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THE NEW ELETTRA 2.0 MAGNETS

D. Castronovo, D. Caiazza, I. Cudin , A.Gubertini, E. Karantzoulis, D. Rainone,
Elettra Sincrotrone Trieste, 34149 Basovizza, Italy

Abstract

The Elettra 2.0 upgrade project [1] requires the realization of a new storage ring that will replace the existing one. The Elettra 2.0 optic, developed on the basis of the magnet feasibility studies, include a total of 552 iron-dominated electro magnets, with all sextupoles and octupoles equipped with additional coils to achieve the combined fields of corrector and skew quadrupoles. This paper reports all the latest magnetic and pre-engineered designs.

MAGNET LAYOUT

The magnet layout of Elettra 2.0 consists of a total number of magnets which can be summarized as show in Table 1.

Table 1: Elettra 2.0 Magnets List

Type	Family name	Totals
Dipole	B64, B80	24, 48
Quadrupole	Q13, Q24, Q24RB	24, 48, 96
Sextupole	Sx12, Sx16, Sx20	60, 132, 48
Octupole	Oc14	48
Corrector	CHV	24
Fast Corrector	FCHV	72

The above-mentioned layout has for four (4) girders for each semi-achromat between which the respective three (3) dipoles are independently supported. The challenge related to the very short drift space between the magnets has been solved by employing a novel kind of longitudinally extended pole tips on the quadrupole and dipoles, which for this reason must be made of solid iron and without letting the coils protrude. Differently, sextupole and octupole yokes are made of laminated iron in order to minimize the effect of the eddy currents induced by the operation of the embedded correctors.

DIPOLES

The Elettra 2.0 lattice requires, for each half-achromat, one (1) dipole B64 and two (2) dipoles B80. The dipole B80 has three (3) sectors along the particle path (BQ, B and BQ). The central sector (B) has a constant field. The other two (BQ) have a transversal quadrupole gradient. Since the BQ sectors required a gradient of medium intensity (20.8 T/m), the magnetic potential can be realized by modelling the two polar profiles. Solutions with four quadrants, similar to that of the ESRF dipole [2] are not necessary. Since the realisation of the longitudinally extended pole tips implies the use of only one main coil for all three sectors, the aperture radius R of the hyperbolic profile of the BQ sectors must be tuned to obtain the required quadrupole strength and beam rigidity, as show in Eq. (1), where: α1, Lm and gap are, respectively angle, magnetic length and gap of the sector B; k is the strength of the sector BQ and η is the efficiency due to iron non-linearity and field dispersion.

$$R = \sqrt{\frac{\alpha 1 * gap}{\eta * L_m * k}} \quad (1)$$

In order to be able to tune the BQ quadrupole strength while maintaining the nominal path geometry, the central B sectors are filled with additional trim coils.

Differently, B64 has a single BQ sector and its opening radius has been minimised with the only constraint being that it can accommodate the relevant vacuum chamber.

Table 2: Dipoles Main Parameters

Parameter	B80	B64	unit
Iron	solid	solid	type
Overall length	770	630	mm
Pole length	750	600	mm
Magnetic length 2.4 GeV	799	642	mm
Nominal current 2.4 GeV	246	241	A
Nominal power 2.4 GeV	1.9	0.87	kW
Coolant total flow	3.4	3.1	l/min
Nom. Temp. rise 2.4 GeV	8.1	4.0	°C

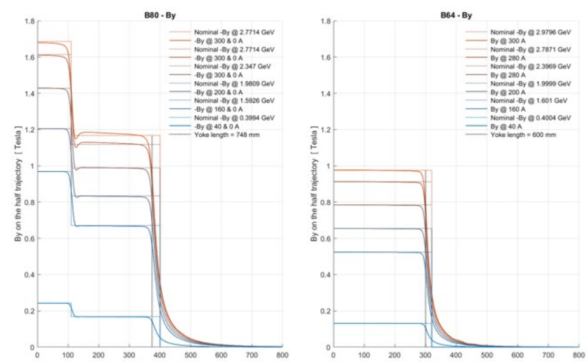

Figure 1: B80 and B64 By field on half trajectory

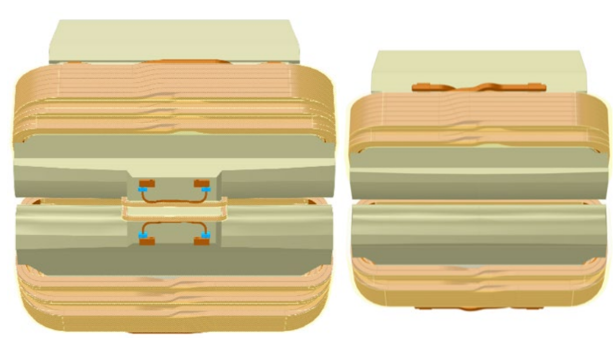

Figure 2: B80 and B64 models

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Table 2 lists the B80 and B64 main parameters while Figure 1 and Figure 2 show the field distributions for several main current values and the pre-engineered models.

QUADRUPOLES

Quadrupoles were the first Elettra 2.0 magnets to be developed [3]. Initially air-cooled, the latest models are water-cooled and have the magnetic yoke separated into two parts by non-magnetic spacers, in some case shaped, to resolve interference with the light exits. The novel type of longitudinal extensions, introduced to solve the issue of insufficient inter-spaces between the magnets, also improved performance by lowering the saturation of the pole tips.

In most cases, quadrupoles are also reverse bending ($Q24_{RB}$); for these magnets, the dipolar component is obtained by a simple transversal offset of about 6 mm and the aperture is bigger than the normal ones (30 mm vs 26 mm) in order to accommodate the vacuum chamber [4], which in the girders' sections always has the same transversal geometry centred on the nominal path. Table 3 lists the quadrupole main parameters while Figure 3 shows the pre-engineered models.

Table 3: Quadrupoles Main Parameters

Parameter	Q13	Q24	$Q24_{RB}$	unit
Iron	solid	solid	solid	type
Overall length	130	240	240	mm
Pole length	90	222	222	mm
Aperture Dia	26	26	30	mm
Mag. length	105.5	240.9	241.4	mm
Max. current	100	100	100	A
Max. B2	38.5	62.3	49.3	T/m
Max. power	303	934	934	W
H_2O tot. flow	0.76	1.53	1.53	l/min
Maximum ΔT	5.7	8.8	8.8	°C

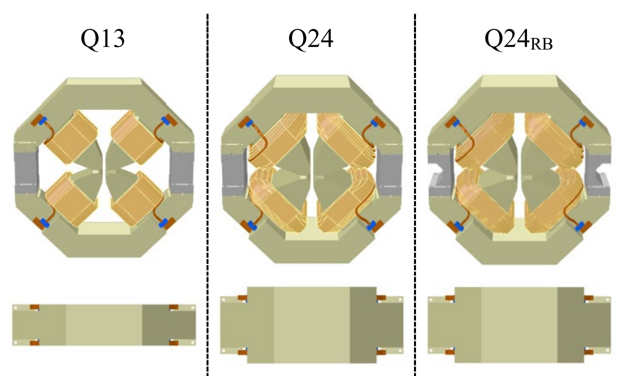

Figure 3: Q13, Q24, Q24 and $Q24_{RB}$ models

SEXTUPOLES

While in the first development also the sextupoles had poles longitudinally extended and magnetic yoke made of separated parts, the need to integrate correctors led to a standard design with laminated iron. With reference to the issue of very short drifts between the magnets, it must be emphasised that this choice was possible thanks to the quadrupoles having overall length equal to or less than their magnetic length. Similar to the quadrupoles, interference with the light exits was resolved with shaped versions (Sx16s and Sx20s). The Sx12 and sx16 families, equipped with 12 additional coils (2 for each pole), can therefore provide the functions of a vertical corrector (SxCV) and, according to the electrical connection, horizontal corrector (SxCH) or skew quadrupole (SxQs).

Table 4: Sextupole Main Parameters

Parameter	Sx12	Sx16/s	Sx20/s	unit
Iron		laminated		type
Overall length	170	210	230	mm
Pole length	110	150	190	mm
Aperture Dia	30	30	30	mm
Mag. length	120.5	160.0	200.0	mm
Max. current	100	100	100	A
Max. B3	5583	5626	5707	T/m^2
Max. power	528	588	600	W
H_2O tot. flow	0.79	0.73	0.73	l/min
Maximum ΔT	9.2	11.7	12.0	°C

Table 4 lists the sextupole main parameters while Figure 4 shows the pre-engineered models. Table 5 lists the sextupole additional function parameters.

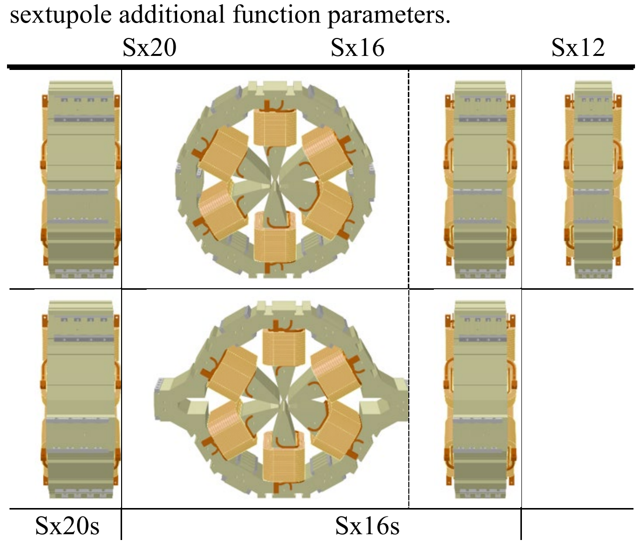

Figure 4: Sx12, Sx16, Sx16s, Sx20 and Sx20s models

Table 5: Sextupole additional function parameters

	Sx16/s		Sx20/s		
	CH	CV	CH	CV	
Parameter	sQ		sQ		Unit
Mag. length	158	156	197	196	mm
Max. Int. B1	62	36	79	45	Gm
Mag. length	128		168		mm
Max. Int B2	0.54		0.70		T

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OCTUPOLES

Similar to sextuples, the octupole family also has a complete laminated iron core with 8 additional coils (one for each pole) to provide horizontal and vertical corrector functions. It should be noted that this model has bigger aperture of 48 mm. This is due to the housing of the vacuum chamber whose cooling system requires a minimum gap between the poles of at least 8 mm. The opening must therefore be such as to have a pole width not less than the radius of the GFR. In order to minimise the number of magnets, in one of the two octupoles of each semi-achromat, the main coils will be used to produce a quadrupolar field and the secondary coils for the octupolar field. Table 6 lists the octupole main parameters while Figure 5 shows the pre-engineered models. Table 7 lists the octupole additional function parameters.

Table 6: Octupole Main Parameters

Parameter	Oc14	unit
Iron	laminated	type
Overall length	140	mm
Pole length	80	mm
Aperture Dia	48	mm
Mag. length	160.0	mm
Max. current	100	A
Maximum B4	174783	T/m^3
Maximum power	480	W
H_2O total flow	0.83	l/min
Maximum ΔT	8.0	°C

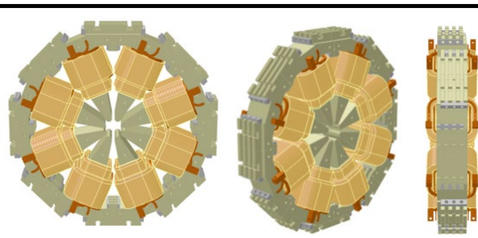

Figure 5: Oc14 model

Table 7: Octupole Additional Function Parameters

Parameter	CH or CV Q_{100A} / Oc_{20A}	unit
Magnetic length	140	mm
Maximum Int. B1	40	Gm
Magnetic length	110	mm
Maximum B2	10.73	T/m
Magnetic length	141	mm
Maximum B4	49938	T/m^3

CORRECTORS

Although not less important, the correction magnets were the last to be designed and are still in the development phase. The difficulties encountered were mainly due to the lack of space in the layout and the need to find and/or modify chamber sections in order to mitigate the eddy current effects. The correctors will be of two families: CHV and fast CHV. While the CHV could be considered as a downsizing of the Elettra 8th corrector [5], the fast corrector will be a simple set of coils installed around the input flanges of the bending chambers. The effect of the 316L flanges has been studied. The cut-off frequency of the fast correctors appears to be around 5 kHz. Further studies and prototyping will be carried out to verify these results.

CONCLUSION

This document merely lists the main parameters of the new Elettra 2.0 magnets. The results of the design will soon be verified [6] with the Q24, Sx16 and B80 prototypes now in their final stages at SEF Technologies. They are scheduled for delivery at the end of June 2023. In addition to this, as of today the first tender for the multipole magnets is completed and in the process of being signed with Danfysik. The tender for the dipoles, on the other hand, is in progress and the corresponding contract could be signed in early 2024.

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