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MAGNETS FOR ELETTRA 2.0

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Abstract

Community with excellent results, Elettra need a major upgrade with a new compact lattice that will replace the existing double bend achromat for the reduction of the horizontal emittance and the increase of the brilliance and coherence of the X-ray beam.

This paper reports the magnetic design development and optimisation carried out in order to satisfy the layout feasibility and magnet strengths.

LAYOUT

The design of new machine optics with the constraint of maintaining the current size of the ring has produced a layout with really short drifts between the magnetic lengths [1]. The design of magnets that can be installed so close to each other is therefore one of the most important challenges of the Elettra 2.0 magnetic layout. Figure 1 shows the half-achromat section of the magnetic layout where several quadrupoles have a transverse offset in order to fulfil the reverse bend function.

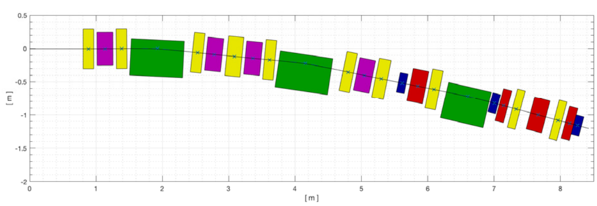

Figure 1: Elettra 2.0 achromat magnet layout.

NOVEL KIND OF MAGNET

Considering the fact that in the Elettra 2.0 magnetic layout the shortest drift among the various magnetic lengths is less than 50 mm, the first challenge was to design magnets with an overall length almost equal to the relative magnetic length ($L_{tot} \approx L_{mag}$). Since the iron-dominated electromagnets have, generally, the L_{tot} bigger than the L_{mag} due to the size of the coils around the pole terminations, the idea was to design a magnet with coils longitudinally inside the poles. Starting from mushroom-shaped terminations, the objective of obtaining a constant distribution of the field on the path has developed a combination between the shape of the pole ends and the reverse winding of the coils. Figure 2 illustrates the geometry of the pole and the coils thus obtained.

It should be noted that the longitudinal elongation of the poles terminations leads to mitigating one of the classic saturation effects on the pole profiles, improving the field quality in the range of use. The longitudinal distribution of the field within the roots of the poles requires yoke made of solid iron. This type of iron is also used to obtain higher mechanical precision as is generally required in small-aperture magnets such as those of Elettra 2.0. Figure 2 shows the yoke shape and the reverse coil winding.

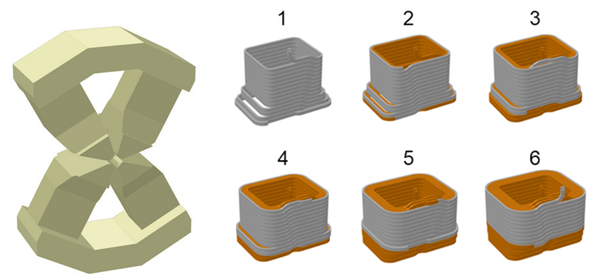

Figure 2: Quadrupole yoke and coil winding.

PROTOTYPE

The objective of the prototype is to prove the feasibility of this new novel kind of magnets. Other objectives are to study the possibility of having air-cooled coil and the study of dynamic supporting systems between the two separate parts in order to allow the optimization their intra-alignment by the magnetic measurements. As already done in other projects [2], also in this case the pole profile shimming was defined by geometric formulas with only four parameters. The used formulas has been the following:

$$y = \frac{R^2}{2x} - K_y \left(\frac{x - x_s}{x_t - x_s} \right)^N \tag{1}$$

Where:

$$K_y = \frac{R^2}{2x_t} - y_t \tag{2}$$

$$x_s = x_t + N \frac{K_y}{\tan\alpha + \frac{R^2}{2x_t}} \tag{3}$$

Figure 3 reports the pole profile parameters plot.

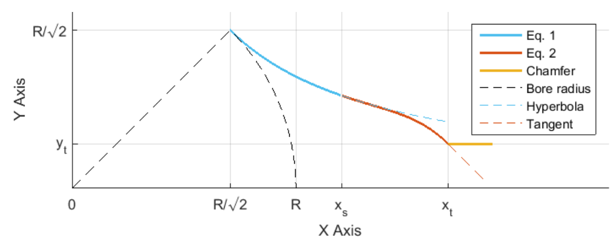

Figure 3: Pole profile equation and plot.

The optimization of the profiles was done using the Esteco MODEfrontier [3] optimization code, which, in turn, coordinated the VF Opera [4] Modeller, Tosca, Elektra and post-processor modules together with the special post-processing data via Matlab [5]. The MODEfrontier

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workflow is illustrated in Fig. 4. The prototype magnetic model is illustrated in Fig. 5 while Fig. 6 shows the longitudinal distribution of the calculated field.

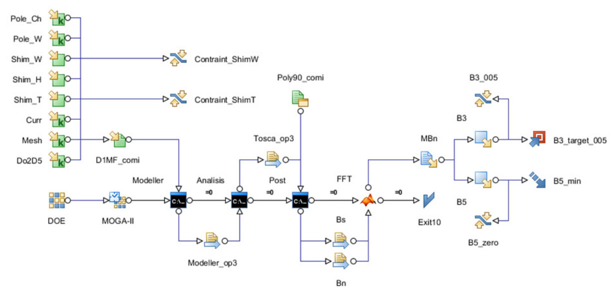

Figure 4: MODEfrontier workflow.

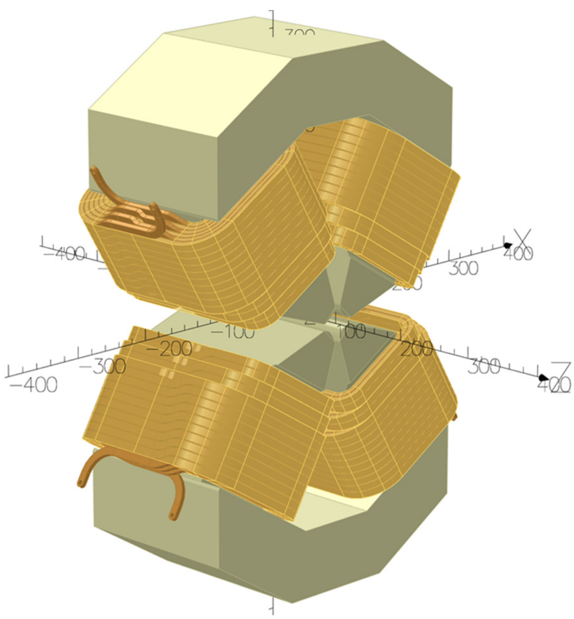

Figure 5: Prototype magnetic model.

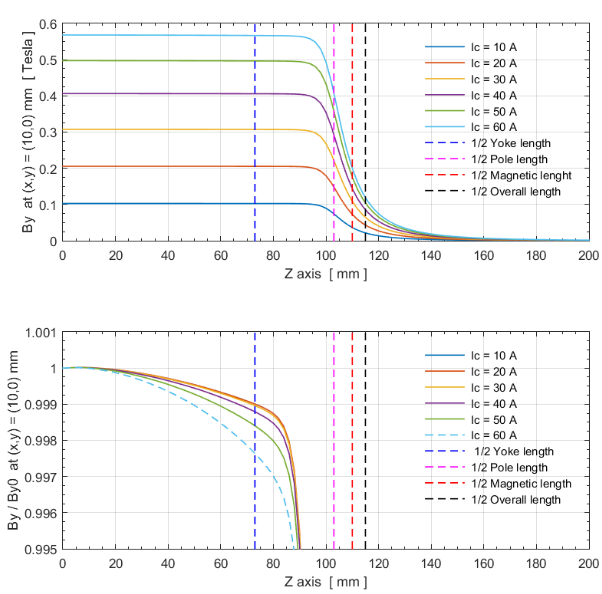

Figure 6: Prototype longitudinal field distributions.

The prototype calculated performances are listed in Table 1.

Table 1: Prototype Calculated Performances

Curr [A]	$\int G$ [T]	sat [%]	$\int G_6 / \int G_2$	$\int G_{10} / \int G_2$
60	12.4772	-8.05	-1.1566e-4	4.5820e-7
50	10.9291	-3.36	-7.8197e-5	2.6946e-6
45	9.9662	-2.08	-6.4622e-5	3.6177e-6
40	8.9355	-1.23	-5.4567e-5	4.3751e-6
30	6.7638	-0.32	-4.1808e-5	5.4433e-6
20	4.5217	-0.04	-3.7949e-5	5.7793e-6
10	2.2617	0.00	-3.7774e-5	5.7953e-6

The prototype will be realized by a scientific collaboration between CERN and Elettra by the end of 2019.

QUADRUPOLES

Starting from the development of the novel kind of magnets, the first magnets defined for Electra 2.0 were quadrupoles. Two families of quadrupoles based on the required magnetic length make it possible to cover all the quadrupoles defined in the Elettra 2.0 magnetic layout. Table 2 and Table 3 report the parameters of the required quadrupoles.

Table 2: Required Quadrupoles

Name	L_{mag} (m)	k	B1 (T/m)	Ø (mm)	$\lvert B_{pole}\rvert$ (T)
Q1	0.13	-2.840	-22.72	26	0.295
Q33a	0.13	-0.380	-3.04		0.040
Q2	0.24	5.490	43.82		0.571
Q33b	0.24	5.720	45.76		0.595

Table 3: Required Quadrupoles with Reverse Bend

Name	Lmag (m)	k	B1 (T/m)	Angle (°)	Ø (mm)	|Bpole| (T)
Q333a	0.24	5.180	41.44	0.4	26	0.539
Q4_1		5.490	43.92	0.4		0.571
Q333b		5.500	44.00	0.5		0.572
Q4		5.687	45.50	0.5		0.591

SEXTUPOLES

Similary to the quadrupoles, also the sextupoles have been developed to have a magnetic length equal to the total length. Also in this case, in order to maximize the gap on the external side for the light exits, the yoke is made with separate parts and asymmetrical pole roots. The optic sextupole specifications required the use of four families that are S23, S18, S16 and S12. Table 4 lists the parameters of the required sextupoles.

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Table 4: Required Sextupoles

Name	L_{mag} (m)	m	B2 (T/m^2)	Ø (mm)	$\|B_{pole}\|$ (T)
SD0	0.12	-146.7	-2347.2		0.300
SEXP	0.12	161.7	2587.2		0.331
SD_1L	0.16	-204.0	-3264.0		0.418
SF	0.16	209.4	3350.4		0.429
SDE_1	0.16	-210.3	-3364.8	32	0.431
SD_2	0.16	-213.1	-3409.6		0.436
SD_1	0.16	-249.1	3985.6		0.510
SFMS_L	0.18	286.6	4585.6		0.587
SFIS	0.23	203.4	3354.4		0.417

BENDINGS

The Elettra 2.0 optics uses bending that mix longitudinal and transversal gradient. The design of these magnets is under development with the task to achieve the required field distribution. In the previous versions the bends with transverse gradient were obtained with the shaping of the poles and appropriate shaping of the coils. Table 5 lists the parameters of the required bending.

Table 5: Required Bending

Name	Lmag (m)	B0 (T)	B1 (T/m)	Angle (°)
BF1	0.66	0.7616	-17.2	3.6
	0.29	0.9148	-22.4	1.9
BFSM	0.22	1.7771	0.0	2.8
	0.29	0.9148	-22.4	1.9

CORRECTORS

Almost all correctors must be combined in the sextupoles. The use of two or more power converter is under study in order to overcome the issue due to the separated yoke parts.

CONCLUSIONS

The magnetic layout needs to be validated by the prototyping of all the required magnets. In particular from the prototyping of the girder assemblies that will have the purpose to test the air-cooling system and the dynamic positioning of the combined quadrupoles. This activity will immediately follow the realization of the first quadrupole prototype.

REFERENCES

[1] E. Karantzoulis, A. Carniel, S. Krecic, “Elettra, Present and Future”, presented at the 10th Int. Particle Accelerator Conf. (IPAC'19), Melbourne, Australia, May 2019, paper TUPGW031, this conference.

[2] D. Castronovo, et all, “ESS Magnets at Elettra Sincrotrone Trieste”, presented at the 10th Int. Particle Accelerator Conf. (IPAC'19), Melbourne, Australia, May 2019, paper THPTS020, this conference.

[3] Esteco, `https://www.esteco.com`

[4] Opera, `https://operafea.com`

[5] Mathworks, `https://www.mathworks.com`