THE ELETTRA BOOSTER MAGNETS

D. Zangrando, D. Castronovo, M. Svandrlik and R.Visintini
Sincrotrone Trieste, s.s.14, km 163.5, 34012 Trieste, Italy

Abstract

The third generation synchrotron light source ELETTRA has been in operation since 1993. A new 2.5 GeV full energy booster injector, which will replace the existing linear injector limited to a maximum energy of 1.2 GeV is now under construction. Commissioning will start this summer [1]. The paper reports on the construction of dipole, quadrupole, sextupole and steerer magnets and on the magnetic measurement results.

INTRODUCTION

The new injector for the ELETTRA storage ring will contain 28 dipoles, 36 quadrupole (18 QD + 18 QF) magnets in two families of different lengths, 24 (12 SF + 12 SD) sextupole magnets, 10 horizontal and 12 vertical steerers [1,2]. The design parameters are shown in [2]. Additional 8 QD magnets were constructed to be used in the 100 MeV pre-injector to booster transfer line. All the magnets have now been constructed: the dipoles, quadrupoles and sextupoles by Danfysik, Denmark, the steerer magnets by Tesla Engineering, England. This report presents the definitive results of the magnetic performances of all the series production. The manufacturers were responsible for the mechanical, magnetic, hydraulic and electric tests, specified by Sincrotrone Trieste. These tests were carried out at the manufacturer's premises. Additional acceptance tests of all received magnets were performed at Sincrotrone Trieste

The contract with Danfysik (Tesla Engineering) was placed in July (August) 2005. The initial contractual delivery time for dipoles, quadrupoles and sextupoles series magnets was foreseen for December 2006. The magnetic measurements of the prototype magnets (dipoles, quadrupoles and sextupoles) were completed by December of last year and the delivery of the series magnets started from January and continued up to May of this year. The horizontal and vertical steerer prototype magnets were approved in November 2006, and the delivery of the series magnets was completed by January 2007. The contractual delivery time, initially agreed, was November 2006. Part of the delay of all magnets was due to the unexpected long time requested for the iron delivery (more than 5 months).

DIPOLE MAGNETS

A dipole magnet during the installation of the vacuum chamber is shown in figure 1. Table 1 shows the main dipole parameters and the results of the electric and hydraulic tests. The design parameters are reported in [2]. The maximum current available from the power supply is 800 A, however the current requested at maximum electron booster energy (2.5 GeV) is about 690 A.

All the used magnetic measurement equipments were developed by Danfysik. On the prototype magnet, complete Hall plate step by step scans along the nominal electron trajectory and at different transverse positions (x = 0, ± 5 mm, ± 10 mm, ± 20 mm) and currents, were carried out. The typical Hall plate positioning accuracy was 0.1 mm rms. A long (integrating) coil, calibrated with the Hall plate data, was used for the magnetic measurements of both prototype and series magnets. It was used to measure both the integrated magnetic field of the nominal trajectory and along parallel trajectories (at x = 0, ± 5 mm, ± 10 mm, ± 20 mm). The central magnetic field has also been measured, at 24 different currents.

Figure 1: Dipole during vacuum chamber installation

Table 1: Booster Dipoles

Cross section	H-type	
Meas.Mag. length (prototype) at 2.4GeV	2.001	m
Curvature angle	12.86	deg
Gap height	22	mm
Max. freq. of operation	3	Hz
B at injection (0.1GeV at I = 28A)	0.037	T
B at extraction (2.5GeV at I = 690A)	0.936	T
Number of turns (total)	24	
Measured single coil resist, (at 20°C)	~7.4	mΩ
Coils in series inductance (at 3Hz)	~8.4	mH
Single coil inductance (at 3Hz)	~2.3	mH
Measured magnet pressure drop	3.5	bar
Measured cooling water flow rate	10	l/min
Cooling water temp. rise (at 690A, DC)	10	°C

Table 2 shows the magnetic measurement results carried out on the series magnets at 4 different energies. The field integrals were fitted with a third order polynomial to determine the multipole field components defined as follow:

$$\int B\,dl = I_{yo}+I_{y1}\,x + I_{y2}\,x^2 + I_{y3}\,x^2$$

The maximum specified peak-peak field integral variation was 0.2%. The maximum measured variation was 0.052% rms at 0.1 GeV (see table 2). The measured field integral homogeneity was very good (see table 2) and well within tolerance (specification ± 0.15% at r = 20 mm). Also the measured magnetic length (2.000 m at 2.5 GeV) is very close to the nominal value and the variation with the energy is acceptable (4 mm). The saturation level at maximum energy is within 1%.

Table 2: Results of the integrated field measurements (integrated coil) for the dipole series magnets

Dipole field comp. at x = 20 mm [%] except (*) [T·m]				
	Syst.	Rand.	Syst.	Rand.
	Ic = 27.6A (0.1 GeV)		Ic = 258.8A (1.0 GeV)	
Iy_0	0,077*	0,052	0,756*	0,025
$Iy_1 \cdot x$	0,021	0,007	0,027	0,003
$Iy_2 \cdot x^2$	-0,022	0,005	-0,024	0,003
$Iy_3 \cdot x^3$	0,003	0,008	0,004	0,003
	Ic = 551.7 (2.0 GeV)		Ic = 689.6A (2.5 GeV)	
Iy_0	1,504*	0,029	1,873*	0,033
$Iy_1 \cdot x$	0,028	0,003	0,026	0,003
$Iy_2 \cdot x^2$	-0,026	0,003	-0,029	0,003
$Iy_3 \cdot x^3$	0,005	0,003	0,004	0,003

QUADRUPOLE MAGNETS

The main (measured) parameters of the focussing (QF) and defocusing (QD) quadrupole magnets are shown in table 3. The design parameters are described in [2]. A QF quadrupole magnet, mounted on its girder and ready for the installation, is shown in figure 2.

Table 3: Booster Quadrupoles

	QD	QF	
Bore radius	28	28	mm
Magnetic length (at 370A, QF and 362 A, QD)	0.275	0.171	mm
Current at max. gradient (20T/m)	370	370	A
Number of turns (per pole)	20	20	#
Magnet resistance (at 40°C)	17	13	mΩ
Magnet inductance (at 3Hz)	3.6	2.3	mH
Magnet pressure drop	6	5	bar
Cooling water flow rate	2	1.6	l/min
Cooling water temperature rise (at 370A, DC)	18	15	°C

The maximum current available from the power converters is for both magnet QD and QF families 400 A. The specified integrated strengths (for the QF: 5.222 T and for the QD, 3.316 T) are obtained with a current of about 348 A (QF) and 357 A (QD), at which level the saturation is respectively about 2% (3%).

The field integral distribution is 0.11% (0.16%) rms for QF (QD) series magnets. They didn't meet the specified tolerances (0.1% peak-peak) so the positioning in the booster had to follow the result of a sorting analysis [3]. In this case they could be accepted [3]. Table 4 and 5 summarize the variation of the main and the multipole components at 3 different currents for each type of series magnet. Both systematic (average) and random (rms) parts are given, separately for normal and skew components. All the measured multipole components are small and within the specified tolerances (0.08% at r = 20 mm).

Table 4: Rotating coil measurement results for QF series magnets

	Ic = 74A		Ic = 222A		Ic = 370A	
QF Normal Components at r = 20 mm [%]						
N	Syst.	Rand.	Syst.	Rand.	Syst.	Rand.
3	0.000	0,009	0,000	0,011	0,005	0,013
4	0,011	0,013	0,009	0,013	0,010	0,013
5	0,000	0,002	0,000	0,002	0,000	0,003
6	0,014	0,002	0,012	0,002	0,005	0,002
10	-0,002	0,000	-0,002	0,000	-0,002	0,000
QF Skew Components at r = 20 mm [%]						
N	Syst.	Rand.	Syst.	Rand.	Syst.	Rand.
3	0,008	0,014	0,002	0,013	0,004	0,014
4	0,005	0,004	0,004	0,004	0,003	0,004
5	0,002	0,002	0,000	0,002	0,000	0,002
6	0,002	0,001	0,001	0,001	0,000	0,001
10	0,001	0,000	0,000	0,000	0,000	0,000

Table 5: Rotating coil measurement results for QD series magnets

	Ic = 72A		Ic = 216A		Ic = 362A	
QD Normal Components at r = 20 mm [%]						
N	Syst.	Rand.	Syst.	Rand.	Syst.	Rand.
3	-0,002	0,008	-0,001	0,009	0,000	0,010
4	-0,006	0,012	-0,007	0,012	-0,006	0,012
5	0,000	0,002	0,000	0,002	0,000	0,002
6	0,021	0,002	0,018	0,002	0,008	0,002
10	-0,005	0,000	-0,005	0,000	-0,005	0,000
QD Skew Components at r = 20 mm [%]						
N	Syst.	Rand.	Syst.	Rand.	Syst.	Rand.
3	0,007	0,010	0,007	0,008	0,002	0,010
4	0,006	0,006	0,004	0,005	0,003	0,004
5	0,002	0,003	0,001	0,002	0,000	0,002
6	0,003	0,002	0,001	0,001	0,001	0,001
10	0,001	0,001	0,000	0,000	0,000	0,000

SEXTUPOLE MAGNETS

The 24 sextupole magnets will be connected in two families, focussing and defocusing. The design parameters are described in [2]. The sextupole magnet is shown in figure 2. Due to the optics requirements, they will be powered by two bipolar power converters with an available maximum current of ± 70 A.

Table 6 summarizes the main measured parameters for the sextupoles magnets. The specified integrated strengths

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of 15 T/m ($0.5 \cdot d^2I/dx^2$) is obtained with a current of about 60 A. Table 7 summarizes the measurement results, referred to a radius of 20 mm.

The measured integrated strength distribution of 0.09% rms for the series magnets is within the specified tolerances (0.3% peak-peak variation). Also each multipole measured components (see table 7) is well within the specified tolerances (the specification was 0.6% at r = 20 mm, for each high order field integral multipole component).

Table 6: Booster Sextupoles

Bore radius	30	mm
Magnetic length (calculated at 60A)	0.098	m
Nominal strength ($0.5 \cdot d^2B/dx^2$)	150	T/m^2
Number of turns (per pole)	18	
Magnet resistance (measured at 40°C)	~36	mΩ
Magnet inductance (measured at 3Hz)	~3	mH

Table 7: Results of the rotating coil measurements for Sextupole series magnets

	Ic = 16A		Ic = 36A		Ic = 60A	
SS Normal Components at r = 20 mm [%]						
N	Syst.	Rand.	Syst.	Rand.	Syst.	Rand.
4	0,006	0,016	0,001	0,016	-0,002	0,016
5	0,008	0,010	0,006	0,007	0,005	0,006
6	-0,017	0,002	-0,018	0,003	-0,018	0,003
10	0,000	0,001	0,000	0,001	0,000	0,000
SS Skew Components at r = 20 mm [%]						
N	Syst.	Rand.	Syst.	Rand.	Syst.	Rand.
4	-0,036	0,022	-0,037	0,020	-0,035	0,020
5	0,010	0,010	0,005	0,004	0,003	0,005
6	-0,006	0,007	-0,009	0,003	-0,011	0,004
10	0,001	0,003	0,000	0,001	0,000	0,001

STEERER MAGNETS

The steerer magnets designed for the new injector have air-cooled coils, with a maximum operational current of 16 A in DC mode. Four additional horizontal steerer magnets powered by adequate power supplies will be used as bumper magnets to extract the electron beam from the booster. A horizontal magnet is visible in figure 2.

Table 8 summarizes the main measured electrical parameters. The magnetic measurements, carried out by Tesla Engineering, were done by moving manually in the horizontal midplane a calibrated Hall plate. For the two prototypes (horizontal and vertical), the longitudinal scans were carried out at x ± 5 mm, ± 10 mm, ± 20 mm. For the series magnets, only the central scan was performed.

The measured transverse field integral variation for the horizontal (vertical) steerer was less than 1% (2.7%) at x = 20 mm and within specification (6%). It didn't not appreciable change with excitation level. The horizontal (vertical) field integral distribution for the series magnets was 5% (0.44%) rms, at 8 A. For each type of magnet, we specified 2% peak-peak.

The saturation level for the horizontal (vertical) steerer at nominal specified field integral of 125 Gm (68 Gm) is 5.5 % (2.5%).

Table 8: Horizontal and Vertical Steerers

	STH	STV	
Gap	22	52	mm
Nominal integrated field	125	68	G·m
Current for Nom.Int..Field	12.5	14.0	A
Integrated field at 16A	145.7	78.9	G·m
Magnetic Length at 16A	98.0	112.1	mm
Max DC current	16		A
Number of turns	192		#
Magnet resistance (in the range 26°C - 28°C)	~62		mΩ
Inductance measured at 3Hz	~43	~35	mH

Figure 2: Horizontal steerer, focussing quadrupole and sextupole magnets assembled on the girder

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REFERENCES

[1] M.Svandrlik et al, "The New Elettra Booster Injector", this conference
[2] D.Zangrando et al, "The ELETTRA booster magnets construction status", EPAC 2006.
[3] F.Iazzourene, private communication.

