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Linear optics calibration and nonlinear optimization during the commissioning of the SSRF storage ring*

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Abstract Phase I commissioning of the SSRF storage ring on 3.0 GeV beam energy was started at the end of December 2007. A lot of encouraging results have been obtained so far. In this paper, calibrations of the linear optics during the commissioning are discussed, and some measured results about the nonlinearity given. Calibration procedure emphasizes correcting quadrupole magnetic coefficients with the Linear Optics from Closed Orbit (LOCO) technique. After fitting the closed orbit response matrix, the linear optics of the four test modes is substantially corrected, and the measured physical parameters agree well with the designed ones.

Key words SSRF storage ring, linear optics, calibration, nonlinearity

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1 Introduction

The Shanghai Synchrotron Radiation Facility (SSRF) is an intermediate energy third generation light source that is built in Zhang-Jiang H-Tech Park in Shanghai, China[1]. Its storage ring is designed to reach very low natural emittance with a structure of 20 Double Bend Achromatic (DBA) cells forming four super-periods[2]. Each super-period contains three standard cells and two matching cells. The total length of straight sections accounts for about 35% of the ring circumference, and can be located by 20 insertion devices or so.

Phase I commissioning of the storage ring on 3.0 GeV beam energy began on the evening of Dec. 21, 2007 ahead of schedule. With about six-month hard work of the commissioning group, different commissioning steps were covered very quickly[3, 4]. During this period, four different optical modes were tested. In this paper, the linear optics design and nonlinear optimization for theoretical models are presented, and the linear optics calibration is discussed, and some preliminary measured results on particle nonlinear dynamics are given.

Table 1. Main parameters of the four commissioned modes.

parameter	Mode I	Mode II	Mode III	Mode IV
tune Q_x/Q_y	22.22/11.29	22.22/11.29	23.324/11.232	19.22/7.32
$\beta_x/\beta_y/\eta_x$(m) in the centers	10/6.0/0.15	10/6.0/0	12.0/6.0/0.17	15.0/8.0/0.15
of the straight sections	3.6/2.5/0.10	3.6/2.5/0.006	2.5/2.0/0.10	13.4/4.6/0.14
natural emittance/(nm·rad)	3.92	11.4	3.36	5.42
	2.86@3.0 GeV	8.4@3.0 GeV	2.47@3.0 GeV	3.98@3.0 GeV
natural chromaticity ξ_x/ξ_y	$-55.7/-17.9$	$-55.6/-18.1$	$-64.4/-19.9$	$-45.8/-21.8$
momentum compactor	4.27×10^{-4}	5.42×10^{-4}	3.61×10^{-4}	5.89×10^{-4}
natural energy spread (RMS)	9.84×10^{-4}	9.84×10^{-4}	9.84×10^{-4}	9.84×10^{-4}
	8.44×10^{-4}@3.0 GeV	8.44×10^{-4}@3.0 GeV	8.44×10^{-4}@3.0 GeV	8.44×10^{-4}@3.0 GeV

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2 Linear optics design and nonlinear optimization

The main designed parameters of the four modes are summarized in Table 1, and the linear optical functions in one fold of the ring are plotted in Fig. 1. The resulting lattice provides a natural emittance of 2.86 nm·rad for Mode I, 8.4 nm.rad for Mode II, 2.47 nm·rad for Mode III, and 3.98 nm·rad for Mode IV, on the 3.0 GeV beam energy. By means of the elaborate nonlinear optimizations, all the four modes are provided with sufficient dynamic acceptances to satisfy the specifications on the injection efficiency and the beam lifetime. Fig. 2 is the schematic for on-momentum dynamic apertures of the four modes, which result from 1000-turn tracking with AT code[5], and are normalized by β functions.

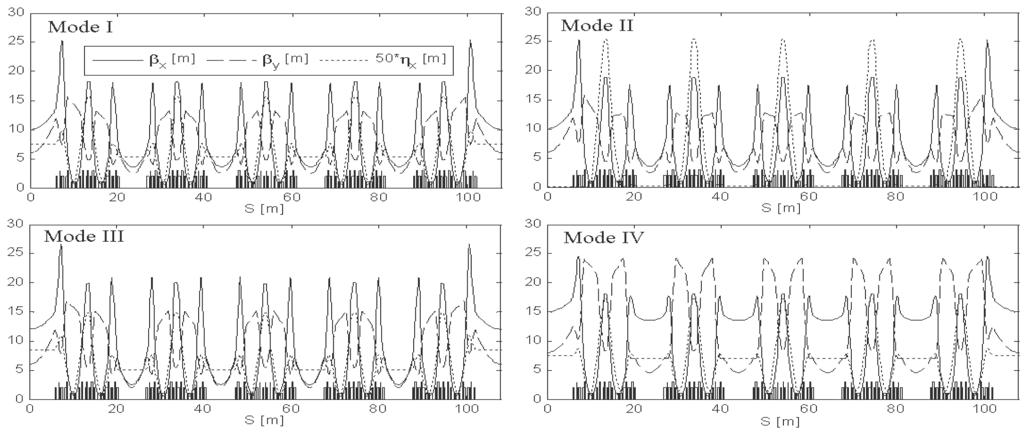

Fig. 1. Linear optical functions and magnet layout of one fold of the storage ring.

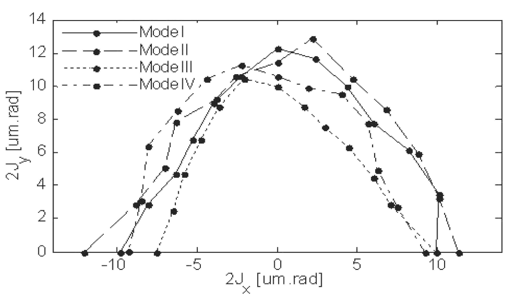

Fig. 2. On-momentum dynamic apertures normalized by β functions for the four optics modes.

3 Linear optics calibrations

At the beginning of the commissioning, the measured linear parameters unfortunately had large difference from the theoretical model, such as the tunes with about 1.5 and 0.4 deviations in the horizontal and the vertical plane respectively. Although it is difficult to distinguish contributions of different error origins, we can correct the gradient errors (calibrate the magnetic coefficients for systematic errors and adjust the gradient of individual quadrupole for random errors) to compensate the total effective integral strength errors. *B-I* curves of the SSRF storage ring quadrupoles are approximated by measuring the integral strengths as a function of the excited current. Due to the very fast convergence of the coefficients, approximation is limited to the third order. The different order magnetic coefficients are listed in Table 2. These coefficients are corrected by means of LOCO[6] fitting family by family, and the scaling results are summarized in Table 3, where all the coefficients decrease by 2%—3% approximately.

Table 2. Magnetic coefficients and effective lengths of the quadrupoles.

type	Q260	Q320	Q580
length	0.276	0.335	0.590
P_0	6.6622×10^{-1}	5.9678×10^{-1}	4.4751×10^{-1}
P_1	6.5964×10^{-2}	6.8714×10^{-2}	7.3481×10^{-2}
P_2	1.8916×10^{-4}	1.6681×10^{-4}	1.2352×10^{-4}
P_3	-5.4336×10^{-7}	-4.7394×10^{-7}	-3.4608×10^{-7}

Table 3. Magnetic coefficient scaling for the quadupoles.

Quad. Fami.	type	Coeffi. scaling
Q1	Q320	97.30%
Q1L	Q320	97.30%
Q2	Q580	97.50%
Q2L	Q580	97.60%
Q3	Q320	97.21%
Q3L	Q320	97.40%
Q4	Q260	98.01%
Q4L	Q260	98.01%
Q5	Q320	97.40%
Q5L	Q320	97.50%

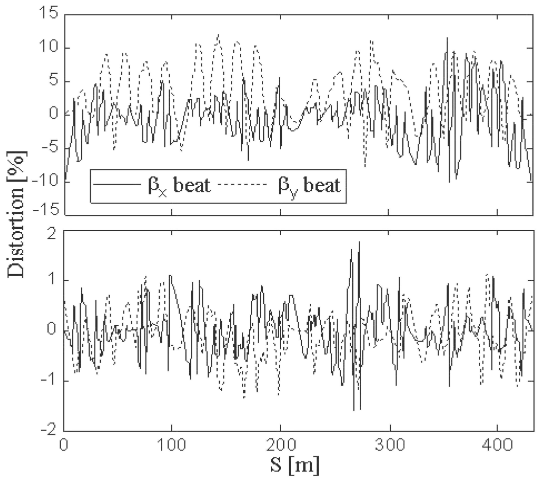

Fig. 3. Beta beating of the realistic machine with respect to the designed mode before (the top figure) and after (the bottom figure) LOCO corrections.

When we set the quadrupole currents resulting from the new transformation to the machine, the RMS beta beatings of the machine are about 5% for both transverse planes. It shows that the *B*-*I* transformation systematic error in each family is successfully corrected. The little residual beatings are corrected down to 0.5% or so with LOCO fitting magnet by magnet. Fig. 3 shows the corrected results of Mode I. The directly measured beta functions at the locations of the quadrupole validated the correction results. Table 4 lists the accurate corrected results of the four modes, containing the RMS quadrupole deviations. The measured parameters of the storage ring agree well with the designed mode and LOCO determination. The results of Mode I are summarized in Table 5. It shows that we can accurately operate the machine with a designed mode.

4 Nonlinear measurements

During Phase I commissioning, the nonlinear dynamics is preliminarily studied, whereas the results show a large difference from simulation. The horizontal dynamic aperture is smaller than the tracking result, but it is not the main restriction to the injection efficiency, which is realized from the injection rate as a function of local bump at the injection point. The tune shifts with horizontal amplitude are larger than the simulation ones. These aberrations of the nonlinear dynamics are being studied further.

Table 4. Linear optics calibration results for the four designed modes.

RMS	Mode I	Mode II	Mode III	Mode IV
Hori. and Verti. beta beat before LOCO	3.91%/5.78%	7.83%/4.08%	6.08%/4.08%	4.37%/4.85%
Hori. and Verti. beta beat after LOCO	0.50%/0.52%	0.52%/0.87%	0.48%/0.71%	0.81%/0.36%
dK between model and machine	0.29%	0.43%	0.33%	0.23%

Table 5. Parameter comparisons of Mode I.

parameter	designed value	LOCO determination	measured value
tune (Q_x/Q_y)	22.22/11.29	22.223/11.292	22.2213/11.2905
natural chroma. (ξ_x/ξ_y)	$-55.7/-17.9$	$-55.68/-17.93$	$-50/-17$
natural emittance/nm·rad	2.86	2.857	2.83
RF frequency/MHz	499.654000	499.674660	499.674640

5 Conclusions

During Phase I commissioning of the SSRF storage ring, different steps were covered very quickly, and ahead of schedule. A lot of machine physics studies were carried out, and many encouraging results achieved. The effective integral strength errors in the quadrupoles were compensated by calibrating the magnetic coefficients, and the linear optics of the machine was brought very close to the designed mode by using the LOCO technique. The measured parameters agreed well with the designed values. The nonlinear dynamical study is underway. The reliable methods and results provide a lot of convenience for Phase II commissioning of the storage ring on 3.5 GeV beam energy.

References

1 ZHAO Z T, XU H J, DING H. In Proc. of APAC. Indore, India, 2007. 593—596

2 LIU Cui-Min, DAI Zhi-Min, LI Hao-Hu et al. HEP & NP, 2006, **30**(Supp.I): 144—146

3 XU Hong-Jie, ZHAO Zhen-Tang. Nuclear Science and Techniques, 2008, **19**: 1—6

4 LIU G M, LI H H, ZHANG W Z et al. In Proc. of EPAC. Italy, 2008, 2079—2081

5 Terebilo A. Accelerator Toolbox for MATLAB, SLAC-PUB-8732

6 Safranek J. Nucl. Instr. & Meth. in Phys. Res. A, 1997, **388**: 27—36