9th International Particle Accelerator Conference IPAC2018, Vancouver, BC, Canada JACoW Publishing
ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPMK009

STATUS OF THE ESRF-EBS MAGNETS

C. Benabderrahmane†, J.C. Biasci, J.F. Bouteille, J. Chavanne, L. Eybert, L. Goirand, G. Le Bec, L. Lefebvre, S.M. Luizzo, D. Martin, C. Penel, P. Raimondi, J.L. Revol, F. Villar, S. White, ESRF, Grenoble, France

Abstract

The ESRF-EBS (Extremely Brilliant Source) is an upgrade project planned at ESRF (European Synchrotron Radiation Facility) in the period 2015-2022. It aims to decrease the horizontal emittance and to improve the brilliance and coherence of the X-ray beams to best serve the new science opportunities. The actual storage ring will be replaced by a new one in the existing complexes. Demanding specifications magnets were designed for this project including dipoles with longitudinal gradient (field ranging from 0.17 T up to 0.67 T), High gradient quadrupoles (up to 90 T/m), combined function dipole-quadrupoles with high gradient (0.57 T and 37 T/m), strong sextupoles and octupoles. The dipoles with longitudinal gradient are based on permanent magnets, they were assembled and measured in house. In this contribution the magnets production status will be presented.

INTRODUCTION

The European Synchrotron Radiation Facility (ESRF) is an intense X-ray source located in Grenoble, France. It is a centre of excellence for fundamental and innovation-driven research. ESRF owes its success to the international cooperation of 22 partners, of which 13 are members and 9 are scientific associations.

A major upgrade project known as ESRF-EBS was launched in 2015. It aims to reduce the horizontal emittance from 4 nm.rad down to less than 140 pm.rad. The brilliance of ESRF-EBS will be increased by a factor of 30 compared to the present one, mainly due to this drastic decrease of the horizontal emittance. The present Double Bend Achromat lattice will be replaced with a Hybrid Multi Bend Achromat one [1].

The reduction of the beam size allows a significant reduction of the magnet apertures. The beam size is smaller in the central part of the cell than in the outer parts, resulting in two different magnet apertures and Good Field Region (GFR). All the ESRF-EBS magnets [2, 3] were designed using Radia software [4].

PROCUREMENT PROCESS

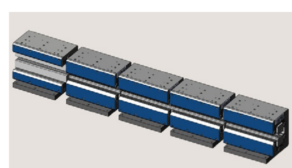
The procurement of the magnets is on progress. A Pre-Qualification Exercise (PQE) was performed to select a short list of electromagnets suppliers for Dipole-quadrupoles, Quadrupoles, sextupoles, octupoles and correctors magnets. This selection is based on a technical questionnaire, administrative document and plant visits.

The contract is divided in 3 main phases. Phase 1 is dedicated to the engineering design, detailed drawing and quality control document. Phase 2 to the production of the pre-series magnets and phase 3 to the production of the series magnets delivered in several batches. All the magnets were delivered to ESRF except dipoles quadrupoles which will be delivered in the coming months. The same process was used for the procurement of the permanent magnet blocks and mechanical parts of the DLs which were assembled in house.

MAGNET PRODUCTION

Longitudinal Gradient Dipoles (DLs)

The design of the DLs is based on permanent magnets [5], it is more compact and less cost operation than the electromagnets. The DL consists of five modules (Fig. 1a). Every module is magnetised by a different amount of permanent magnet in a way that the DL produces a longitudinal gradient magnetic field (Fig.1b). The permanent magnet used is Sm_2Co_{17} because of its resistance to radiation damage [6] and its temperature stability, three times better than the $Nd_2Fe_{14}B$.



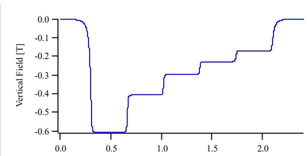


Figure 1: a) DL design with five modules, b) Field versus longitudinal position.

Table 1: Main Parameters of the DLs

Parameters	DL1	DL2
Gap [mm]	25.5	25.5
Field B [T]	0.67-0.17	0.54-0.17
Length [mm]	1788	1788
GFR [mm]	13	13
ΔB/B	$<10^{-3}$	$<10^{-3}$

A dedicated area at ESRF was prepared for the DLs assembly. It is equipped with workshops for the mounting of permanent magnet blocks on the modules, and the assembly of modules on the DLs supports. Two stretched wire magnetic benches [7] were installed in this area to perform the magnetic measurement and fiducialization of the DLs.

The first step of the DLs assembly consists to the mounting of the permanent magnet blocks in the modules, thanks to

† bchams@esrf.fr

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPMK009

the dedicated assembly tool designed in house. The thermal compensation Fe-Ni material [8] is also mounted on the modules at this step, its magnetisation has a strong dependence to temperature. The exact amount of this material was designed and calibrated on the prototype modules. Each module is measured and shimmed using soft magnetic material to reach the required magnetic field quality.

Figure 2: Assembled DL under magnetic measurement.

The five modules of the DL are assembled on the top plate support (Fig.2). The field integrals of the DLs are measured on the magnetic bench, a fine tuning is performed by using the End Iron Shunt mounted on the two extremities of the magnet. Figure 3 presents the field integrals of DL2 magnets before and after the tuning. All the DLs are within 2. 10^{-5} after tuning.

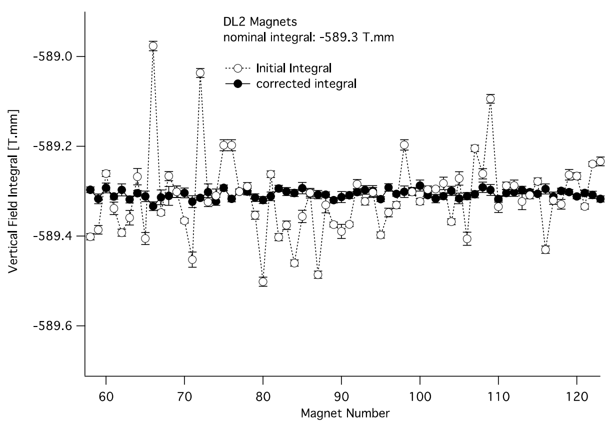


Figure 3: Field integral of the DL2 magnets before and after tuning.

The fiducialization is done on each DL by using a Laser Tracker. The coordinates of ten points (two points per modules) were measured and will be used for the alignment of the DL on the girder. All the DLs are assembled and ready for the installation on the girders.

Combined Dipole Quadrupoles (DQs)

The combined dipole quadrupole has a high gradient field that cannot be obtained with a tapered dipole design. The final design of the DQ is a single sided quadrupole. The main parameters of the DQs is shown in table 2.

Table 2: Main Parameters of the DQs Magnets

Parameters	DQ1	DQ2
Field B [T]	0.57	0.39
Gradient G [T/m]	36.8	31.2
Length [mm]	1028	800
GFR [mm]	7	7
ΔG/G	$<10^{-2}$	$<10^{-2}$

The DQs are built by Tesla Engineering Ltd as a solid magnet. It is constituted by seven low carbon steel plates, the machining and the assembly of this magnet is a real challenge because of the size and the shape of the poles (Fig.4a). After the production of the pre-series magnets, an important modification was done on the connection to improve their robustness and reduce any potential leak in the operation phase (Fig.4b). A deformation of the yoke back plate was observed when the magnet is powered because of its C-shape. This deformation is proportional to the current and reaches 0.1 mm at nominal current (according to computation). The series production of the QD1 magnets is on progress, two batches were delivered and the last one will be delivered within two months. The production and delivery of DQ2 magnets will be done after the DQ1s.

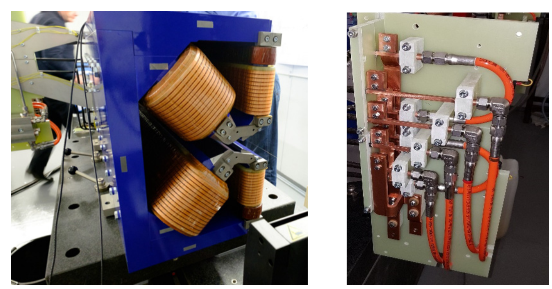


Figure 4: a) Pre-series DQ1 magnet, b) New design of the connections.

Quadrupole Magnets

The ESRF-EBS lattice includes two types of quadrupoles; moderate gradient (MG) quadrupoles (Table 3) and high gradient (HG) quadrupoles (Table 4). All the quadrupoles are iron dominated normal conducting magnets.

Table 3: Main Parameters of MG Quadrupoles

Parameters	QF1	QD2-QF4-QD5	QD3
Bore radius	16.4	16.4	16.4
Gradient G [T/m]	50.4	53.9	47.9
Length [mm]	295	212	162
GFR [mm]	13	13	13
ΔG/G	$<10^{-3}$	$<10^{-3}$	$<10^{-3}$

The moderate gradient quadrupoles (Fig.5a) are manufactured by Tesla Engineering Ltd, it is a laminated magnet with final machining of the pole shape and the reference surfaces. The design of the connections was modified after

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPMK009

the production of the pre-series magnets to improve their robustness. All the moderate gradient quadrupoles are built and delivered to ESRF.

Table 4: Main Parameters of HG Quadrupoles

Parameters	QF6	QF8
Bore radius	12.6	12.6
Gradient G [T/m]	89	87.6
Length [mm]	388	484
GFR [mm]	7	7
ΔG/G	$<10^{-3}$	$<10^{-3}$

The High gradient quadrupoles (Fig.5b) are manufactured by Danfysik. It is a solid magnet constituted by four quadrants, each quadrant is machined with wire erosion from one low carbon steel block. All the high gradient quadrupoles are built and delivered to ESRF.

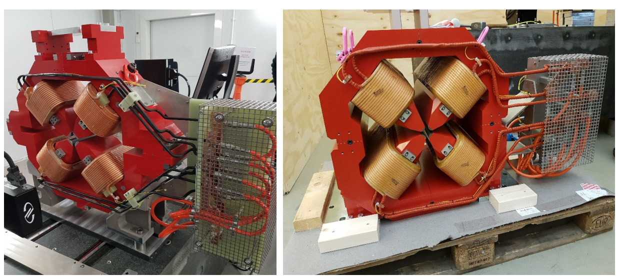


Figure 5: a) MG quadrupole, b) HG quadrupole.

Sextupole Magnets

The sextupole (Fig. 6a) is an iron dominated normal conducting magnet. It is manufactured by Danfysik as a solid magnet, constituted by six sextants cut by wire erosion from six low carbon steel blocks. The sextupole magnet is equipped with six correction coils for horizontal, vertical and skew quadrupole DC corrections. All the sextupoles are built and delivered to ESRF.

Table 5: Main Parameters of Sextupole Magnets

Parameters	SD1	SF2
Bore radius	19.2	19.2
Strength S [T/m2]	1716	1716
Length [mm]	166	200
GFR [mm]	13	13
ΔS/S	$<10^{-2}$	$<10^{-2}$

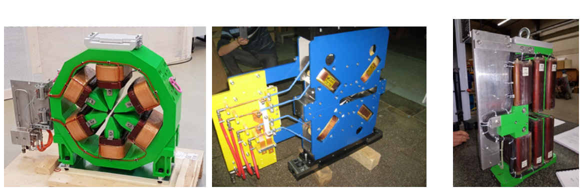


Figure 6: a) Sextupole, b) Octupole, c) Corrector.

Octupole and Corrector Magnets

The octupole magnet (Fig. 6b) is constituted by four yokes and four coils, each yoke has two poles and equipped with one coil. The octupoles are built by BINP as a solid magnet. There is a large margin on the octupole strength, and the nominal value of 36000 T/m^3 can be doubled if needed. The corrector magnet (Fig. 6c) is C- type structure compatible with the stay clear for the vacuum chamber. It can be simultaneously used for horizontal, vertical and skew quadrupole corrections. The correctors are built by SEF as a laminated magnet to operate for both AC and DC modes. All the octupole and corrector magnets are built and delivered to ESRF.

MAGNETIC MEASUREMNETS AND FIDUCIALIZATION

The magnetic measurements and the fiducialization of the electromagnets (except the correctors) are parts of the supply. ESRF stretched wire benches were installed and calibrated on the Tesla and Danfysik sites. A dedicated rotating coil bench was designed and built by BINP for the octupoles measurements. MG quadrupoles, sextupoles and octupoles are shimmed during the magnetic measurements to correct the magnetic centre to reach the tolerance of ± 0.05 mm and the roll angle of ± 0.1 mrad. HG quadrupoles and DQs are not shimmed and will be adjusted on the girders. After the difficulties encountered by the magnets suppliers, it was decided to perform the fiducialization of all the magnets in house. A dedicated area equipped with magnetic benches and Laser Trackers was prepared. More than 80% of the magnets have been fiducialized so far, this operation will be finished by the end of September.

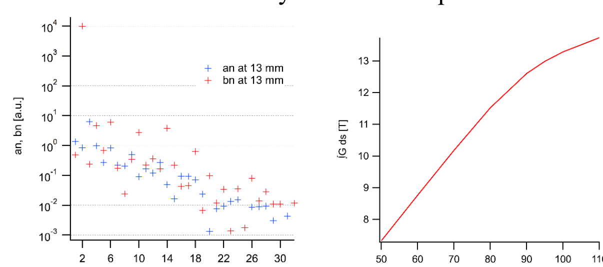


Figure 7: Magnetic measurements of QD2 MG quadrupole, a) Normalized harmonic components at 13 mm, b) Integrated gradient versus current.

CONCLUSION

The magnets of the ESRF-EBS project were designed. Innovative solutions were used for the longitudinal gradient dipoles and combined dipole quadrupoles.
The procurement of the magnets is on progress. The DLs were assembled, measured and fiducialized in house. All the DLs are assembled and ready for installation on the girders. More than 80% of the electromagnets have been delivered to ESRF. The magnetic measurement and shimming are performed by the magnets suppliers, however the fiducialization is performed in house.

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPMK009

The assembly of the magnets, vacuum chambers and other equipment on the girders has started, it is progressing well and it will be finished within 6 months.

REFERENCES

[1] P. Raimondi, "Hybrid multiband achromat: From SuperB to EBS", *in Proc. of IPAC'17,* Copenhagen, Denmark, May 2017, paper. THPPA3, pp 3670-3675.

[2] C. Benabderrahmane *et al*, "Magnets for the ESRF-EBS project," in *Proc. of IPAC'16*, Busan, Korea, May 2016, pp. 1096-1099.

[3] G. Le Bec *et al*, "Magnets for the ESRF diffraction limited light source project", *IEEE transactions on applied superconductivity*, vol. 26(3), 2016.

[4] O. Chubar, P. Elleaume and J. Chavanne, "A three-dimensional magnetostatics computer code for insertion devices," *J. Synchrotron Radiat.*, vol. 5, pp. 481-484, 1998.

[5] J. Chavanne and G. Le Bec, "Prospects for the use of permanent magnets in future accelerator facilities," in *Proc. of IPAC'14*, Dresden, Germany, 2014, pp. 968-973.

[6] T. Bizen *et al.,* "Demagnetization of undulator magnets irradiated high energy electrons," *Nucl. Instr. Meth. Phys. Res. A*, vol. 467–468, Part 1, pp. 185-189, 2001.

[7] G. Le Bec, J. Chavanne and Ch. Penel, "Stretched wire measurement of multipole accelerator magnets," *Phys. Rev. ST Accel. Beams*, vol. 15, p. 022401, 2012.

[8] K. Bertsche, J.-F. Ostiguy and W.B. Foster, "Temperature Considerations in the design of a permanent magnet storage ring," in *Proc. of PAC'95*, 1995, pp. 1381-1383.