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Excitation curve calibration for the SSRF magnet system*

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Abstract The needed electrical current for the magnet working under different energy loads can be easily calculated once the right relation between the magnet and the electrical current has been found. Therefore the excitation curve calibration for the magnet system is important to the SSRF. The measuring method on the magnet and the result of the excitation curve calibration are presented. The application of the excitation curve calibration for the bending magnet is given, and it is proved that the COD (Closed Orbit Distortion) and the working point of the storage ring are greatly affected by the current of the bending magnet.

Key words SSRF, storage ring, excitation curve calibration

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1 Introduction

The SSRF includes a linear accelerator to accelerate particles up to 150 MeV, a low transport beamline (LTB), a booster, a high transport beamline (HTB), a storage ring (SR) and seven beamlines. The excitation curve calibration for the SSRF magnets is important for providing the suggested magnet current configurations under different working modes and under different beam energies while the beam is ramped. Polynomial coefficients for each type of the magnets and the results of the excitation curve calibration for LTB, HTB and SR are presented. Finally, the application of the excitation curve calibration for the bending magnet is given. The polynomial coefficients for each type of the magnets for the booster have been introduced in Ref. [1].

2 Magnet excitation curve calibration

2.1 Magnet system for the SSRF

The SSRF magnet system includes bending magnets (BEND), focusing and defocusing quadrupole (QUAD) magnets (QF and QD), focusing and defocusing sextupole (SEXT) magnets (SF and SD), and corrector magnets in both horizontal and vertical planes (CH and CV). The main parameters of the low and high transport beamline (LTB, HTB) magnets and the storage ring (SR) in design are shown in Table 1 and Table 2 [2], respectively. The design requirements of the magnet corrector and the coil corrector in SR are shown in Table 3 [2]. The measurement error of the effective length of the magnets is about 2%.

Table 1. The magnet design requirements for LTB and HTB.

type		No.	L_{design}/m	L_{eff}/m	power supply
	BEND	2	0.30	0.39846	in series
LTB	QUAD	11	0.10	0.125027	independence
	CH/CV	4/4	0.10	–	independence
	BEND	5	1.90	1.934359	in series
HTB	QUAD	15	0.40	0.422244	independence
	CH/CV	5/5	0.15	–	independence

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Table 2. The magnet design requirements for the SR.

type SR	No.	L_{design}/m	L_{eff}/m	power supply
BEND	40	1.44	1.454696193	in series
Q260	40	0.26	0.276068459	independ
Q320	120	0.32	0.334516271	independ
Q580	40	0.58	0.59027164	independ
S200	80	0.20	0.21308738960674	in series
S240	60	0.24	0.2526004811	in series

Table 3. The design requirements for the magnet corrector and the coil corrector in the SR.

type	No.	L_{eff}/m	W_{pole}/mm	H_{gas}/mm	$A_{x/y}$/mrad
SMC[a)]	80	0.220	130	50	1.2/1.0
DCC1[b)]	20	0.150	—	44	0.08/0.05
DCC2[b)]	40	0.120	—	36	0.08/0.05

a) means: static magnet corrector, b) means: dynamic coil corrector. L means the length of the magnet, W means the width of the magnetic pole, H means the high of the gas, A means the most oriented angle.

2.2 Method of the magnetic field measurement

The excitation curve calibration is based on the measurement of data of the transfer functions [3]. The integral field strengths $\int B\mathrm{d}z$, $\int G\mathrm{d}z$, $\int S\mathrm{d}z$ (BL [T·m], G[T/m], S[T/m^2] are magnet strengths) for BEND, QUAD and SEXT have been measured for different currents. A conversion is needed for an advantageous using: $\bar{G}(I)=\int G\mathrm{d}z/L$, $\bar{S}(I)=\int S\mathrm{d}z/L$, where L is the effective length of the magnet. Polynomials are fitted based on the measured data referred above as $F=\sum\limits_{i=0}^{n}P_iI^i$. The same order n=3 is selected for BEND, QUAD, SEXT. For CH and CV a linear behavior was assumed, n=1 and P_0=0. The function F is different for each type of magnet.

We measured the data for these functions for different currents, the polynomials have been obtained with the help of the program Matlab Middle Layer (MML) [4]. The excitation currents for the different types of magnets are shown in Table 4.

2.3 Results of the excitation curve calibration

The coefficients P of the fitted polynomials for the various types of magnets are shown in Table 5, 6 and 7.

Table 4. Measured excitation currents for various types of magnets.

type	LTB excitation currents/A	HTB excitation currents/A	SR excitation currents/A
BEND	0–10	10–420	10–760
QD	−1.57, −0.8, 0.8, 1.57	−7.08, −3.5, 3.5, 7.08	50, 80, 100–260
QF	−1.57, −0.8, 0.8, 1.57	−7.08, −3.5, 3.5, 7.08	50, 80, 100–260
SD	—	—	0, 50, 100, 115, 130, 145, 165, 180, 255, 260, 270, 280, 200–250
SF	—	—	0, 50, 100, 115, 130, 145, 165, 180, 255, 260, 270, 280, 200–250
CH/CV	1.07, 0.50, −0.50, −1.07	8.34, 4.0, −4.0, −8.34	9.08/16.55

Table 5. Calibration coefficients P for the LTB magnets.

type	P_3	P_2	P_1	P_0
B.BL-I/(T·m)	-2.8522×10^{-6}	4.3364×10^{-5}	1.9434×10^{-2}	1.7950×10^{-3}
Q.G-I/(T/m)	-2.7024×10^{-2}	-1.9020×10^{-3}	4.18731710	1.7198×10^{-2}
CV.BL-I/(T·m)	—	—	1.9736×10^{-3}	0
CH.BL-I/(T·m)	—	—	1.9736×10^{-3}	0

Table 6. Calibration coefficients P for the HTB magnets.

type	P_3	P_2	P_1	P_0
B.BL-I/(T·m)	-1.0488×10^{-9}	4.9011×10^{-7}	5.0638×10^{-3}	2.3442×10^{-3}
Q.G-I/(T/m)	-1.3780×10^{-3}	1.6207×10^{-4}	2.9188227	8.9254×10^{-3}
CV.BL-I/(T·m)	—	—	3.9411×10^{-3}	0
CH.BL-I/(T·m)	—	—	3.9411×10^{-3}	0

Table 7. Calibration coefficients P for the SR magnets.

type	P_3	P_2	P_1	P_0
B.BL-I/(T·m)	-7.0352×10^{-10}	6.1844×10^{-7}	2.4869×10^{-3}	4.7394×10^{-3}
Q260.G-I/(T/m)	-5.4336×10^{-7}	1.8916×10^{-4}	6.5964×10^{-2}	6.6622×10^{-1}
Q320.G-I/(T/m)	-4.7394×10^{-7}	1.6681×10^{-4}	6.8714×10^{-2}	5.9678×10^{-1}
Q580.G-I/(T/m)	-3.4608×10^{-7}	1.2352×10^{-4}	7.3481×10^{-2}	4.4751×10^{-1}
S200.S-I/(T/m^2)	-5.7567×10^{-6}	1.7226×10^{-3}	1.7841	2.158234
S240.S-I/(T/m^2)	-5.7776×10^{-6}	1.7300×10^{-3}	1.7833	2.172634
CH.BL-I/(T·m)	—	—	1.5531×10^{-3}	0
CV.BL-I/(T·m)	—	—	0.8029×10^{-3}	0

3 Application to the SSRF

We use MML and the Accelerator Toolbox (AT) as the main software for the SSRF. The conversion of the strength of the magnet can be easily switched by using k2amp&amp2k which are involved in the AT. With the following relationships [5] one can calculate the polynomial expansions of the function F for different beam energies, and then the corresponding current can be determined by the calibration coefficients of Table 5, 6 and 7.

For BEND, CH and CV,

$$BL_{\text{eff}} = \theta\,|_{\text{AT}} \times B\rho;$$

for QUAD,

$$G = K\,|_{\text{AT}} \times B\rho;$$

for SEXT,

$$S = 2\times S\,|_{\text{AT}} \times B\rho,$$

where

$$B\rho = \frac{10}{2.99792458}\sqrt{E^2-E_0^2},$$

$$E_0 = 0.51099906\times10^{-3}(\text{GeV}).$$

θ, K, S_{AT} are already known for the designed magnets. The currents at the magnet for different energies can be calculated using the calibration coefficients released by the academic foundation for the design and commissioning of the SSRF.

A great progress was made in a short time by using the excitation curve calibration when the SSRF came into the commissioning stage at 21$^{\text{th}}$, Dec., 2007. The current of the bending magnet is 601.748 A based on the excitation curve calibration at θ of 9° and energy of 3.0 GeV for the SSRF. The actual

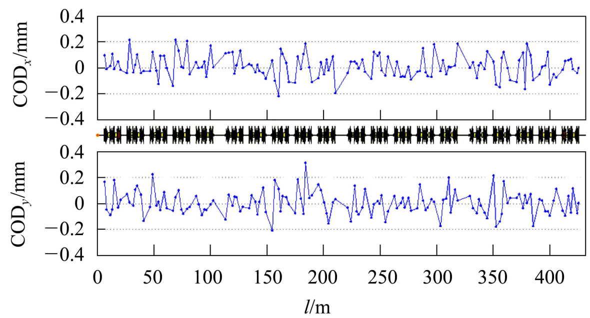

Fig. 1. The COD of the storage ring for a bending magnet current of 599.2442 A.

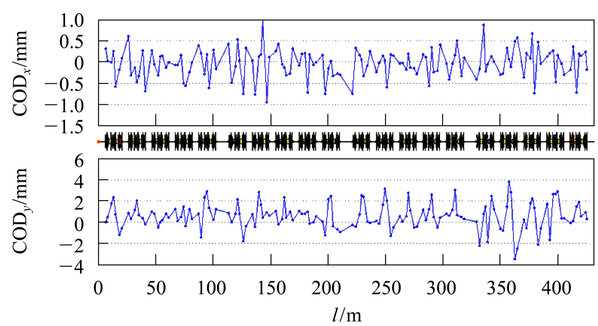

Fig. 2. The COD of the storage ring for a bending magnet current of 598.9442 A.

current is around the calculated value of 601.748 A taking the error of the perimeter between the actual and the designed value into account. If the current has the canonical value of 601.748 A, the closed orbit distortion (COD) is not small; if the current is reduced by 0.416% from its canonical value to 599.2442 A, the COD is smaller (Fig. 1); if the current is reduced by 0.47% from its canonical value to 598.9442 A, the COD is bigger (Fig. 2). The Mean and rms values for the horizontal and the vertical orbits are shown in Table 8 for a changing current of the bending magnet.

Table 8. The Mean and rms of horizontal and vertical orbit.

current/A	orbit	mean/mm	rms/mm
599.2442	x	1.169206×10^{-2}	8.726785×10^{-2}
	y	3.894171×10^{-3}	8.966757×10^{-2}
598.9442	x	-3.530144×10^{-2}	3.468660×10^{-1}
	y	6.213818×10^{-1}	1.238389

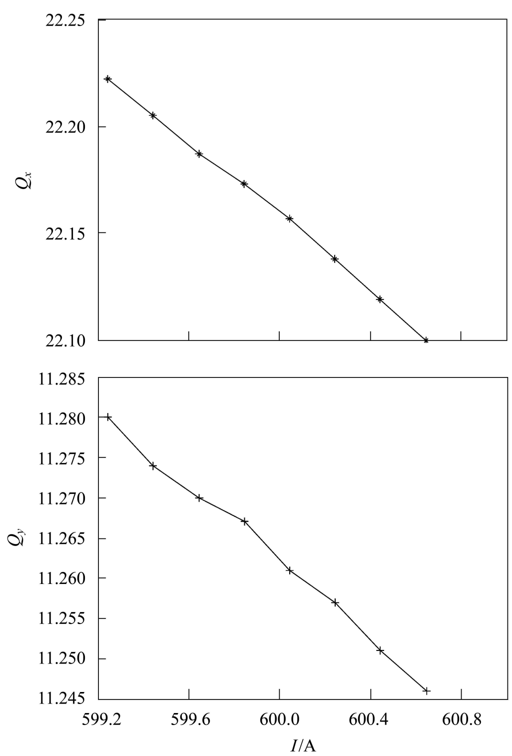

Fig. 3. Change of the horizontal and the vertical working point with the bending magnet current.

From Table 8 one can see that the orbit is greatly affected by the choice of the bending magnet current.

The designed horizontal and vertical working points of the SSRF are 22.22 and 11.29. Fig. 3 shows the working point as a function of the current (in steps of 0.2 A) in the interval from 599.2442 A to 600.6442 A. This corresponds to a deviation from the canonical value by an error of 0.416% to 0.18%.

From Fig. 3 we observe that the changes of the working point and the current of bending magnet are connected by a nearly linear relation. The horizontal and the vertical linear relations are given below.

$$\frac{\Delta Q_x}{Q_x} = -2.3579\cdot\frac{\Delta I}{I}\,, \tag{1}$$

$$\frac{\Delta Q_y}{Q_y} = -1.2931\cdot\frac{\Delta I}{I}\,, \tag{2}$$

Q_x and Q_y denote the horizontal and vertical working points and ΔQ_x, ΔQ_y are the corresponding changes. I and ΔI denote the current and its change, respectively. From this it is obvious that the working point is greatly affected by the current of the bending magnet.

4 Discussion and conclusions

The effective length of a magnet is different from its designed value. This would affect the working points and the Lattice of the SSRF, which implies the need for a correction. A new matching (the method of correction) based on the Lattice of the SSRF and the effective length of the magnet gives the right field strength of the magnet. Then the relevant current can be obtained, based on the excitation curve calibration. The right current for the magnet under different working modes can be given based on the excitation curve calibration, a procedure which has successfully been used in the commissioning of SSRF. The right calibration offers an important basis in commissioning. The excitation curve calibration of the magnet strength and the current is meaningful to the SSRF, although it might be amended properly because of uncertain facts, such as the change of the perimeter for the storage ring.

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