

ELETTRA 2.0 MAGNETS AND MAGNETIC MEASUREMENTS RESULTS

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Abstract

The Elettra 2.0 project involves the installation of 648 new electromagnets for the upgrade of the existing light source [1]. Following the design and prototyping phase, the magnet series are currently being manufactured and delivered to Elettra to be suitably characterized before the installation. To this aim, a new magnetic measurement laboratory has been built and equipped during last year.

The measurements currently being performed at Elettra consists of the magnetic field quality measurement (for acceptance tests), magnetic field excitation curves, the alignment of multipole magnet, and the 3D magnetic field mapping. This article presents the results of the magnetic measurements performed until now.

MAGNETS

As previously reported [2], the magnet layout of Elettra 2.0 consists of 552 iron-dominated magnets, comprising 72 dipoles, 24 correctors, 168 quadrupoles, 240 sextupoles, 48 octupoles, and 72 fast correctors made from air coils. The magnets were procured through two international tenders: one comprising two lots of solid-iron quadrupoles and laminated-core sextupoles and octupoles; the other comprising a single lot of all solid-iron dipoles. The former and latter tenders were awarded to Danfysik A/S (DK) and SigmaPhi Electronics (FR), respectively. The contracts for the quadrupole and multipolar magnets tender were countersigned by Danfysik in August 2023, and the relevant deliveries were completed in March 2026. The contract for the dipole magnets tender was counter-signed by SigmaPhi in December 2023, and the relevant deliveries will be completed by August 2026. As stipulated in the aforementioned contracts, magnetic measurements are not included in the scope of supply and are performed at Elettra [2]. Until April 2026, 120 multipolar magnets were measured, including 36 Q24RB, 12 Q24RBs, 14 Sx20, 48 Sx16 and 9 Sx16s.

Measurement results are presented and discussed in the following paragraphs.

QUADRUPOLES

Unlike all other magnets, in the case of quadrupoles, the production of the First of the Serie (FoS) revealed an effect that had not been predicted in the simulations. The high quality of the magnetic field (achieved through the optimisation of the pole profiles and the precision of the assembly of the pole roots) has, in fact, emphasized a constant sextupole component stemming solely from the Earth's magnetic field. After some investigations, it became clear that the reason for this anomaly was due to the fact that the yoke of the quadrupoles consisted mainly of two magnetic halves separated by non-magnetic aluminum spacers. By

manufacturing the spacers from iron too, it was possible to close the magnetic circuit around the poles and thus cancel out the magnetic potential (and the associated sextupole component) of the Earth's magnetic field.

Figures and table below report the results of the magnetic measurements carried out using the rotating coil technique [3]. Table 1 and Figure 1 report the Q24RB results.

Table 1: Q24RB Magnetic Measurement Average Values

Current [A]	$-\int B_2$ [T]	$\int c_3$ [units]	$\int c_4$ [units]	$\int c_6$ [units]
50	6.65	1.34	0.24	0.06
70	9.23	1.40	0.25	0.06
90	11.71	1.29	0.26	0.06
100	12.71	1.25	0.25	0.07

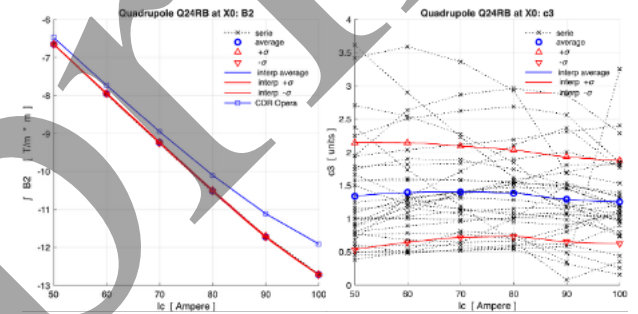


Figure 1: Q24RB magnetic measurement results.

Table 2 and Figure 2 report the Q24RBs results.

Table 2: Q24RBs Magnetic Measurement Average Values

Current [A]	$-\int B_2$ [T]	$\int c_3$ [units]	$\int c_4$ [units]	$\int c_6$ [units]
50	6.65	1.39	0.17	0.04
70	9.26	1.33	0.17	0.03
90	11.71	1.46	0.21	0.04
100	12.66	1.28	0.25	0.07

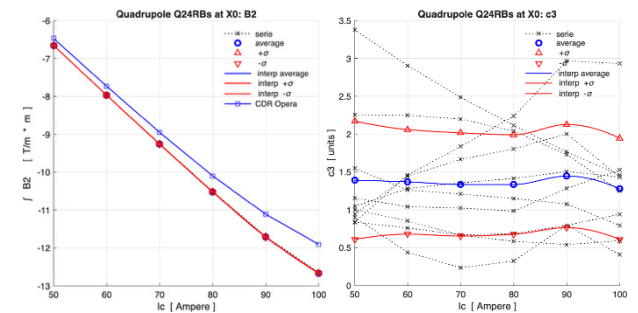


Figure 2: Q24RBs magnetic measurement results.

SEXTUPOLES

Unlike quadrupoles, the sextupole FoSs did not produce any unexpected results, and the construction of the series largely followed the initial design. The only difference was the modification of the clamping system for the two halves of the shaped versions (Sx16s and Sx20s). This modification was proposed by Danfysik to increase the rigidity of the closure. Figure and tables below report the results obtained. Table 3 and Figure 3 report the Sx16 results.

Table 3: Sx16 Magnetic Measurement Average Values

Current [A]	$\int B3$ [T]	$\int c4$ [units]	$\int c5$ [units]	$\int c9$ [units]
50	474	4.72	1.12	4.15
70	661	4.67	1.09	4.15
90	840	4.57	1.07	4.15
100	922	4.39	1.04	4.16

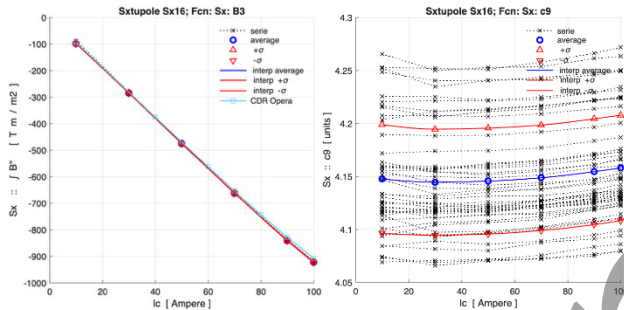


Figure 3: Sx16 magnetic measurement average values.

It should be noted that the magnetic measurements of the sextupole magnets confirmed a systematic value for the c9 component that was identical to that obtained from the magnetic simulations carried out for the design. Figure 4 and Table 4 report the Sx16 results.

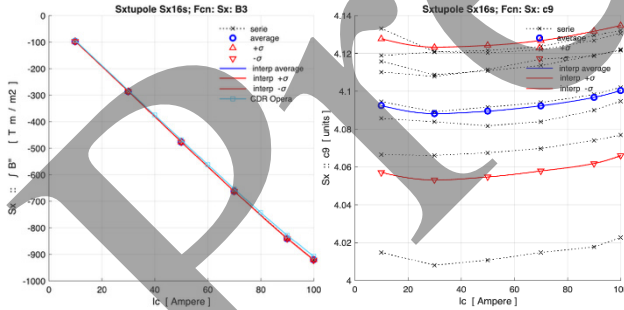


Figure 4: Sx16s magnetic measurement average values.

Table 4: Sx16S Magnetic Measurement Average Values

Current [A]	$\int B3$ [T]	$\int c4$ [units]	$\int c5$ [units]	$\int c9$ [units]
50	477	4.13	1.67	4.09
70	662	4.12	1.43	4.09
90	840	3.98	1.47	4.10
100	921	3.75	1.83	4.10

With the exception c4 and c5, which are highly sensitive to the alignment of the yoke and coil assemblies, all other

errors are less than one (< 1) units. Table 5 and Figure 5 report the Sx20 results.

Table 5: Sx20 Magnetic Measurement Average Values

Current [A]	$\int B3$ [T]	$\int c4$ [units]	$\int c5$ [units]	$\int c9$ [units]
50	594	5.23	0.87	4.04
70	829	5.21	0.89	4.04
90	1055	5.09	0.93	4.05
100	1160	4.86	0.94	4.05

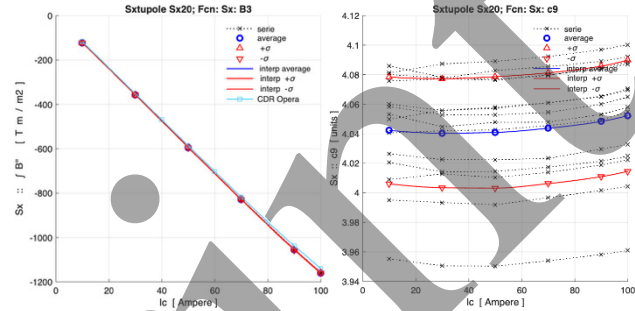


Figure 5: Sx20 magnetic measurement average values.

Since sextupole magnets have additional coils for the embedded vertical correction (CV) and horizontal correction or skew quadrupole (CH or Qs) functions, particular attention has been paid to measuring the magnetic center when these functions overlap with the sextupole field. In particular, the Qs function will be used to perform the beam base alignment (BBA).

Figure 6 shows that the average transverse displacement (X, Y) of the magnetic center is less than $3 \mu\text{m}$ across the entire current range.

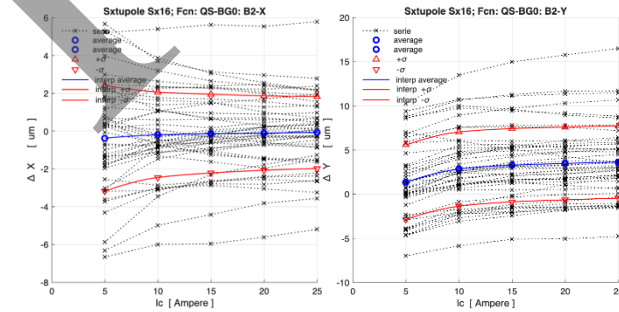


Figure 6: Sx16 Qs magnetic centre results.

DIPOLES

The measurements of the dipolar magnets carried out to date have been intended to verify the mechanical construction of the pole head profiles. Post-processing of the field mapping made it possible to assess the correlations between the magnetic errors b3 and b4 and the profile machining errors and allowed for a slight relaxation of the tolerances on the quadrupole sector poles.

During the post-processing of the field mappings, once the optimal trajectory has been calculated, the multipolar components (primarily the quadrupole component) are calculated along this trajectory (s path). The mappings are

repeated tuning the main and trim currents until the required specifications ($\int B_1 ds$ and $\int B_2 ds$) are achieved.

Figure below show the results obtained from mapping the bending fields of B80 SN.03 and B64 SN.02.

Figure 7 shows the B80 measured B_y map and the calculated trajectory, whilst Figure 8 illustrates the distribution of B_y and B_2 along that trajectory.

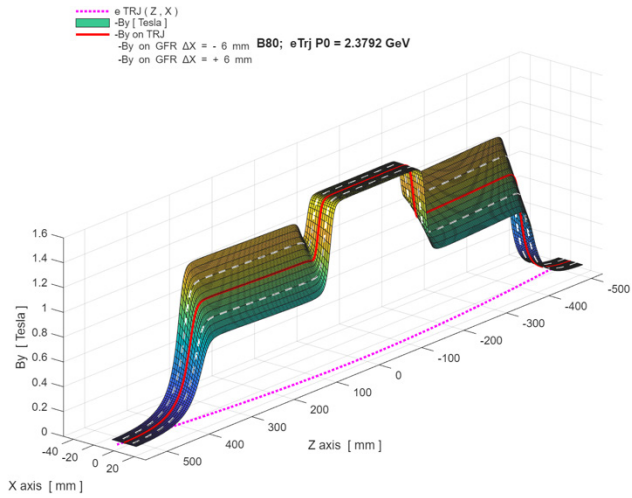


Figure 7: B80 SN.03 B_y map.

The next phase will involve measuring the dipoles in the layout configurations, i.e. with the sextupoles at their ends, in order to calibrate the cross-talk effects. Once this has been done, the series magnets will be measured for calibration and fiducialization so that they can be correctly aligned within the ring. As regards the B64 SN.02, Figure 10 shows the measured B_y map, whilst Figure 11 shows the distributions of B_y and B_2 in a similar way to B80.

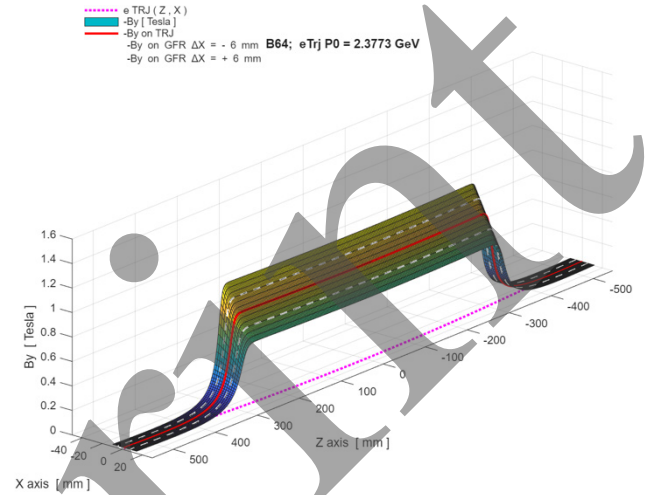


Figure 10: B64 SN.02 B_y map.

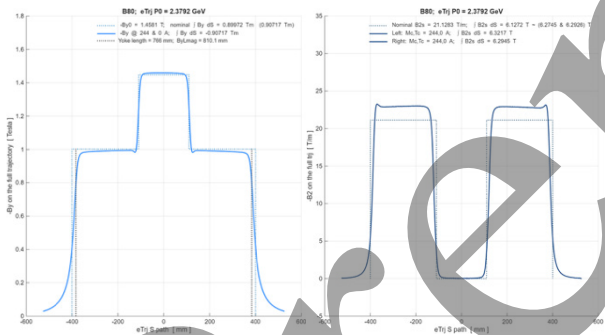


Figure 8: B80 SN.03 B_y and B_2 along the path.

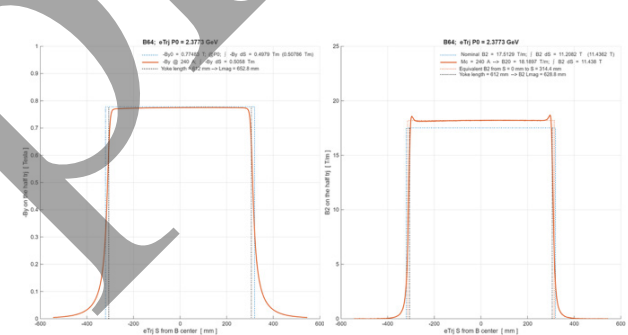


Figure 11: B64 SN.02 B_y and B_2 along the path.

Figure 9 show the B80 B3 and B4.

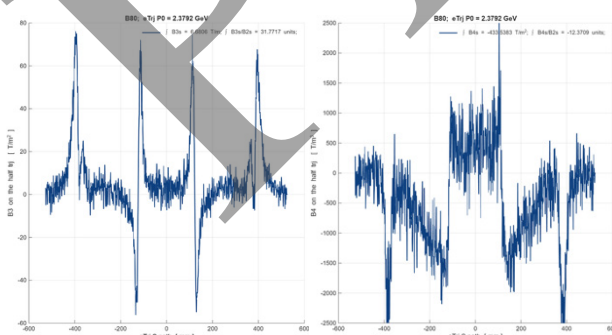


Figure 9: B80 SN.03 B_3 and B_4 along the path.

CONCLUSION

The magnetic measurement outcomes for the series magnet confirmed the design robustness and quality achieved by means of the performed optimisations and, at the same time, the high quality of manufacture by the companies involved, as well as the reliability of the measurement systems developed at Elettra [3].

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