Design, Construction & Testing of the Corrector Magnets for ELETTRA

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Abstract

The ELETTRA storage ring contains 82 combined horizontal and vertical corrector magnets. The design of the magnets, which because of their unusual shape required a 3D optimisation, and their construction are described. The results of detailed magnetic field measurements to determine the longitudinal field profile, integrated multipole components and to asses hysteresis and field superposition effects, are presented.

1. INTRODUCTION

A series of 82 corrector magnets installed in the ELETTRA 1.5-2.0 GeV storage ring form part of the magnetic elements reference to [1]. They carry out a number of essential tasks, for example, global closed orbit correction in order to optimize beam lifetime and emittance, and closed bumps for synchrotron radiation beam steering. An additional requirement on the magnet and power supplies is for a fraction of the correction capacity (2.5%) to be able to be modulated at up to 50 Hz for use in both global (harmonic) and local (insertion device) closed orbit feedback systems.

Because of the limited space available a maximum overall length of 220 mm was allowed for a combined horizontal and vertical correction magnet, with maximun strength of 140 G·m and 130 G·m in the two planes respectively. Another major restriction was that the correctors had to be installed around a vacuum pump. A free aperture was therefore required on the lower side, which necessitated an inverted U shape for the magnet. The internal aperture in the horizontal plane was also restricted to a minimum value of 110 mm.

2. DESIGN & CONSTRUCTION

2.1 Magnetic Design

The main challenge of the steerer magnet design was to produce a sufficiently homogeneous magnetic field both in the vertical and in the horizontal direction, in spite of the wide aperture, the structure being open on the lower side and, last but not least, of the relatively low iron length/total length ratio.

The above requirements forced us to perform 3D magnetic simulations, which have been carried out by TOSCA. The optimisation of the magnetic field distribution has been made by acting on the iron shape, on the coil positions and on the current density distribution (figure 1).

The central position of the good field region is placed 60 mm from the iron, relatively far from the center of the magnet internal window, in order to be less sensitive to the effect of the lower iron "noses". The two noses are necessary to provide the most homogeneous path for the vertical magnetic flux lines, but they also act as a short circuit for the horizontal magnetic flux lines, therefore their length has been chosen as a compromise between the two requirements.

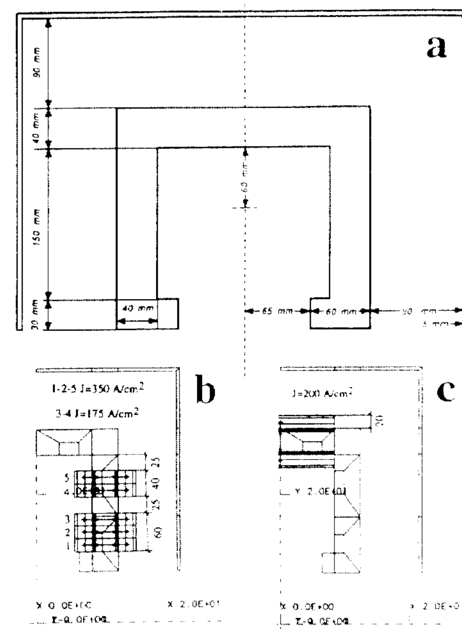

Figure 1. Iron elements cross sectional view (1a), vertical field configuration mesh (1b) and horizontal field mesh (1c) used for TOSCA simulations.

The position of the coils and the relevant current densities also contribute to a large extent to the field homogeneity around the central beam position.

The wide window aperture means that the magnetic field produced by the local effect of the coils , which are relatively close to the central field region, is not negligible when compared to that coming from the iron, which depends on the iron shape. Therefore, to limit this strong contribution, no coils are present in the central part of the vertical legs. Moreover the two central coils (numbers 3 and 4 in figure 1b) are connected in parallel, in order to be supplied with half the current flowing in the other coils (numbers 1,2 and 5).

For the horizontal field the design was easier, as the local effect of a single homogeneously supplied horizontal coil has been sufficient to correct the effect of the lower aperture of the iron window.

2.2 Construction

The 82 magnets (figure 2), plus one spare and one prototype, have been manufactured by the TESLA Engineering Company, England.

The yoke is composed of three glued stacks of 1 mm thick low carbon steel laminations. There are two vertical L shaped stacks and one horizontal I shaped stack for each magnet. The three stacks were assembled, after having inserted the coils, by means of four M8 screws.

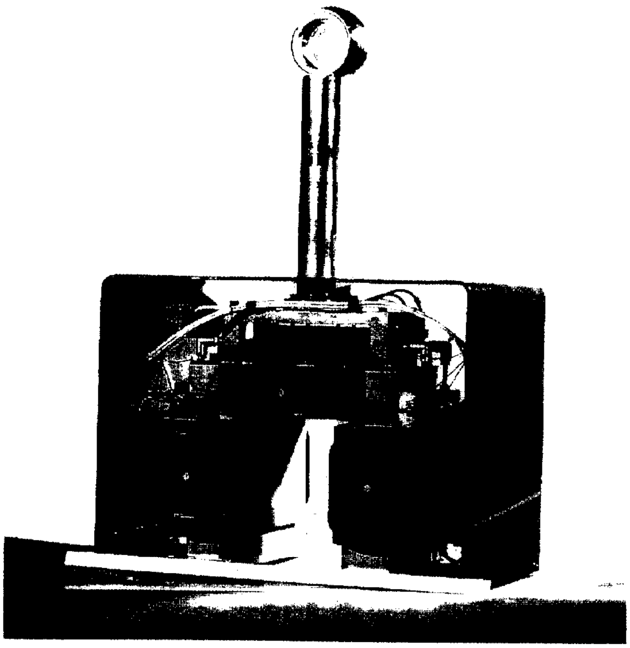

Figure 2. The steerer magnet.

The coils was made with 3.18x1.45 mm solid copper conductor already resin coated, then thermally cured. The coating was a polyimide/polyamide resin, which has been proven at DESY to be radiation hard.

Each of the two vertical coils is made of five 114 turn racetrack windings plus an aluminium spacer; the horizontal coil is a single 564 turn racetrack winding.

The horizontal and vertical coils are cooled by means of external copper jackets wound on the coils in such a way as to avoid complete conductive paths around the yoke to allow the AC magnetic field to be produced. A single copper cooling tube, isolated in the middle of its path, was then welded to the three jackets.

Table 1
Main design parameters for the Steerers Magnets.

Number of units	82
shape	inverted U
vertical & horiz. steel length	150 mm
Total length	220 mm
Free horizontal aperture	110 mm
Horizontal field strength	142 Gauss·m
Vertical field strength	130 Gauss·m
Up to 50 Hz (vert. & horiz.)	5%
Field harmonic content	2.5% at r=25 mm
Dist. centre-reference sphere	450 mm
Maximum current (H field)	12 A
Maximum current (V field)	15.5 A
Vertical coil resistance	1.8 Ω
Horizontal coil resistance	1.2 Ω
Vertical coil inductance	0.15 H
Horizontal coil inductance	0.24 H
Horizontal number of turns	564
Vertical number of turns	10x114

To limit the heating of the internal part of the coils, which was influenced also by the iron, it was necessary to add for the vertical coils, where the current density can reach up to 3.5 A/mm^2, a copper plate directly connected with the cooling tube. The maximum temperature measured in the internal part of the coils, with all the coils energised at the same time, was not higher than 90 °C.

An anticorodal support for a Taylor Hobson sphere is fixed on the top of the magnet in order to place the centre of the sphere 450 mm from the optical centre of the magnet, which is the same distance adopted for the quadrupoles and the sextupole. In this way it has been possible to easily align the magnets in the ring.

3. MEASUREMENTS

3.1 General

Magnetic measurements have been carried out with the same rotating coil system used to measure the quadrupole and sextupole magnets of the storage ring [2]. Ref. 2 also presents the preliminary magnetic measurement results of the steerer prototype. The 82 steerer magnets have been measured in two months, at a rate of about 3 magnets per day.

To perform the field integral measurements, a coil with a radius of 36.17 mm has been used, however all the results presented here have been scaled to a radius of 25 mm.

A rotating hall plate [2] has been used to analyse the field strength (and hence to calculate the magnetic length, shown in table 2) at any desired longitudinal position. Fig.3 presents the horizontal and vertical field as a function of the longitudinal position.

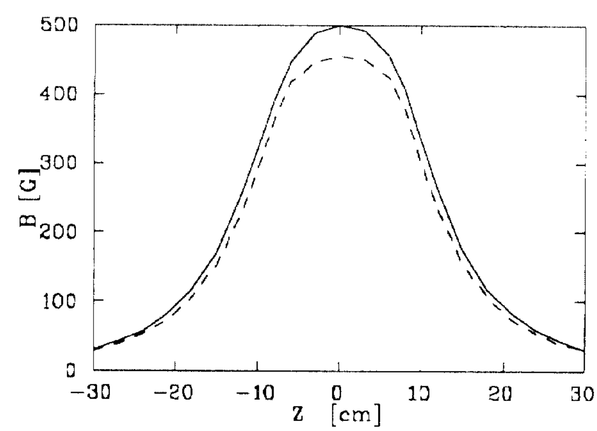

Figure 3. Horizontal (solid) and vertical (dotted) magnetic field variation with longitudinal position.

The excitation curve measurement has been executed separately for the vertical and the horizontal field and after a cycling procedure. Due to the shape of the magnet, the optimum cycling procedure for both field components was found to be one that used only the horizontal coil, for which the flux flows uniformly thorough the iron circuit. The procedure adopted was :

I_x = 0-->12 A -->-10 A -->8 A --> -6 A --> 4 A --> -2 A -->0

After cycling the residual horizontal (vertical) magnetic field at the centre of the magnet was 0.4 G (not measurable,

<0.1 G). The residual horizontal field integral was not measurable (<0.01 G·m), the vertical was 0.1 G·m.

The field integral reproducibility after cycling was within the reproducibility of the measuring system (10^{-4}).

The difference, without any cycling, between the field integral measured at I_{max} and at $-I_{max}$ was for the horizontal component 0.04% and for the vertical 0.22%.

The difference between the field integral measured at $I_{max}/2$ after a complete cycling and after a cycle 0 --> I_{max} --> $I_{max}/2$ was for the horizontal component 0.18% and for the vertical 0.6%.

No field integral saturation has been measured at I_{max} for either component.

3.2 Field measurement and analysis

Table 2 presents the main magnetic measurement results for the steerers. For the main component (n=1) we found out a difference of about 2% for the horizontal and vertical field with respect the data of table 1, however this difference was acceptable. In table 2 is also reported the "field homogeneity", i.e. the field deviation calculated in the horizontal plane at a distance of 25 mm. This quantity has been defined in the following way : the field integral can be writen as

$$\int(B_y+iB_x)\,dl = \Sigma(B_n+iA_n)(x+iy)^{n-1} \quad (1)$$

where A_n and B_n are the integrated normal and skew multipole components respectively. In the horizontal plane (y=0) we obtain:

$$\int B_x\,dl = A_1 + A_2\,x + A_3\,x^2 + A_4\,x^3 + \ldots \quad (2)$$

$$\int B_y\,dl = B_1 + B_2\,x + B_3\,x^2 + B_4\,x^3 + \ldots \quad (3)$$

The A2,A4,.. terms are anti-symmetric, while A3,A5,... are symmetric, so we have defined the field homogeneity in the horizontal plane for the horizontal coil to be as follows :

$$\Delta I_x/I_x = |A_2\,R + A_4\,R^3| + |A_3\,R^2 + A_5\,R^4| \quad (4)$$

$$\Delta I_y/I_x = |B_2\,R + B_4\,R^3| + |B_3\,R^2 + B_5\,R^4| \quad (5)$$

and similarly for $\Delta I_{x,y}/I_y$ (vertical coils).

The $A_n.R^{n-1}$ coefficients are directly calculated from the measurements by a FFT analysis and scaled to a distance of 25 mm. It can be seen from table 2 that the field quality meets the required specification of 2.5%.

Table 2
Main field components

	Hor.	Vert.
I(A)	12	16
B_o (G)	499	454
Lmag (mm)	279.6	279.0
$<I_{x,y}>$ (G·m)	139.1	126.9
$I_{rms}/<I>$ (%)	0.51	0.34
Field homogeneity (averaged over 82 steerers) :		
$<\Delta I_x/I_{x,y}>$ at x=25mm (%)	1.27	0.16
$<\Delta I_y/I_{x,y}>$ at x=25mm (%)	1.94	0.78

Tables 2 and 3 summarise the multipole components at the max. current for the horizontal and the vertical integral field. In these tables are reported both systematic (average) and random (r.m.s.) parts at a reference radius of 25 mm. The components with n>6 are not shown because of their small values (less than 10^{-4}). For the horizontal field the main errors are a normal quadrupole component (2%) and a skew sextupole (1.2%) due to the shape of the magnet; the quality of the vertical field is better and only a normal sextupole of 0.8% has been measured.

Table 3
Multipole content of Horizontal Integral Field at R=25 mm and I=12A.

	Normal (%)		Skew (%)	
n	syst.	random	syst.	random
2	2.08	0.13	-0.03	0.13
3	-0.01	0.01	-1.19	0.03
4	-0.15	0.01	0.00	0.00
5	0.00	0.00	0.02	0.00
6	0.00	0.00	0.00	0.00

Table 4
Multipole content of Vertical Integral Field at R=25 mm and I=16A.

	Normal (%)		Skew (%)	
n	syst.	random	syst.	random
2	-0.00	0.03	-0.02	0.09
3	-0.82	0.03	0.00	0.01
4	0.00	0.01	-0.04	0.01
5	-0.08	0.01	-0.01	0.00
6	0.00	0.01	-0.10	0.00

The lack of saturation in the magnet also leads to a linear superposition of the two field components. At I_{max} for both the components, we measured a difference of only 0.12% (0.15%) for the horizontal (vertical) field with respect to the value measured when the other component is switched off.

4. CONCLUSIONS

The 82 corrector magnets have been measured and installed in the ELETTRA storage ring and are in routine use. Many of the magnets, especially in the first phase of the commissioning period from October to December 1993, have been operated at maximum current values without any problems. The use of an AC feedback correction has been successfully tested in the laboratory and will soon be implemented in the storage ring.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

[1] G.Petrucci, D.Tommasini, "The Elettra Storage Ring Magnets", Proc. 1993 US Particle Accelerator Conference, May 93, p.2820.

[2] D.Zangrando and R.P.Walker, "Magnetic Measurement and Alignment of the ELETTRA Storage Ring Quadrupole, Sextupole and Steerer Magnets", Proc. 1993 US Particle Accelerator Conference, May 93, p.2844.