MAGNET SYSTEM DESIGN FOR THE STORAGE RING OF THE LSB

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Abstract

The Storage Ring of the LSB has a TBA based magnetic lattice with 12 sections. The dipole magnet will be of the combined function type. At 2.5 GeV the magnetic field at the central point is 1.0 T and the magnetic gradient 3.34 T/m. There are 36 of these combined magnets. A good magnetic field region with $\Delta B/B_0 \leq 2\ 10^{-4}$ in a region of $-40 \leq x \leq 35$ mm has been obtained. There will be three families of quadrupoles. The maximum magnetic gradient is 14.2 T/m. The quadrupoles have an aperture diameter of 70 mm and due to space requirements most of them will have to be split. The sextupoles, with a maximum second order differential around 440 T/m^2, will have an aperture diameter of 84 mm. Corrector magnets will be installed in the sextupoles.

1 INTRODUCTION

The principal parameters of the storage ring magnet system are determined by the Triple Bend Achromat (TBA) lattice that has been chosen [1]. The lattice requires four types of magnets for normal operation:

- Combined magnets: These are gradient bending magnets which have the combined function of bending and focusing the beam
- Quadrupole magnets to focus the beam
- Sextupole magnets for chromaticity correction
- Small dipole magnets for vertical and horizontal steering. These correctors may also sit in the sextupoles and have not yet been designed

2 COMBINED DIPOLE MAGNET

The combined magnets of the storage ring are of the C-type, curved and with parallel end plates. The C-shape permits an easy extraction of synchrotron radiation and the accommodation of the vacuum chamber.

The combined magnets have magnet poles with a hyperbolic contour so that they provide a magnetic strength $k = -0.4$ m^{-2} giving a magnetic gradient of 3.34 T/m, as well as a dipolar field of 1.01 T at the centre of the magnet. The main specifications of the storage ring combined magnets are given in Table 1.

Figure 1 shows a close-up view of the pole area of the combined magnet.

Table 1 Main specifications for the Combined Magnet

Parameters	Units	
Number of magnets		36
Bending radius	m	8.25
Bending angle	degrees	10
Bending field	T	1.0108
Magnetic strength	m^{-2}	0.4
Field gradient	T/m	3.34
Effective length	m	1.44
Gap	mm	50
Number of A-turns	A-t/coil	20420
Number of turns/coil		24
Current	A	850.8
Current density	A/mm^2	3.3
Resistance	mΩ	12.8
Power consumption	W	9295.5
ΔT	ºC	10
Water Flow (total)	l/min	13.9

The pole width and the shim profile have been optimised by 2D calculations using POISSON code [2] to achieve the required field quality. Figure 2 shows the field quality along the middle of the gap. It can be observed that the homogeneity of the field is within $\pm 2.10^{-4}$ in a horizontal region of 75 mm.

At the gap field of 1.01 T the magnetic flux induction at the root of the pole, where the shims are, is about 1.75 T and the flux in the horizontal and vertical yoke has been kept below about 1.5 T to prevent the end leakage flux inducing saturation. The iron losses at 1.01 T are about 1.5 %.

The winding of the magnets will be made with hollow copper conductor insulated and cooled with demineralized water. The coil section is 17.5 x 17.5 mm^2 with a cooling channel of 8 mm in diameter. The coils for the combined magnet will consist of at least two separately cooled pancakes, each comprising two layers of 6 turns (total of 24 turns per coil). The four pancakes will be connected electrically in series but will be connected hydraulically in parallel. With an acceptable increment of temperature of 10 K, the pressure drop in 1 pancake will be around 1.1 bar and the total water flow 14 l/min.

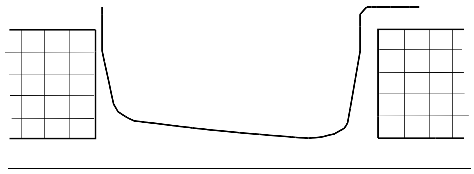

Figure 1 Detail of the pole area of the combined magnet for the storage ring

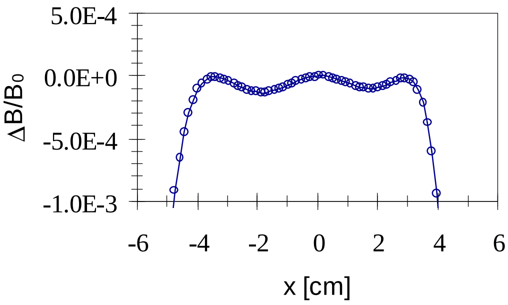

Figure 2 $\Delta B_y(x)/B(0)$ for y=0

3 QUADRUPOLE MAGNETS

The LSB lattice design requires 72 quadrupoles. The maximum gradient is 14.24 T/m. We propose to have three different families of quadrupoles. All of them will have the same radius of aperture but they will be of different size. The difference between cross section A and B comes from the smaller strength of quadrupole B, just half of that for quadrupole A.

Table 2 presents the main specifications for the quadrupoles.

Table 2 Parameters of the LSB quadrupoles

Name	Cross section	Length [m]	qnty.	Gradient [T/m]
Q1	A	0.6	24	14.24
QF	A	0.4	24	11.39
QD	B	0.4	24	5.95

The A quadrupole presented here has been optimised for a magnetic gradient of 18.2 T/m so that with an increase in the gradient strength of the 20 % the present design can still be used. The B quadrupole has been optimised for a maximum gradient of 8.2 T/m. Figure 3 shows schematically the designed quadrupole and table 3 gives its main parameters.

The aperture radius of the quadrupoles is 35 mm and has been chosen taken into account the vacuum chamber layout. The pole width is 77 mm for the A quadrupoles and 38 mm for the B quadrupoles. The vertical clearance is 10 mm at the corner of the pole of quadrupole A.

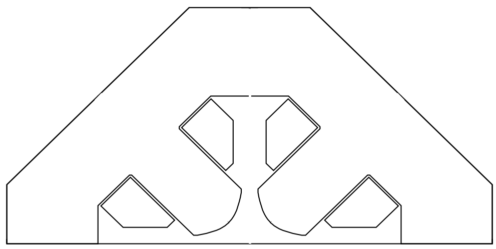

Fig 3 Physical layout of the A quadrupole

Table 3 Main parameters for the quadrupoles

Parameters	units			
Cross Section		A	A	B
Mag. strength	m^{-2}	1.707	1.366	0.714
Max.gradient	T/m	14.24	11.39	5.95
B at pole tip	T	0.53	0.42	0.21
Eff. length	m	0.6	0.4	0.4
Radius	mm	35	35	35
Ampere turns	A-t/coil	7000	5590	2900
turns/coil		18	18	8
Current	A	388.9	310.6	362.5
Current density	A/mm^2	3.84	3.06	3.58
Power	W	3234	1377	840
ΔT	ºC	10	10	10
P drop/coil	bar	1.04	0.23	0.10
Water Flow/coil	l/min	1.21	0.52	0.31

The pole tips contours of the storage ring quadrupoles have been optimised using the 2-D code POISSON. The best results are obtained by terminating the central hyperbolic pole region with a linear tangent commencing at,

x = 55.0 mm for quad. A
x = 30.8 mm for quad. B

The point of termination combined with the length of the linear shim, determines the gradient quality of the magnet. The resulting gradient quality is shown in figure 4, where dB_y / dx is plotted as a percentage of the gradient at the origin versus *x*. It can be seen that the gradient is within 0.05 % out to *x*=24 mm for quadrupole A. That the smaller region of good field quality for quadrupole B is sufficient must be assessed together with the machine group.

The magnetic induction in the steel has been kept everywhere below 1.6 T for quadrupole A, being much lower for quadrupole B owing to its lower strength.

The windings of the quadrupoles will be made with hollow copper conductor insulated and cooled with demineralized water. The copper cross section is

11 x 11 mm^2 with a cooling channel of 5 mm in diameter.

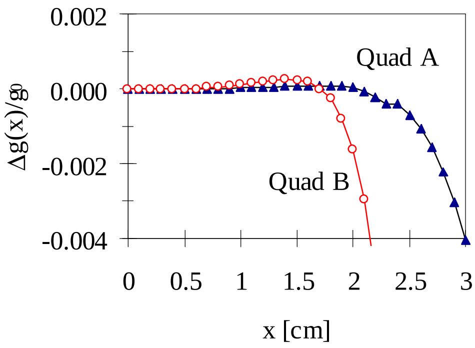

Fig 4 Gradient quality for the quadrupole magnets

The Q1 quadrupoles with cross section A will have to be splitted horizontally to allow the beam lines to emerge from the dipole ports. Symmetry considerations indicate that under such circumstance it is better to remove the steel return path at both sides of the magnet. The flux return is then in the top and bottom yokes, and provided these are broad enough to give a low reluctance path, the octupole field distortion resulting is very small. We have not been able to appreciate any induced octupolar component in these quadrupoles.

4 SEXTUPOLE MAGNETS

The TBA lattice for the Synchrotron Laboratory in Barcelona has three families of sextupoles with two different cross sections. Table 4 presents the sextupoles required for the TBA lattice together with the main parameters.

The A sextupoles will have an inscribed radius of 42 mm and a pole width of 62 mm. The inscribed radius and the pole width have been determined by geometric constraints set by the vacuum chamber envelope and by field quality requirements. The vertical clearance is 10 mm at the pole corner. The B sextupole will be much smaller owing to its lower strength.

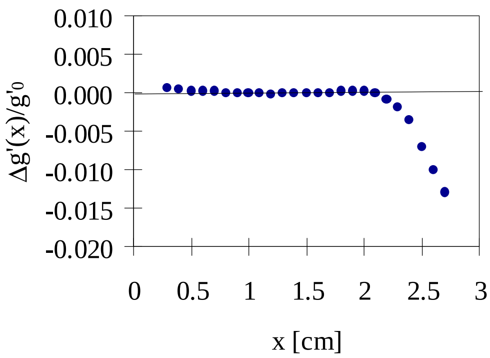

Fig 5 Sextupole field quality

The resulting magnetic quality is estimated using POISSON and it is shown in figure 5 where the sextupole component d^2B_y / dx^2, represented as a percentage of the value at *x*=10 mm is plotted as a function of *x*. It can be seen that the second differential is within 0.5 % out to 24 mm.

Table 4 Main parameters for the sextupoles

Parameters	Units			
Name		s1	s2	sf
Cross sect.		A	A	B
Mag. strength	m^{-3}	52.9	50.5	1.11
Max.. gradient	T/m^2	441.5	421.4	9.25
B at pole tip	T	0.33	0.31	0.01
Eff. length	m	0.3	0.2	0.2
quantity		24	24	24
Radius	mm	42	42	42
Ampere turns	A-t	4227	4033	88
turns/coil		16	16	30
Current	A	264.2	252.1	2.9
Current density	A/mm^2	3.9	3.7	0.4
Power	W	1517	920.6	2.3
ΔT	ºC	10	10	
P drop/coil	bar	0.2	0.05	
Water Flow/coil	l/min	0.4	0.23	

The windings of the A sextupole are made with hollow copper conductor insulated and cooled with demineralized water. The coil cross section is 9 x 9 mm^2 with a cooling channel of 4 mm in diameter. The B sextupole has a solid conductor, 3 mm in diameter.

5 CONCLUSIONS

The magnetic system for the LSB has been presented. The system consists of 36 combined magnets, three families of quadrupoles and three families of sextupoles making a total of 180 magnets for the Storage Ring. The field quality of the different magnets comforms with the specifications set by the machine dynamics.

Acknowledgements

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References

[1] M.Muñoz, *Linear Lattice for the LSB Storage Ring*, these Proceedings

[2] Los Alamos Accelerator Code Group, Reference Manual for POISSON/SUPERFISH codes, Los Alamos Laboratory, LA-UR-87-126, 1987