THE ESRF LOW EMITTANCE UPGRADE

P. Raimondi, ESRF, Grenoble, France

Abstract

This talk focuses on novel aspects of the lattice design, describes the technical solutions that have been found for meeting the design goals (including the use of permanent magnet dipoles), outlines the main challenges that will be faced in commissioning and operating the new lattice in a very demanding parameter regime, and discusses how it is hoped to maximize eventual benefits for users while minimizing disruption during the upgrade process.

INTRODUCTION

The European Synchrotron Radiation Facility (ESRF) is running an accelerator complex based on a linac, a synchrotron booster and a 6.04 GeV Storage Ring (SR). The electron beam stored in the SR has 4 nmrad horizontal emittance, 3.5 pmrad vertical emittance and a beam lifetime between 10 and 60 hours depending on the filling mode. There are 42 beamlines, 12 using dipole radiation and 30 using insertion devices installed in the available 31 straight sections. The Extremely Brilliant Source (EBS) [1, 2] accelerator upgrade aims to:

- substantially decrease the storage ring equilibrium horizontal emittance,
- increase the source brilliance,
- increase its coherent fraction.

In the context of the R&D on "Ultimate Storage Rings", the ESRF has developed a solution based on the following requirements and constraints:

- Reduce the horizontal equilibrium emittance from 4 nm to less than 140 pm
- Maintain the existing ID straights beamlines
- Maintain the existing bending magnet beamlines
- Preserve the time structure operation and a multibunch current of 200 mA
- Keep the present injector complex
- Reuse, as much as possible, existing hardware
- Minimize the energy lost in synchrotron radiation
- Minimize operation costs, particularly wall-plug power
- Limit the downtime for installation and commissioning to less than 18 months
- *Maintain standard User-Mode Operations until the day of shut-down for installation.*

During the next decade several facilities will implement low horizontal emittance lattices [3–13].

The small horizontal emittance will increase the performance of the source by a factor 50 to 100 [1]. Figure 1 shows this effect.

The increased number of bending magnets per cell used to achieve the small emittance is however in conflict with the hard X-ray demand from bending magnets source (BM). The field of the BM will go from 0.85 T to 0.54 T. The BM

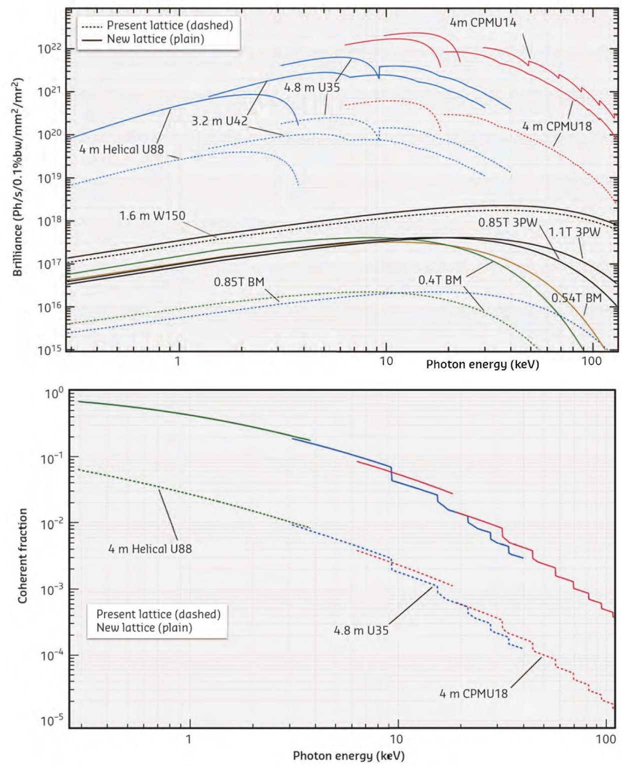

Figure 1: Brilliance and Coherence for the current and upgraded source.

sources will thus be replaced by a less than 15 mm long 2-pole wigglers (2PW), 3 pole wiggler (3PW) or short bending magnets [14]. The source will have customized field and a large fan with flat top field. This sources will be shifted by 3 m longitudinally and by 1 to 2 cm horizontally. The flux obtained by the 3PW is depicted in Fig. 2.

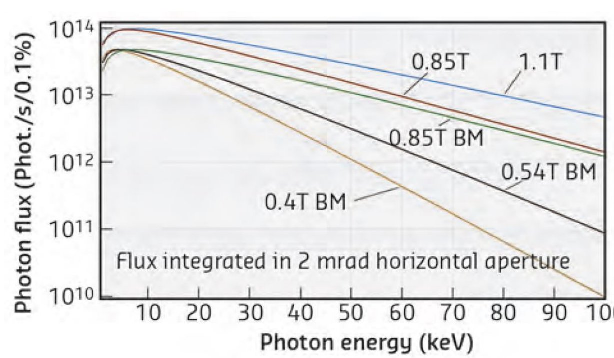

Figure 2: Flux from 3PW.

LATTICE OPTICS

For the EBS upgrade the ESRF Duble Bend Achromat (DBA) arcs will be replaced by the Hybrid Multi Bend

ISBN 978-3-95450-147-2

Acrhomat (HMBA) lattice with a horizontal emittance of 132 pmrad [2].

This cell (see Fig. 3) has several advantages:

- Multi bend for lower emittance
- dispersion bump for efficient chromaticity correction (weak sextupoles, less then 1600 T/m^2)
- fewer sextupoles than DBA
- longer and weaker dipoles (less synchrotron radiation)
- small dispersion at the inner dipoles

The ring is composed by 30 arc cells plus two specific cells to increase off-axis injection efficiency.

Lattice Optimizations

Several optimizations (with realistic errors [15]) have been done to improve lifetime and injection efficiency for the cell as described in [16]. Averaging over 10 error seeds and correction, the dynamic aperture extends at injection up to −10 mm and touscheck lifetime is about 21 h for multibunch mode (*S28B* lattice version). In Fig. 4 one such optimization using genetic algorithms is shown [17, 18]. The Pareto front of optimal sextupoles and octupole settings to improve lifetime and injection efficiency is evidenced by the green points.

A detailed study of the Touschek losses in the lattice showed that vertical losses at the undulators can be concentrated (up to 80%) using two horizontal scrapers. The details of this study are described in [19, 20]. Figure 5 shows the effect of the collimators on the losses over one cell.

The final design of the lattice cell required several iteration between:

- Optics optimizations: emittance, dynamic aperture, energy spread, lifetime
- magnets requirements: fields, gradients, etc.
- Vacuum system requirements: chambers, absorbers, pumping, etc.
- diagnostic requirements
- bending beamlines source

TECHNICAL CHALLENGES

Magnets System

The magnets system is described in detail in [21]. The required magnets are:

- 132 permanent magnet (Sm_2Co_17) dipoles with field between 0.16 T and 0.65 T,
- 398 quadrupoles with gradients about 52 T m^{-1}
- 128 high gradient quadrupoles, 90 T m^{-1} and 12.5 mm bore radius
- 99 combined dipole-quadrupoles, 0.54 T and 34 T m^{-1}
- 196 sextupoles with strength about 1500 T/m^2
- 64 octupoles, strength 30 kT/m^3
- 100 correctors, for horizontal and vertical steering and coupling correction.

The mechanical design of the above magnets is in the final drawing phase. Large positioning pins have been included for opening repeatability and tight tolerances have been set on pole profiles (±20 µm). Prototypes of these magnets have been delivered between September 2014 and spring 2015.

Figure 6 shows that all magnets cope with the requirements of 11 mm stay clear from pole to pole for optimal synchrotron radiation handling.

The longitudinal gradient dipoles are made of 5 modules (see Fig. 7). The lower field module has a larger gap to allow the installation of an absorber. The engineering and prototyping of this magnets is completed. The magnets will be built directly by ESRF.

Dipole quadrupoles are machined out of 7 solid iron plates. The poles are curved for a maximum stay clear and good field region (7 mm) as depicted in Fig. 8.

More than 1000 magnets will be procured by the end of 2018 (see [21]).

Vacuum Chambers

The vacuum system is composed of more than 450 chambers to be procured in less than 3 years. There are 14 main families for the arc cells, and several specific chambers.

The design of the chamber is reported in Fig. 9. As an example the chamber number 8 is composed of 2 straight sections and a curved section to host the DQ magnet in the center. Two different profiles are used for the antechember in the two regions, in order to stiffen the structure and allow the installation of ports for pumps and absorbers.

Photon Absorbers

Several (391) photon absorbers are installed to dump the synchrotron radiation emitted in the dipoles. The total power to be absorbed is 504.5 kW with a density normal to the beam of at most 110 W/mm^2. These values are moderate compared to the current ESRF installation (more dipoles and lower fields for the EBS lattice). The scattered radiation is blocked in the absorber in order to avoid cooling of the vacuum chamber. Two main families of absorbers have been designed that do not require welding nor brazing: frontal absorbers (up to 50 W/mm^2) and teeth absorbers (up to 110 W/mm^2). The first one intercepts the photon beam directly on a flat surface. The teeth structure of the second one, reduces the thermal stress on the structure distributing the heat over a large surface (see Fig. 10).

Power Supply

About 1000 large power supply will be necessary for the independent control of the magnets described above. Additionally other 1000 small power supplies will power the correction coils installed on the correctors and on the sextupoles. About 1000 DC-DC low voltage converters will be necessary with an average channel power of 1 kW and a maximum of 2.3 kW. Stability will be 15 ppm with a mean time between failure of more than 400 kh. This power supplies will be installed in 32 cabinets per cell considering redundancy and the possibility of hot-swap.

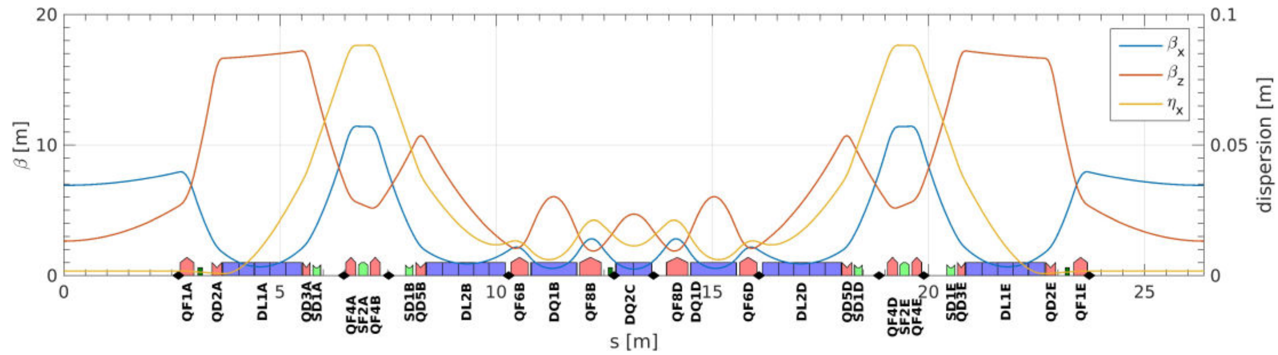

Figure 3: Arc cell optics and layout.

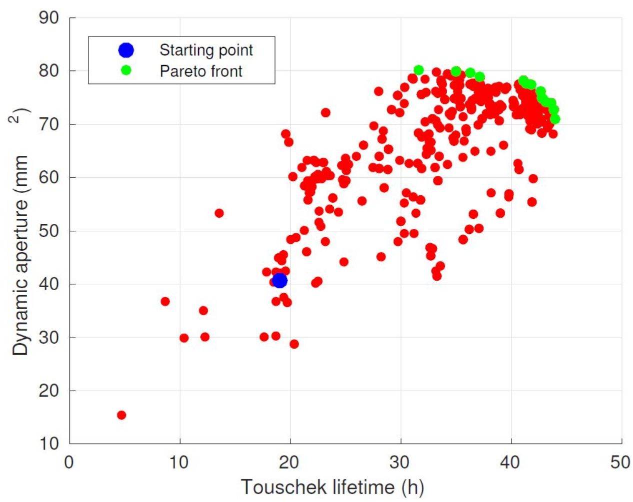

Figure 4: Optimization using multi objective genetic algorithms.

Girders

Each arc cell is supported by 4 identical girders (see Fig. 11) expect for few particular cases. The girder is made of carbon steel and the parts are jointed using full penetration and continuous welding. The girder weight is below 3.5 Mg unloaded, and arrives to a maximum of 11 Mg when fully assembled, according to the location on the cell.

The girder position is adjustable in all directions and motorized only for the vertical displacement. Mechanical and transportation tests have been performed using dummy magnets installed on the girder. The first vibrational mode has been measured at 40 Hz, with virtually no amplification of natural ground motion. All girders will be fully assembled before starting the shutdown for installation.

STATUS OF THE UPGRADE

After several very positive Committee (Accelertor project Committee, Science advisory Committee, Cost Review Panel) the project has been approved and founded on 1st Jan 2015.

Today the master schedule is finalized, the design phase is completed and the procurement phase has been launched.

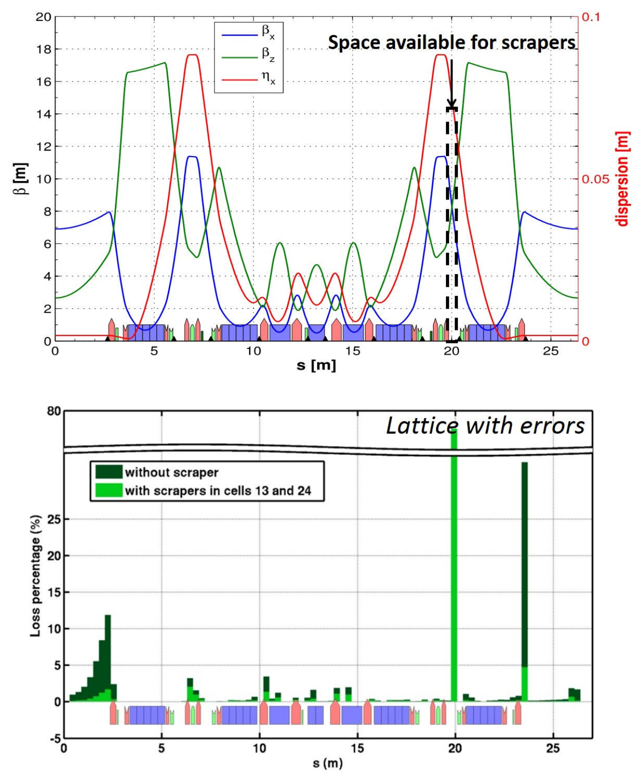

Figure 5: Losses simulated along the cell with and without collimators for a lattice with errors.

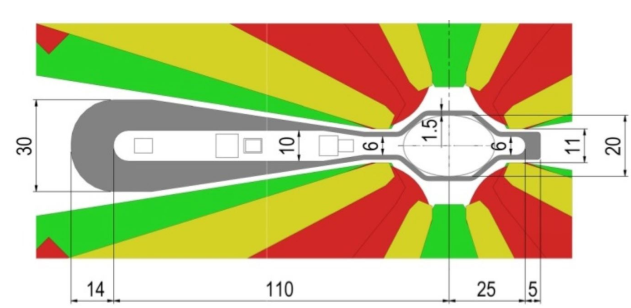

Figure 6: Vacuum chamber and magnet sections.

A fully resource loaded assembly phase planning and installation planning are under preparation. Together with the

ISBN 978-3-95450-147-2

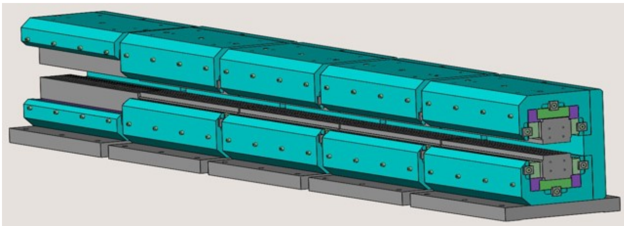

Figure 7: Longitudinal gradient dipole.

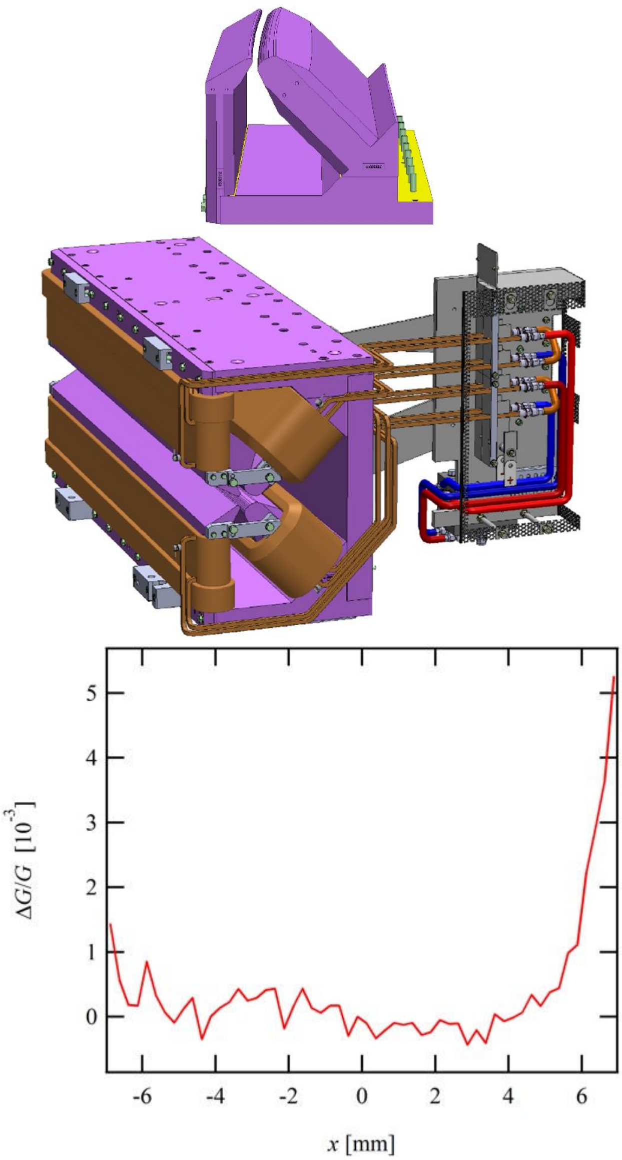

Figure 8: Combined function magnet design and field quality along electron trajectory.

Accelerator and Source division (ASD), all the divisions at ESRF are fully committed on the EBS project.

The design of all the components is nearly completed. The parts still to be designed are one of a kind elements: injection kickers, permanent magnets septa, vacuum chambers for the injection cell and scrapers, collimators. All elements in the

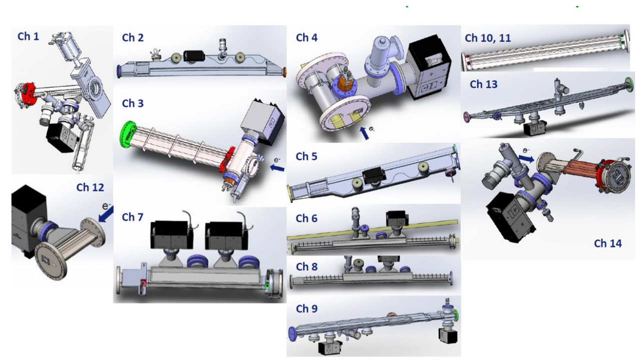

Figure 9: Mechanical design of vacuum chambers.

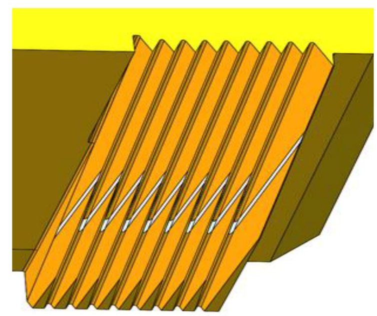

Figure 10: Distribution of radiation on toothed absorber.

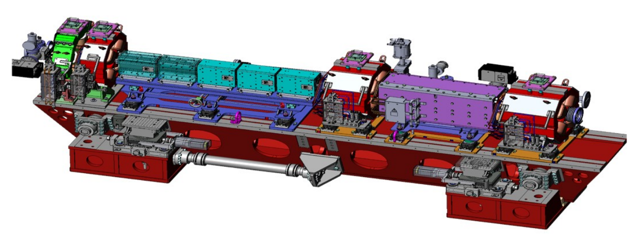

Figure 11: Girder design to support the magnets.

design have been fully integrated and are consistent with the overall specifications.

All contracts for magnets, vacuum chambers and girders are already in place. The adaptations of the infrastructures are finalized and Calls For Tender are in progress. All large scale procurements will be in place by mid 2016 and the delivery of serial components will start by the end of 2016 and will last about 2 years.

The main steps in the master schedule are:

- January 2017 to June 2018: delivery of the components
- 01/10/2017: start of the assembly phase
- 17/12/2018: start of the machine shutdown and dismantling
- 18/03/2019: end of dismantling phase and start of installation phase
- 04/11/2019: end installation phase
- 02/12/2019: start of storage ring commissioning
- 09/01/2020: start of beamlines commissioning
- May-July 2020: Friendly users
- 25/08/2020: start of user standard mode

CONCLUSION

The EBS project is officially started on January 1st 2015. The engineering design is virtually finished and the procurement is in full swing. Delivery of all the pre-series components is expected by the end of 2016, however the schedule is now heavily linked to external manufacturers.

ACKNOWLEDGMENT

The work presented in this paper is the outcome of the collaboration of all the divisions at ESRF an contains contributions from external experts and the scientific community. In particular the following people contributed to the present paper: D. Andrault, R. Barrett, S. Bayat, P. Berkvens, J.-C. Biasci, S. Billinge, B. Boulanger, J.-F. Bouteille, A. Bravin, E. Brun, F. Carla, N. Carmignani, H. Castillo-Michel, J.-M. Chaize, J. Chavanne, F. Cianciosi, P. Cloetens, P. Coan, S. Corr, M. Cotte, D. Coulon, Y. Dabin, I. Daniel, D. de Sanctis, M. DiMichiel, R. Dimper, J. Drnec, L. Dubrovinski, L. Ducotté, F. Ewald, P. Fajardo, L. Farvacque, R. Felici, C. Ferrero, G. Fiquet, A. Götz, L. Goirand, Y. Gouez, M. Hahn, J. Härtwig, P.F. Henry, O. Hignette, J. Hudspeth, S.D.M. Jacques, J. Jacob, N. Janvier, J. Kieffer, S.A.J. Kimber, C. Knabe-Ducheyne, M. Kocsis, M. Krisch, B. Lebayle, G. Le Bec, G. Le Duc, G. Leonard, S.M. Liuzzo, P. Loubeyre, P. Mackrill, T. Marchial, T. Mairs, P. Marion, D. Martin, T. Martin, M. McMahon, J. Meyer, M. Mezouar, E. Mitchell, C. Morawe, J. Morse, B. Müller, C. Müller-Dieckmann, T. Narayanan, B. Nash, B. Ogier, S. Pascarelli, H. Pedroso Marques, P. Pernot, T. Perron, F. Pfeiffer, E. Plouviez, C. Ponchut, A. Popov, A. Poulin, A. Rack, J.-L. Revol, H. Reichert, A. Royant, L. Sánchez Ortiz, M. Sanchez del Rio, M. Santoro, M. Scandella, K. Scheidt, T. Schülli, V. Serriere, F. Sette, A. Snigirev, V.A. Sole, J. Susini, O. Svensson, P. Tafforeau, G. Vaughan, R. Versteegen, F. Villar, B. Winkler, S. M. White, J. Wright, L. Zhang.

REFERENCES

[1] "ESRF upgrade programme phase II", ESRF, December 2014.

[2] J.C. Biasci *et al.*, "A low emittance lattice for the ESRF", Synchrotron Radiation News, vol. 27, Iss.6, 2014.

[3] C. Steier *et al.*, "Physics Design Progress towards a Diffraction Limited Upgrade of the ALS", presented at IPAC'16, Busan, Korea, May 2016, paper WEPOW049, this conference.

[4] V. Sajaev *et al.*, "Commissioning Simulations for the APS Upgrade Lattice", in *Proc IPAC'15*, Richmond, Virginia, USA, May 2015, paper MOPMA010, pp. 553–555.

[5] A. Alekou *et al.*, "Study of a Double Triple Bend Achromat (DTBA) Lattice for a 3 GeV Light Source", presented at IPAC'16, Busan, Korea, May 2016, paper WEPOW044, this conference.

[6] T. Honda *et al.*, "Present Status of KEK Photon Factory and Future Project", presented at IPAC'16, Busan, Korea, May 2016, paper WEPOW020, this conference.

[7] A.R.D. Rodrigues *et al.*, "Sirius Status Report", presented at IPAC'16, Busan, Korea, May 2016, paper WEPOW001, this conference.

[8] S.Q. Tian *et al.*, "Lattice design of the SSRF-U Storage ring", in *Proc. IPAC'15*, Richmond, Virginia, USA, May 2015, paper MOPJE009, pp. 304–306.

[9] H. Tanaka *et al.*, "SPring-8 Upgrade Project", presented at IPAC'16, Busan, Korea, May 2016, paper WEPOW019, this conference.

[10] E. Ahmadi *et al.*, "Designing an Ultra Low Emittance Lattices for Iranian Light Source Facility Storage Ring", presented at IPAC'16, Busan, Korea, May 2016, paper WEPOW016, this conference.

[11] E. Karantzoulis *et al.*, "Elettra Status and Upgrades", presented at IPAC'16, Busan, Korea, May 2016, paper WEPOW018, this conference.

[12] A. Streun *et al.*, "Proposed Upgrade of the SLS Storage Ring", presented at IPAC'16, Busan, Korea, May 2016, paper WEPOW038, this conference.

[13] R. Nagaoka *et al.*, "Design Considerations of a 7BA-6BA Lattice for the Future Upgrade of SOLEIL", presented at IPAC'16, Busan, Korea, May 2016, paper WEPOW003, this conference.

[14] J. Chavanne, "Implementation of short wigglers as photon sources for the bending magnet beamlines in the new ESRF lattice", ESRF, Grenoble, France, 01-15/IDM, Sep. 2015.

[15] S.M. Liuzzo *et al.*, " Influence of errors in the ESRF upgrade lattice", in *Proc. IPAC'15*, Richmond, Virginia, USA, May 2015, paper TUPWA014. pp. 1426-1429.

[16] N. Carmignani *et al.*, "Linear and Nonlinear Optimizations for the ESRF Upgrade Lattice", in *Proc. IPAC'15*, Richmond, Virginia, USA, May 2015, paper TUPWA013, pp. 1422–1425.

[17] K. Deb *et al.*, "A fast and elitist multiobjective genetic algorithm: NSGA-II", Evolutionary Computation, IEEE Transactions on 6.2 (2002): 182-197.

[18] Song Lin, "NGPM – a NSGA-II program in Matlab".

[19] R. Versteegen *et al.*, "Modelling of beam losses at ESRF", in *Proc. IPAC'15*, Richmond, Virginia, USA, May 2015, paper TUPWA017, pp. 1434–1437.

[20] R. Versteegen *et al.*, "Collimation scheme for the ESRF upgrade", in *Proc. IPAC'15*, Richmond, Virginia, USA, May 2015, paper TUPWA016, pp. 1430–1433.

[21] C. Benabderrammane *et al.*, "Magnets for the ESRF-EBS Project", presented at IPAC'16, Busan, Korea, May 2016, paper TUPMB001, this conference.