Construction of Wiggler W14.0 for ELETTRA

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Abstract

The construction and performance of a 4.5 m, 1.6 T hybrid multipole wiggler for ELETTRA is described, including the novel method used to measure and sort the permanent magnet blocks and the results achieved.

1. INTRODUCTION

A 140 mm period, 1.6 T, hybrid multipole wiggler is near to completion for the ELETTRA storage ring. This is the third insertion device to be installed in the ring [1]. The total length is approximately 4.5 m and consists of three separate sections each containing 19 full strength poles and 2 half poles. The first section was installed in the ring in April 1994 and is operational with the present minimum gap of 26 mm, giving a field of 1.3 T, see fig. 1. The effects on the electron beam will be discussed in a future report [2]. The second section is currently undergoing final magnetic field measurement and the remaining section is under construction.

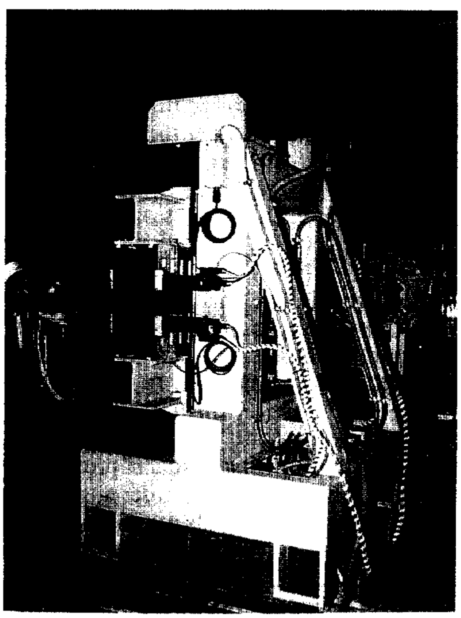

Figure 1. The first section of W14.0 installed in ELETTRA.

2. DESIGN AND CONSTRUCTION

Wiggler W14.0 was designed to reach the highest possible field level with the given constraints on minimum gap (20 mm) and radiation opening angle and without using an excessive volume of permanent magnet material. The radiation angle was required to be close to the maximum value of 4.5 mrad at 2 GeV in order to maximize the critical energy for off-axis radiation. The optimization resulted in a period length of 140 mm and nominal field of 1.55 T. A 0.5 m long prototype was constructed which reached a peak field of 1.54 T with Armco poles and 1.60 T with iron-cobalt poles [3,4]. The same magnetic design has been maintained for the final version, with dimensions (x,y,z) in mm as follows; poles : (100, 97, 22.4); magnets : (140, 130, 23.8). The pole width was chosen in order to achieve a nominal quadratic field roll-off at minimum gap given by $k_x/k < 0.1$, i.e. $k_x < 4.5\ m^{-1}$, where $B_y=(1-k_x^2x^2/2)\cos(kz)$.

The mechanical construction is similar to that of the prototype : separate half-period cells are assembled using aluminium structures; seven such cells are mounted onto 0.49 m long base plates; three base plates are mounted onto each I-beam and clamped to the standard dovetail. Additional M8 bolts are used to support the total force of 56 kN at minimum gap. The cells are accurately pinned to the baseplates to guarantee the periodicity, which allowing for component tolerances is 140.4 mm. The cell construction has been modified compared to the prototype to permit the four blocks that make each cell (dimensions 140x65x23.8), to be clamped into position, in order to avoid the need for gluing.

The outermost cells are special types that incorporate half-height magnets (external positions), a split pole and a rotating permanent magnet block. The split pole has a fixed part 49 mm high near the beam axis and a moveable part 20 mm high that can be actioned without dis-assembling the wiggler by means of a gear connection. The rotating magnet is 110 mm wide with a cross-section of 10 x 10 mm, of NEOREM 440 i material. The block is rotated using a Berger VRDM 568/50LHC stepping motor through a 10:1 reduction. A rotary switch is included to set the zero position, and an electromagnetic brake. Attached to each end-cell is a field clamp whose base extends into contact with the iron I-beam.

NdFeB permanent magnet blocks were obtained from Outokumpu magnets (NEOREM 440i) with an average magnetization of 1.17 T and intrinsic coercive force of 1400 kA/m. The estimated remanent field is 1.21 T. The blocks were passivated and oiled to prevent corrosion. Total magnetic moment data (M_x, M_y, M_z) were provided by the supplier for all of the blocks. Before deciding on the philosophy for the placement of the blocks in the wiggler preliminary measurements were made using an array of 4 cells, two above and two below the beam axis. A particular block was selected which had near-zero M_x and M_y components. Measurements of the transverse (x) variation of the field integrals were made with the block in one position, and then with the block flipped around the z-axis. The experiment was carried out twice, with the block in an internal and external position with respect to the beam axis. Since the contribution from the total magnetization was negligible the difference in field integral caused by inverting the block is due only to the inhomogeneity. Figures 2 and 3 show the field integral changes for the block in the internal and external positions. It is clear that the effect of inhomogeneity is very significant in the internal position, but negligible in the external position. The same block was also measured on its own in a corresponding position to that in the array, in the internal position. The difference in field integrals from inverting the block in this case are shown in fig. 4. The correlation with fig. 2 is seen to be very good, indicating that

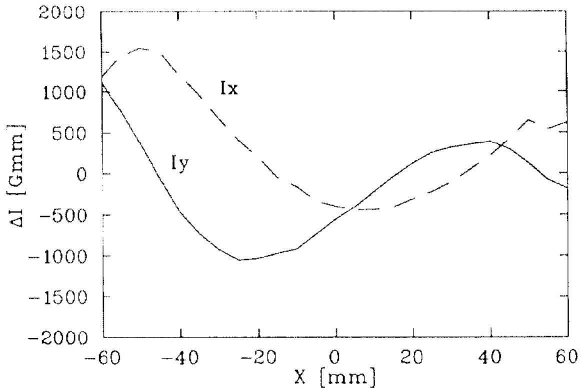

Figure 2. Changes in horizontal and vertical field integrals after flipping an internal magnet block.

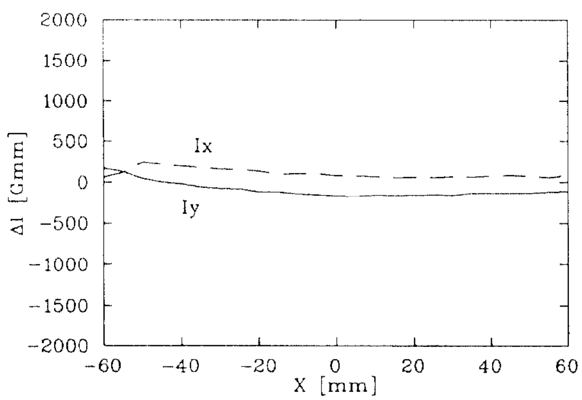

Figure 3. As fig. 2, for an external magnet block.

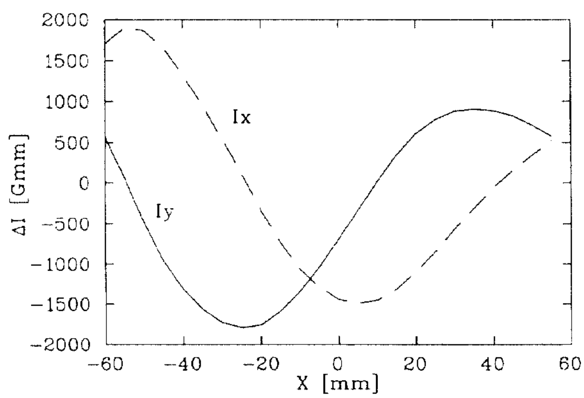

Figure 4. As fig. 2 for an isolated magnet block.

the effect of the inhomogeneity is not strongly affected by the iron, but is a direct field effect. It follows also that the effect can be easily measured for each block, without inserting in the iron structure.

On the basis of the above the following novel procedure was adopted to optimize the block configuration. After selecting at random the blocks for each of the 3 sections, they were then divided into 2 equal groups : blocks with the smallest values of $(M_x^2 + M_y^2)$ were selected for placement in the internal position i.e. close to the beam axis; the other blocks were used in the external positions. The internal blocks were then measured with the flipping coil in the two positions allowed by the assembly to obtain the field integrals at 13 transverse positions (x) over the range ± 60 mm, at a position corresponding to the minimum gap. About 30 minutes were required in total for each block and 8 days to measure the blocks for each section. A reference block was measured each day in order to guarantee that there were no changes in conditions during the measurement period. On the basis of both the Helmholtz coil and flipping coil data two separate optimizations were then carried out using a simulated annealing program. For the internal blocks the program attempted to minimize i/ the total horizontal and vertical field integrals at each x position, ii/ the sum of the integrals for the 4 blocks that excite each pole and iii/ the variation in pole strength i.e. $\Sigma(M_z - \langle M_z \rangle)$, where $\langle M_z \rangle$ is the average of the main magnetization component for all internal blocks. The optimization for the external blocks was similar except that the flipping coil data was replaced by the M_x and M_y components. By optimizing separately the internal and external blocks it was not necessary to know the "transfer function" between the measured field integral (or magnetization component) and the actual effect in the wiggler structure. After optimization the "prediction" for the final configuration from the flipping coil data of only, neglecting the external blocks and the presence of the iron, was a field integral error of < 1 G m at any x position for each section.

3. PERFORMANCE

Measurement of the first two sections before any correction was undertaken showed that the first field integrals were within about ± 2.5 Gm over the good field aperture of ± 25 mm, for gaps larger than about 25 mm. This is very much better than would be achieved from a random configuration of the magnet blocks and not far outside the specified limits of ± 1 Gm. The second field integrals were within the specified limits of ± 2.5 Gm^2. The r.m.s field strength variation was also small, less than 0.4 % for both sections at minimum gap. It is clear therefore that the optimization method based on separate block measurements was successful. Although not part of the optimization, the rms phase error was also very small, less than 4° at minimum gap for both sections.

The first step in the field adjustment procedure was to fix the position of the mobile poles in order to achieve zero first and second vertical field integrals at some intermediate gap, such that the rotating blocks could correct the integrals to zero at all gaps. Given the correction capacity of each pair of rotating blocks of between 27 Gm at minimum gap and 4 Gm at maximum gap this was not difficult to achieve.

During the initial measurements it became apparent that the results were being influenced by hysteresis effects, both due to the rotating block and gap changes. Comparison of measurements after various cycling operations revealed that the rotating block hysteresis effect is localized to the end poles, due presumably to saturation in the iron circuit. The gap change hysteresis is due to the saturation of the central poles and the consequent non-compensation by the end-poles. This is clear from fig. 5, which shows the integral of the field difference at 25 mm gap before and after performing the cycle 25 mm → 20 mm → 25 mm. The magnitude of both effects is about 1 Gm. In order to make an accurate compensation of the field integrals therefore it was necessary to define a suitable cycling procedure, both for the rotating

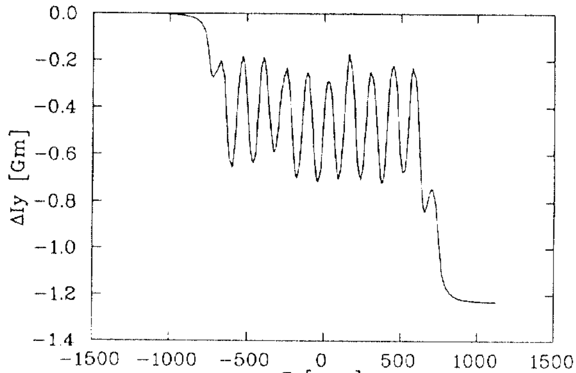

Figure 5. Hysteresis effect due to change in gap.

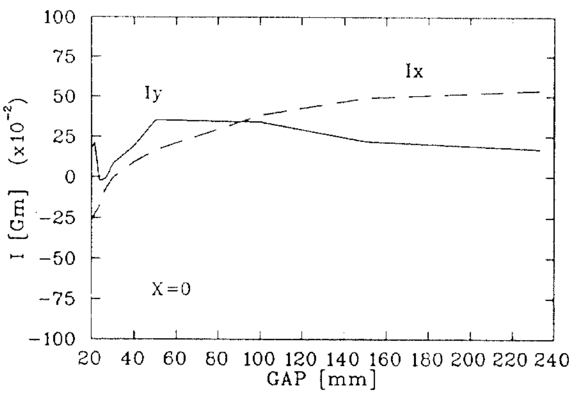

Figure 6. Field integrals as a function of gap.

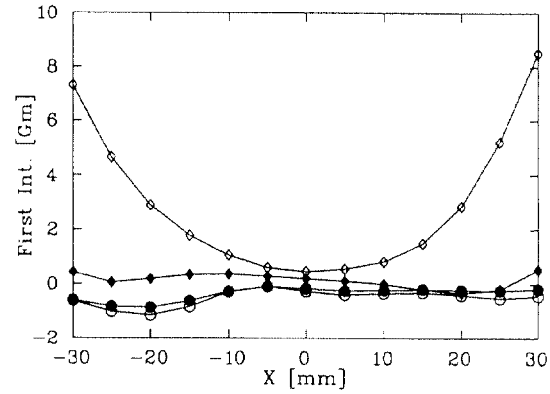

Figure 7. First field integrals of vertical (diamonds) and horizontal (circles) field components at 20 mm (open symbols) and 25 mm gap (solid symbols).

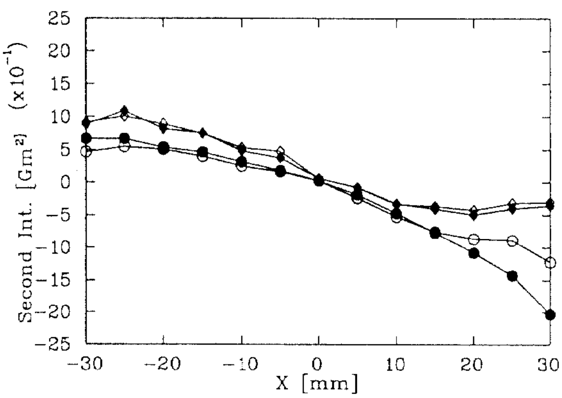

Figure 8. As fig. 7, second field integrals.

blocks and the gap change. Having done this, the block angles were defined as a function of gap, separately for closure and opening, to zero the first and second field integrals. Symmetry was maintained with respect to the median plane so as not to induce a B_x field component. The residual field integral variation is shown in fig. 6. The second order integrals are constant within ± 0.25 Gm^2 in both planes.

A complication for the correction of the first order (multipole) field integrals was the fact that there was a rapid change between 25 mm and 20 mm gap, the main effect being the appearance of an integrated sextupole component. Measurements confirmed that this was due to the saturation of the central poles. Since the present operational gap is close to 25 mm it was decided to apply the shimming for this gap, and re-shim if necessary in the future if a smaller gap vacuum vessel is installed.

The final results for the field integral measurements for the first section are shown in figs. 6 and 7 at both 20 and 25 mm gap. Tuning studs were used on the first section to correct most efficiently a skew-quadrupole error, before applying a small number (14) of shims. It can be seen that the integrals are all within specification apart from the above mentioned integrated sextupole field at 20 mm gap, which has a magnitude of about 0.5 T/m. Similar results are being obtained at present for the second section.

Table 1 shows the final measured field parameters as a function of gap for the first two sections of the wiggler. Apart from the rms field amplitude variation, the results are very similar to those obtained previously with the prototype [3]. The field roll-off increases at the smallest gap due to saturation, however is considered acceptable. At maximum gap (233 mm) the field is 7.9 mT, which is sufficiently small to guarantee negligible effect on the electron beam.

Table 1

Average results for the first two sections of W14.0

Gap (mm)	B_o (T)	B_3/B_1 (%)	k_x (m^{-1})	ΔB/B rms (%)
20.0	1.606	13.8	5.6	0.35
25.0	1.352	10.6	4.2	0.42
30.0	1.129	8.0	3.1	0.52
50.0	0.616	2.9	5.7	0.63
100.0	0.180	0.4	11.8	1.25

4. REFERENCES

[1] B. Diviacco et al., these Proceedings.

[2] B. Diviacco and R.P. Walker, to be published.

[3] R.P. Walker et al., "Status of Development of the Insertion devices for ELETTRA", Proc. 3rd European Particle Accelerator Conference, Berlin, March 1992, p.1656.

[4] B. Diviacco et al., Rev. Sci. Instr. 63 (1992) 388.