PERFORMANCE OF BEPC-SR MAGNET SYSTEM

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Abstract

Beijing Electron Positron Collider Storage Ring (BEPC-SR) magnet system consists of 40 bending magnets, 60 quadrupoles and other correction elements. All of them have been installed in the tunnel by the end of October 1987. In this paper, the magnet system is described with respect to their design, fabrication, magnetic measurement and performance.

The BEPC-SR (Beijing Electron Positron Collider Storage Ring) magnet system consists of 40 bending magnets 70B, 4 low field bending magnets 70BL, 60 quadrupoles 110Q, 8 insertion quadrupoles 160IQ,34 correction dipoles 215BHV and 36 sextupoles 140S. There are also skew quadrupoles and wiggler magnets. Electron and positron beams are injected at 1.4 Gev and accelerated up to 2.8 Gev. The parameters of these magnets are given in Table 1.

Table 1. Parameters of BEPC-SR magnets

Magnet type	70B	70BL	110Q	160IQ	215BHV	140S
Gap height (mm)	70	70	——	——	215	——
Bore diameter (mm)	——	——	110	160	——	140
Field strength	9028 (Gs)	4514 (Gs)	1118 (Gs/cm)	1106 (Gs/cm)	500 (Gs)	150 (Gs/cm^2)
Effective length (mm)	1600	500	400	648	454	295
Coil turns / pole	24	12	41	24	179	35
Current (A)	1073	1073	338	1257	24	197
Resistance (Ohm)	0.0074	0.002	0.035	0.016	0.196	0.048
Inductance (H)	0.071	0.006	0.09	0.028	0.058	0.015
Power consumption (kw)	8.53	2.1	4.0	25.6	0.114	1.86
Core length (mm)	1523	423	356	600	250	260
Core width (mm)	680	680	770	880	435	560
Core height (mm)	860	860	770	880	325	560
Core weight (t)	6.6	1.8	1.58	3.3	0.117	0.15
Coil weight (t)	1.1	0.28	0.26	0.4	0.067	0.048

1. Magnet system

1.1 Bending magnet 70B

Bending magnet 70B has a C-shaped core and 4 pancake coils (Fig. 1). C-shaped dipole permits easier to access to the vacuum chamber and to utilize the synchrotron radiation. The vertical and horizontal dimensions of useful region are 52 mm and 132 mm (including 31 mm sagitta) respectively. The core was made of 0.5 mm thick high induction cold rolled isotropy electrotechnical steel sheets DW540G-50 (made in Wuhan Iron and Steel Company). The laminations having inorganic insulation layers were stacked between two DT-4 electrotechnical soft iron (made in Taiyuan Iron and Steel Company) end plates and welded together with side plates in the stacking fixture. Before stacking, laminations were shuffled to have an uniform magnetic performance. The coils were made of T2 copper hollow conductor 23 x 27 Ø8 mm and insulated with the mica-powder fiber-glass tape pre-impregnated with epoxy resin. Both for turn-to-turn and ground insulations the same kind of tapes was used. Bending magnets have backleg coils wound around the yokes for the horizontal orbit correction.

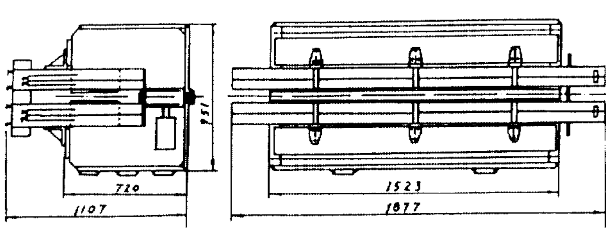


Fig. 1 BEPC-SR Bending Magnet 70B

1.2 Quadrupole magnet 110Q

Normal quadrupole has a symmetrical pole profile because of their good field symmetry (Fig. 2). Quadrupole magnets were made up by 4 quadrants. However, the upper and lower cores were left seperable for the convenience of the vacuum chamber installation. The quadrant cores were made of DW540G-50 laminations and DT-4 end plates, too. The coils were made of copper conductor 12 x 12 Ø4.5 mm and insulated with fiberglass tapes for both turn-to-turn and ground insulations and then impregnated with epoxy resin.

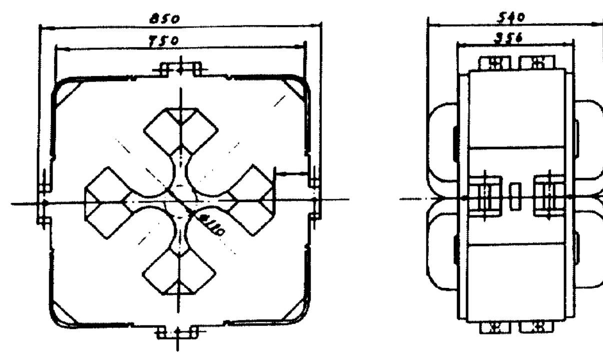


Fig. 2 BEPC-SR Quadrupole Magnet 110Q

1.3 Sextupole magnet 140S

Sextupole magnet 140S (Fig. 3) consists of two half-ring yokes and six poles, and it can be seperated at the median plane for the vacuum chamber installation. The core was made of DT-4 electrotechnical soft iron. The coils were made of T2 copper hollow conductor with an outer dimension 8 x 8 mm^2 and an inner square hole 4 x 4 mm^2.

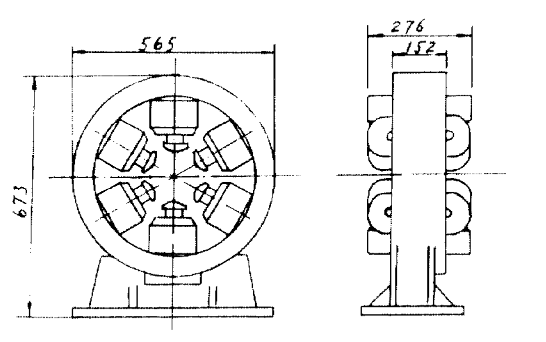


Fig. 3 BEPC-SR Sextupole Correction Magnet 140S

2. Performance of magnets

2.1 Bending magnet 70B

The integrated field $\int B(0)dl$ of bending magnets were measured with pulsatory excitation by means of reletive measurement method (Fig. 4).

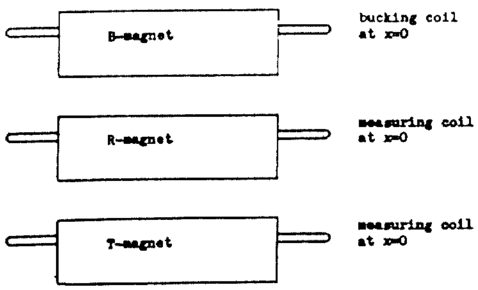


Fig. 4 $\Delta\int B(0)dl$ measurement of bending magnet

Choosing one magnet as bucking magnet (B-magnet in Fig. 4) and another one as reference magnet (R-magnet), all others are called test magnets (T-magnets). The reletive deviation between T-magnet and R-magnet

$$\frac{\Delta\int B(0)dl_{T-R}}{\int B(0)dl_R} = \frac{\int B(0)dl_T - \int B(0)dl_R}{\int B(0)dl_R}$$

Denominator $\int B(0)dl_R$ of R-magnet can be measured absolutely and the numerator $\Delta\int B(0)dl_{R-T}$ difference between T-magnet and R-magnet can be measured reletively. In magnetic measurement, R- and T-magnets are in turn connected in series with B-magnet and excited. Measuring coil is in turn put into R- and T-magnets and connected opposite seriesly with bucking coil. So we can get

$$\Delta\int B(0)dl_{R-B} = \int B(0)dl_R - \int B(0)dl_B$$

and

$$\Delta\int B(0)dl_{T-B} = \int B(0)dl_T - \int B(0)dl_B$$

From above, we get

$$\Delta\int B(0)dl_{T-R} = \Delta\int B(0)dl_{T-B} - \Delta\int B(0)dl_{R-B}$$

It must be noted, the effect of residual field should be extra added.

Fig. 5 is a histogram of discrepancy of $\int B(0)dl$ of 70B bending magnets at I = 860 A. Its standard deviation S.D. = 1.02×10^{-4}.

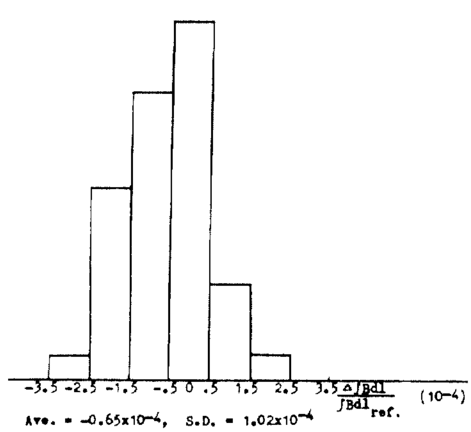


Fig. 5 $\int B(0)dl$ histogram of 70B bending magnets

For field distribution measurement, we use following method (Fig. 6)

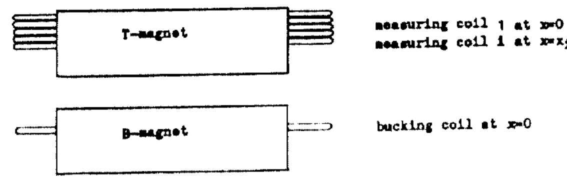


Fig. 6 Field distribution measurement of 70B bend.

T-magnet is excited statically. A set of measuring coils (in our case 5 coils) is placed in T-magnet and can be pushed in and pull out from it. Measuring coil i (i = 2, 3, 4, 5) is in turn bucked with measuring coil 1. So, the difference is

$$\Delta\int B(x)dl_T = \int B(x)dl_T - \int B(0)dl_T$$

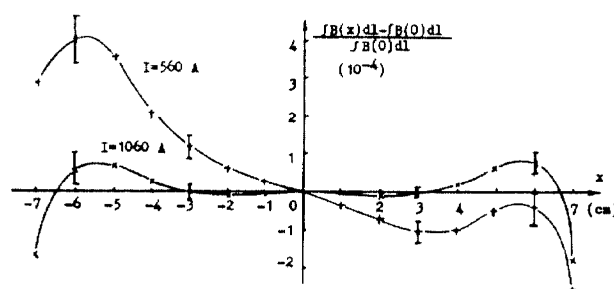
Then we have

$$\frac{\Delta\int B(x)dl_T}{\int B(0)dl_T} = \frac{\int B(x)dl_T - \int B(0)dl_T}{\int B(0)dl_T}$$

Denominator $\int B(0)dl_T$ of T-magnet can be measured absolutely.

The difference between measuring coil 1 and i should be noted. Correction of this difference are as follows. Measuring coil 1 and i are in turn positioned at x = 0 in T-magnet and are bucked with bucking coil in B-magnet (Fig. 6). Two magnets are seriesly excited with pulsative current. The difference between two measurements is their inherent discrepancy and it can be introduced in calculation.

Fig. 7 is the field distribution of 70B bending magnets.



unit; 10^{-4}

x (cm)		-6	-3	0	3	6
I=1060 A	Ave.	0.567	-.037	0	-.045	0.648
	S.D.	0.391	0.163	0	0.158	0.230
I=560 A	Ave.	4.005	1.211	0	-1.05	-.468
	S.D.	0.649	0.291	0	0.306	0.476

Fig. 7 Field distribution of 70B bending magnets

2.2 Quadrupole magnet 110Q

The integrated field gradient $\int G(0)dl$ of quadrupole magnets is measured by using the same method as in bending magnets. Instead of long coils, there are long coil pairs to be used. Fig. 8 is an $\int G(0)dl$ histogram of 110Q quadrupole magnets at I = 320 A. Its standard deviation S.D. = 0.58×10^{-3}.

The field harmonic contents are measured by means of rotating coil method. A long rotating coil rotates in the aperture. The induced signal is sent to the A/D convertor. Making use of angular encoder triggers, 256 data were sampled in one full revolution. A computer program FFT analyses the averaged data to get the harmonic contents B(k). Here k = 1, 2, 3, ..., 15. Fig. 9 is a spectrum B(k)/B(2) of 110Q quadrupole magnets at I = 320 A.

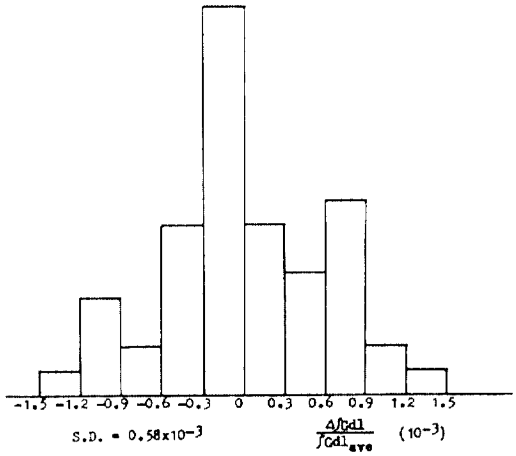


Fig. 8 $\int G(0)dl$ histogram of 110Q quadrupole magnets

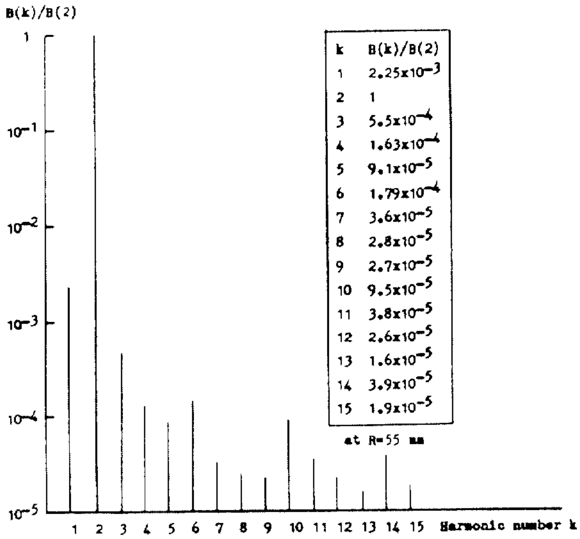
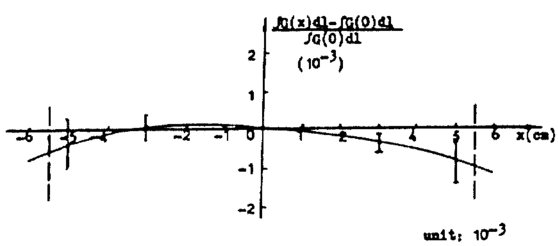
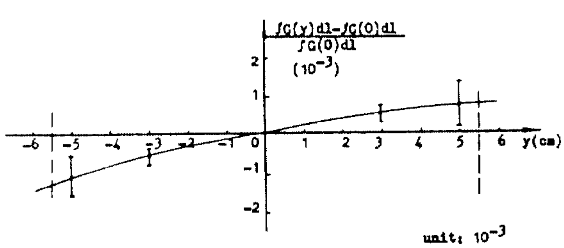


Fig. 9 Spectrum B(k)/B(2) of 110Q quadrupole magnets



x (cm)	-5	-3	0	3	5
Ave.	-0.364	0.056	0	-0.382	-0.796
S.D.	0.648	0.276	0	0.252	0.626



y(cm)	-5	-3	0	3	5
Ave.	-1.026	-0.513	0	0.548	0.787
S.D.	0.549	0.270	0	0.238	0.617

Fig. 10 Field gradient distribution of 110Q

From these harmonic contents we can calculate the field gradient distribution. The radial distribution has been adjusted by chamfering a 60° angle with depth of 10 mm on the pole end. Fig. 10 is the field gradient distribution of 110Q quadrupole magnets along x- and y-axis respectively.

2.3 Sextupole magnet 140S

The field harmonic contents of sextupole magnets are measured by means of rotating coil too. Fig. 11 is a spectrum B(k)/B(3) of 140S sextupole magnets at I = 120 A. From these harmonic contents, we can calculate the field error distribution. See Fig. 12.

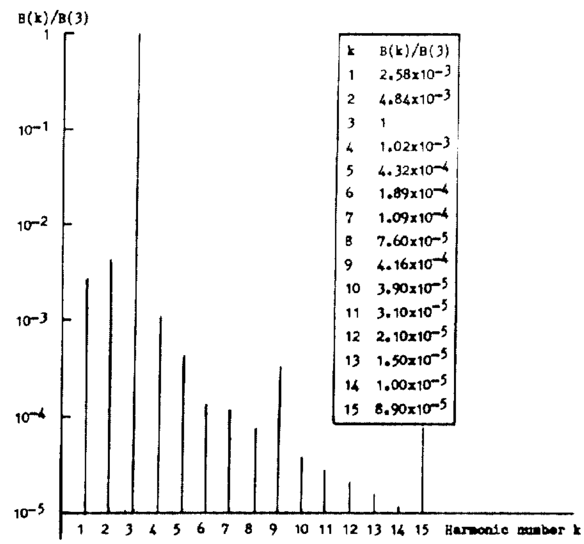
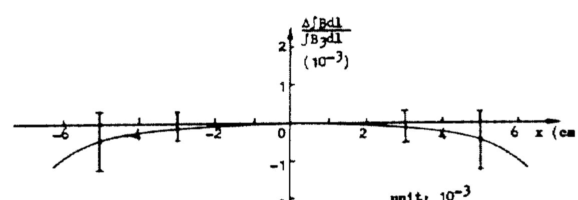


Fig. 11 Spectrum B(k)/B(3) of 140S sextopole magnets



x (cm)	-5	-3	0	3	5
Ave.	-0.498	-0.133	0	-0.095	-0.485
S.D.	0.814	0.463	0	0.454	0.796

Fig. 12 Field error distribution of 140S at I=120 A

Conclusions

All magnets have been tested. On the basis of measured data, we can state, that the magnets to be installed in the tunnel, all met specified values and were suitable for BEPC-SR.

Aknowledgement

We would like to thank all colleagues in IHEP, who have participated in the design, construction and tests of magnets and provided various kinds of information.