FERMI@Elettra MAGNETS*

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ABSTRACT

FERMI@Elettra is a single-pass FEL user-facility located next to the third generation synchrotron radiation facility ELETTRA in Trieste, Italy [1, 2]. The linear accelerator contains more than 200 electromagnets. This paper reports on their design, construction, magnetic measurement and installation.

INTRODUCTION

All the magnets were designed by the Elettra Team [3] and built by SigmaPhi (France), except for the bunch compressors (BC01 and BC02) bending magnets built by Tesla (UK). The air-dominated correctors were developed and built in house. All the magnets design was based on the internal FERMI Physics Requirements Documents (FPRD) [4, 5, 6, 7]. Some FPRDs and machine layout specifications had to be developed in parallel to the magnet design in order to make them feasible and to reduce costs and electrical power consumption. An important result was having the major part of the magnets powered by bipolar low current power supplies - 5A and 20A - both developed at home.

DIPOLES

The designed dipoles magnets (Tab. 1) are installed in the following sections: Spectrometers, Laser Heater (LH), BC01 and BC02, Beam Transport (Spreaders) and Delay Line sections [1]. For the Diagnostic and the Main Beam Dump sections old magnets, already present at Elettra, have been reused.

Spectrometers

Three spectrometer lines are present in the machine layout; two of them (Injection Gun and BC01) have dipoles magnets expressly developed for this application.

The Injection Gun spectrometer (SPINJ) dipole is positioned on a precision movable slide in order to have the possibility to move the magnet off the beam trajectory, thus removing any residual field effect on the electron beam. Since the available space did not allow the optimization of its length and gap (Fig. 1), in order to obtain the specified field homogeneity along the real beam trajectory, a particular pole shape was developed (Fig. 1), with a well-defined quadrupole component along the longitudinal axis of the magnet.

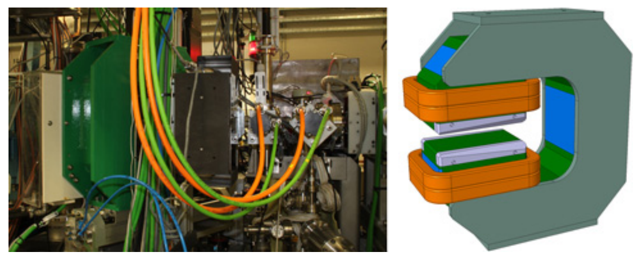

Figure 1: FERMI@Elettra Gun and SPINJ Dipole

Laser Heater

The LH section consists on a chicane with a close bump of 30.5 mm, realized by means of four dipoles. These magnets (Fig. 2) are powered in series and the closure of the bump is guaranteed only by magnet sorting and positioning which calculation was based on the magnetic measurements results. No trim coils system was needed.

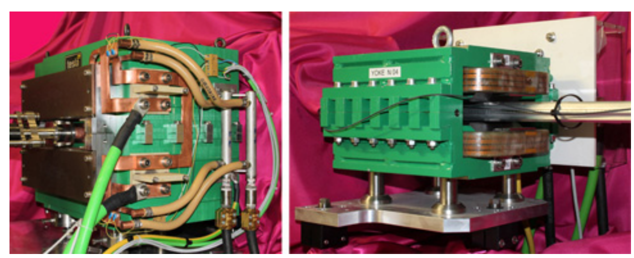

Figure 2: BC02 and LH dipoles.

Table 1: Dipoles Data

Parameters (#) Measured mean value		Unit	SPINJ	LH	BC01	SPBC01	BC02	Spreader	Delay
Nominal energy	E_0	MeV	5	100	350	350	800	1500	1500
Bending Angle	phi	deg	60	3.5	0 to 7	25	0 to 4.8	3.5	0 to 2.2
Yoke length	L_{Yoke}	m	0.140	0.194	0.340	0.800	0.340	0.350	0.176
Pole minimum gap	H	mm	42	24	32	32	32	26	32
Max current	I_{max}	A	100	101.5	350	500	330	500	500
Reference field# at I_{max}	B_0	T	0.1408	0.1251	0.6416	0.9196	0.6095	0.8584	1.0555
Integrated field# at I_{max}	BL	Tm	0.0262	0.0192	0.2353	0.7524	0.2233	0.3183	0.1925
Good field region	R	mm	20	25	20	15	20	15	20
$\|\Delta BL/BL\|^{\#}$ on range ±R	Δ	#	< 1.9E-3	< 2.1E-3	< 9.0E-5	< 1.5E-4	< 1.1E-4	< 2.5E-4	< 2.1E-3

* This work was supported in part by the Italian Ministry of University and Research under grants FIRB-RBAP045JF2 and FIRB-RBAP06AWK3

Table 2: Quadrupoles Data (where Cn = quadratic sum of the normal and skew error components)

Parameters (#) Measured mean value		Unit	SPINJ	Q0T4	Q0T8	SPBC01	Q7T7	Q7T7s	Q2T1
Number of magnets	Tot	#	1	26	12	2	46	5	26
Yoke length	L_{Yoke}	m	80	50	72	170	270	270	150
Bore diameter	∅	mm	72	32	32	80	26	26	28
Max current	I_{max}	A	100	5	20	100	20	100	20
Turns per pole	N	#	12	108	44	45	96	21	52
Integrated grad# at I_{max}	IntG	T	0.2635	0.3521	0.7707	1.519	8.1602	9.0527	2.2174
Good field region	R	mm	20	13	13	30	10	10	10
$\sum Cn^{\#}_{(n=2 \text{ to } 9)}$ at R & I_{max}	$\sum C_n$	%	< 0.1	< 0.37	< 0.4	< 0.15	< 0.32	< 0.30	< 0.13

Table 3: Correctors data

Parameters (#) Measured mean value		Unit	INJ1	INJ2	LH	12Gm	60Gm	6Gm
Number of magnets	Tot	#	1	1	2	14	37	26
Type		~	Air	Air	Air	Air	Iron	Air
Overall length	L	M	80	86	82	200	182	124
Minimum gap	H	Mm	60	32	26	26	26	26
Max current	I_{max}	A	5	5	5	5	20	5
Total turns of the horizontal	NH	#	128	144	240	400	192	280
Total turns of the vertical	NV	#		96	144	272		216
Reference field By# at I_{max}	B_y	G	11.77	34.3	37.9	130.3	895.2	123.2
Reference field Bx# at I_{max}	B_x	G		22.7	25.6	62.5		68.5
Integrated field By# at I_{max}	B_yL	Gm	0.82	1.21	1.88	13.22	62.02	5.96
Integrated field Bx# at I_{max}	B_xL	Gm		1.23	1.91	12.72		5.86

Bunch Compressors

To optimize costs and time, the Linac accelerator machine has two identical (mechanical and magnetic structures) bunch compressors. The field homogeneity along the different real electron beam trajectories was obtained by the optimization of the pole width and the field clamps dimensions. This optimization included the study of the fringe field on a wide region (±80mm). Each magnet (Fig. 2) is provided by trim coils and their calibration has been performed in order to minimize the deflection angle and the offset at the chicane output. The main and trim coils calibrations were computed for several angles by means of a particles tracking script in Matlab [8] based on the measured maps of the magnetic fields.

Spreader

Six dipole magnets, arranged in three pairs, are installed in the Spreader section that delivers the electron beam to FEL01 and FEL02. They are powered with the same current value and the nominal trajectory requirements are met only by sorting the three pairs (without the use of trim coils).

Delay Line

The FEL02 delay line consists on a chicane realized by four dipoles. The overall section length is less than 1.5 m and the distance between the dipoles yokes is shorter than the fringe field extension. In order to minimize the effect caused by the fringe fields overlapping, each magnet has been equipped by field clamps placed around the coils. The field homogeneity has been guaranteed minimizing the poles saturation by mean of a pseudo Rogowski profile on both (longitudinal and transversal) directions.

QUADRUPOLES

At the beginning, FPRD and layout requirements called for a lot of different types of quadrupole; many efforts have been dedicated to reduce the total number of the families (Tab. 2). Additional effort was also dedicated to optimize the yokes dimensions (overall length and bore diameter) and to limit the maximum excitation currents to only two values: 5A and 20A.

In order to meet the requirements and speed up the design, an empirical formula was appositely developed to define the pole shimming profile:

$$y = \sqrt{x^2 + R^2} - k \cdot \left(\frac{x - x_0}{w/2 - x_0} \right)^n$$

$$x_0 = \frac{w}{2} + \frac{n \cdot k}{\tan(\alpha) - 1/\sqrt{1 + (R/w)^2}}$$

where:
$x_0 \le x \le w/2$
n = order (≥ 2)
R = bore radius [mm]
w = pole profile width [mm]
k = shimming thickness [mm]
α = shimming tangent angle [rad]

These parameters and the pole chamfers were optimized (Fig. 3) using the following software packages: Tosca [8], Matlab [9] and modeFRONTIER [10]. All the calculations were compared to the magnetic measurements with a good agreement.

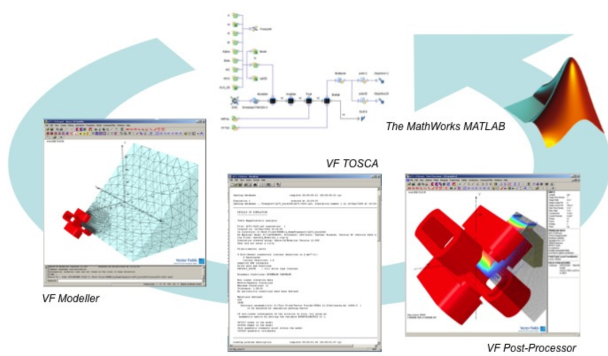

Figure 3: Pole profile optimization flow chart.

Linac, Tranfer Line and FELs

Four families, named Q0T4, Q2T1, Q7T7 and Q0T8 (Fig. 4), satisfy all the machine requirements, except for the Spectrometers and the Spreader, where specials quadrupole have been developed.

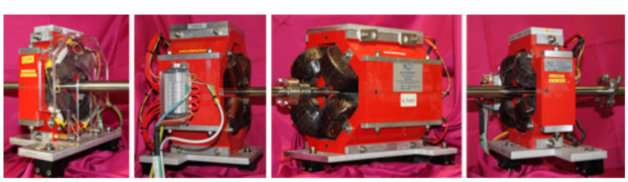

Figure 4: Q0T4, Q2T1, Q7T7 and Q0T8 quadrupoles.

Gun and BC01 Spectrometers

Tight constraints (optics and layout) were present in Gun spectrometer section [5], which called for a quadrupole design with integrated horizontal and vertical correctors. This magnet has a particular geometry with the corrector coils placed on each back leg.

The optics requirements of the BC01 spectrometer [4] called for a more powerful magnet. For this section two quadrupoles have been designed and installed.

Spreader

This region calls for a modified version of the Q7T7 family equipped with a compact coils (Q7T7s) with less turns and, consequently, higher maximum current (see Tab. 2). Therefore the coils have been cooled by water.

CORRECTORS

Air-dominated

They are made up by two pairs of coils (horizontal and vertical oriented) made by a suitable conductor wounded around special Delrin® supports, which are then assembled around the vacuum chamber (Fig. 5). The accuracy of the winding gave a very good agreement (Tab. 3) between the simulations and magnetic measurement results (< 0.5 Gauss at max field).

Iron-dominated

The iron-dominated correctors are realized integrating the horizontal and the vertical correctors into a single assembly (Tab. 3). The two dipoles have the same yoke around the poles with a longitudinal drift between them. This drift has been necessary to minimize the sextupole component and to reduce as much as possible the gap between the coils pairs. A particular arrangement allowed designing only one quarter of the yoke, which has been then replicated in the construction (Fig 5).

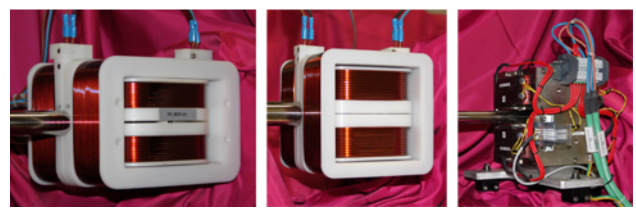

Figure 5: Air and iron dominated correctors.

SPECIALS

Dispersion Lines Magnet

FERMI@Elettra has three dispersion lines in total, with different physics requirements [6, 7]. To reduce costs and time, only one magnet has been developed. This magnet has a three dipoles structure (a short wiggler) with three main and trim coils pairs that can be vertically tuned in order to optimize the field integrals errors.

REFERENCES

[1] C.J. Bocchetta et al., “FERMI@Elettra Conceptual Design Report”, Sincrotrone Trieste, Italy, Tech. Rep. ST/F-TN-07/12, 2007.
[2] D.Zangrando et al., Status Report on FERMI@Elettra Project, this conference, San Sebastian, Spain.
[3] R. Fabris and D. Castronovo, internal notes (i.n.) FESD 34, 37 to 41, 47 (2008)
[4] S. Di Mitri, i.n. FPRD 14 to 23, 48, 55 to 57 (2008)
[5] G. Penco, i.n. FPRD 34 (2008).
[6] G. De Ninno, i.n. FPRD 55 (2009).
[7] G. De Ninno and E. Allaria, i.n. FPRD 62, 63 (2009).
[8] Cobham Technical Services, Vector Fields Software.
[9] The MathWorks, Inc.
[10] ESTECO s.r.l. www.esteco.com