad/.

[5] J. Safranek, "Experimental determination of storage ring optics using orbit response measurement", Nuclear Instruments and Methods, A388 (1997): p27-36.

[6] D. Robin, J. Safranek, W. Decking and H. Nishimura, "GLOBAL BETA-BEATING COMPENSATION OF THE ALS W16 WIGGLER", PAC'97, p.797.

[7] J. Safranek, G. Portmann, A. Terebilo, "MATLAB-BASED LOCO",EPAC'02, Paris, France, p.1184.

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