

## ESRF UPGRADE PHASE II

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### Abstract

Four years after the launch of the upgrade programme, the European Synchrotron Radiation Facility (ESRF) is midway through its first phase (2009-2015) and has defined the objectives for the ensuing second phase. The first paved the way for a new generation of nano-beam X-ray beamlines fed by a source improved in terms of reliability, stability and brilliance. The second phase envisions a major upgrade of the source to best serve the science case of this new generation of beamlines. In December 2012, the ESRF Council endorsed the management's proposal to launch the technical design study of a new 7-bend achromat lattice. This new configuration will allow the ESRF storage ring to operate with a horizontal emittance about 30 times smaller than now and an inversely proportional increase in brilliance and coherence of the photon beam. The increase will be substantially higher at X-ray energies larger than 50 keV.

### THE ESRF IN A NUTSHELL

The ESRF is a user research facility located in Grenoble, France, supported and shared by 19 countries. Researchers from both academia and industry use the intense X-rays beams produced by the 6-GeV electrons circulating in the storage ring. Founded in 1988, it began operations in 1994 and has since exceeded all initial objectives. The 6000 researchers from all over the world who visit the ESRF every year to carry out experiments demonstrate its success. The facility hosts 42 highly specialised X-ray beamlines equipped with state-of-the-art instrumentation. More than 21700 scientific articles based on work carried out at the ESRF have been published since the facility's foundation. The laboratory is in a well advanced stage of an ambitious upgrade programme (UP). The first phase (2009-2015), designed around new and improved beamlines and instrumentation, is already more than halfway through. The second phase, foreseen for the period 2015-2019, is devised to optimise the source for brighter and smaller X-ray beams.

### PROJECT FRAMEWORK

Much progress has been made in the framework of UP phase I to increase the brilliance and the reliability of the source [1]. However, the reduction of the horizontal emittance remains a recurrent request from the ESRF beamlines. The strong constraints of re-using the same tunnel and infrastructure proved very challenging. Thanks to the world-wide effort over the last few years to develop solutions for diffraction limited storage rings, the lattice solutions are more and more mature.

New lattice designs and technical developments allow re-addressing the issue with the following requirements, specific for the ESRF infrastructure:

- Reduce the horizontal equilibrium emittance from 4 nm to less than 200 pm
- Keep the existing insertion-device (ID) beamlines
- Maintain the existing bending magnet beamlines
- Preserve the time structure operation and a multibunch current of 200 mA
- Keep the present chain of injectors,
- Reuse, as much as possible, existing hardware
- Minimize the energy lost in synchrotron radiation
- Minimize operation costs, mainly wall-plug power
- Limit the downtime for installation and commissioning to about one year

The experience gained during phase I sets a valuable starting point for the complete renewal of the storage ring. The conversion of some ID straight sections from 5 to 6 and 7 metres, along with the canting, required the design of new strong quadrupoles and permanent-magnet (PM) steerers, which paves the way towards the development of the strong magnets required for the new lattice. The expertise acquired in state-of-the-art vacuum technology during the last decade (among which an in-house NEG coating facility), especially in long straight-section vacuum chambers, represents a solid basis for the design of a new vacuum system in the achromats. The ultra-low vertical emittance (already at diffraction limit) and the orbit stability provided by the orbit feedback are already compatible with the specifications of the new generation of storage rings. The new HOM-damped RF cavities developed at the ESRF will help to reduce the longitudinal instabilities of the new lattice. The new RF solid-state amplifiers installed in the booster will guarantee the requirements of top-up operation. Needless to say, comprehensive R&D programmes are necessary to achieve all specifications required by the new design.

### CONCEPTUAL DESIGN

#### *Lattice Design*

The lattice [2] should maintain the ring circumference, the 32-cell periodicity, the beamline positions, with an energy kept at 6 GeV. It is based on a 7-bend achromat cell (Figures 2 and 3) and represents a hybrid configuration that takes advantage of the large number of bending magnets (to reduce the horizontal emittance) and regions with localized large dispersion (to allow an efficient chromaticity correction, as in the classical double-bend achromat). In the latest lattice configuration

a horizontal emittance of about 150 pm.rad (4 nm.rad today) is obtained thanks to stronger focusing and softer bending magnets. The baseline lattice provides identical optics in all straight sections, with a horizontal  $\beta$  function of 3.6 m, hence removing the alternation of high- $\beta$  (38 m) and low- $\beta$  (0.35 m) beamlines. In order to guarantee sufficient injection efficiency, a dedicated cell has been conceived to increase the horizontal beta function to about 17 m. The design beam current in multibunch mode is maintained at 200 mA. The main lattice and beam parameters are listed in Table 1.

### Photon Source

The majority of IDs presently installed are expected to be used in the upgraded source. The new lattice, with an horizontal emittance decreased by a factor of about 30, will provide a consequent increase in brilliance and transverse coherence of the photon beam by the same amount (Figure 1). The increase will be substantially larger than 30 at X-ray energies above 50 keV. In addition, the new ring will be operated in top-up mode.

The existing 0.85T and 0.4T dipole sources will be maintained for the bending-magnet beamlines.

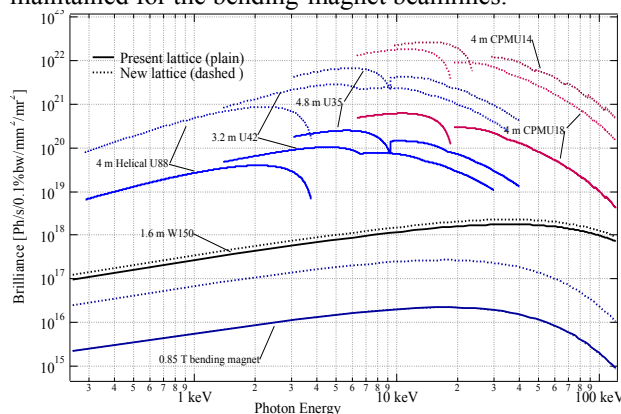


Figure 1: Brilliance of the existing and new lattices for present or planned insertion devices.

### Magnet System

The new lattice is composed of 31 magnets per cell, about twice as many as in the present machine. High-gradient quadrupoles (100T/m) and sextupoles (1.5 kT/m<sup>2</sup>) are needed, requiring small magnet bores. Moreover, minimization of cost and power requirement leads to optimized design of electromagnetic magnets to improve efficiency. To this end, designs based on high-performance PM are also envisaged.

The four long dipole magnets requiring longitudinal field gradient will be based on a configuration using PM assemblies, with a small-range tuning coil. The three short dipoles comprising strong transverse gradients, with a structure open externally for the extraction of the X-ray beam, are under design. The magnetic design of the high-gradient quadrupoles is well advanced (11 mm bore radius, 100 T/m, 1 kW). Prototypes will be built during the second half of this year. Sextupole magnets, with a design that allows extraction of the X-ray beam, are under study. Additional coils will enable flexible correction

functions as in today's sextupoles. The experience gained during the last two decades in the use of PMs (both for IDs and for canting steerers) is being applied to the design of high-performance small-aperture PM multipoles, in parallel to the design of conventional electromagnets.

### Vacuum System

The vacuum chambers will have low vacuum conductance due to the low aperture of the magnets and the extremely compact lattice. With a total magnetic cell length of about 18 m and the ID straight section kept at 5.4 m, only 3.4 m of distributed drift tube remains for the rest of the equipment, compared to today's 8m. The main chambers will be made from extruded aluminium profiles; where necessary a passage to stainless steel. Non-evaporable-getter coating all along the electron beam path will provide vacuum pumping, along with localised pumping. Lumped absorbers will collect the radiation from the dipole magnets; as the power generated by a single dipole magnet is lower than in the actual machine, these absorbers will be downscaled from prototypes already installed in the present storage ring.

### Radiofrequency System

The low field bending magnets result in a reduction of the synchrotron radiation loss from 5.4 to about 3.8 MeV/turn, including 0.5 MeV ID radiation. The longitudinal damping time increases from 3.5 to 6.3 ms, and the momentum compaction factor is halved. As a result, the new machine will only need 6 MV of RF voltage (9 MV today) to guarantee an RF energy of about  $\pm 4\%$ . The beam power at 200 mA will drop from 1100 kW to 700 kW. The new lattice will be more sensitive to longitudinal coupled-bunch instabilities (a factor two). The required stability will be obtained replacing the five-cell cavities with 12 HOM-damped single-cell cavities.

### Diagnostics and Instrumentation

The BPM number will increase from 7 to 12 per cell because of the larger phase advance. The existing Libera electronics will be reused and additional units installed. The BPM blocks could be made out of aluminium, positive experience being already gained at the ESRF in testing such a design. Orbit correction and stabilization will rely on a combination of slow, fast and bunch-by-bunch feedback loops similar to the existing ones.

### Injector

The present chain of injectors will be reused to feed the new storage ring. The injector upgrade, part of the UP phase I, will meet the requirements for the new machine, in particular the top-up operation. The booster RF system has been recently upgraded to solid-state amplifiers. Ramped power supplies allowing a 4 Hz cycle of the booster magnets will replace the existing 10 Hz resonant one, in order to enhance stability and allow shaping of the accelerating ramp. The new design will make it possible to implement bunch cleaning in the booster (today carried out in the storage ring with disturbances on the stored

beam) [1]. The consolidation programme to guarantee the reliability and redundancy, which is in progress, will also benefit the new machine.

## ROAD MAP FOR UPGRADE PHASE II

The technical aspects of the proposal, outlined in the white paper endorsed by the November 2012 ESRF Council, are challenging [3]. The ESRF's plans are based on pushing existing technologies to their limits, but R&D will also be undertaken into PM designs, high-gradient quadrupoles and low-conductance vacuum chambers. The overall cost of the new machine is expected to be around 100 M€, with an additional 50 M€ needed for building, beamlines and instrumentation. Since the white paper's approval, the ESRF is now progressing on a technical design study to be presented to the Council in autumn 2014, in order to get the approval of the construction phase. The study will also address procurement and

installation strategy, and radioprotection aspects. A 2500 m<sup>2</sup> extension of the experimental hall, to be used as a storage and preparation area for the new equipment, and later to create long beamlines is included in the proposal.

Should the green light be given, the procurement and pre-assembly phase will begin in 2015. The machine will be stopped for approximately one year, starting in August 2018, for the installation and commissioning of the new ring. The User-Mode Operations are expected to begin in the fall of 2019.

## REFERENCES

- [1] JL Revol et al., "ESRF Operation and Upgrade Status," MOPEA009, these proceedings.
- [2] L Farvacque et al., "A Low-emittance Lattice for the ESRF," MOPEA008, these proceedings.
- [3] White paper –ESRF  
<http://www.esrf.eu/news/general/whitepaperupgradephaseII>

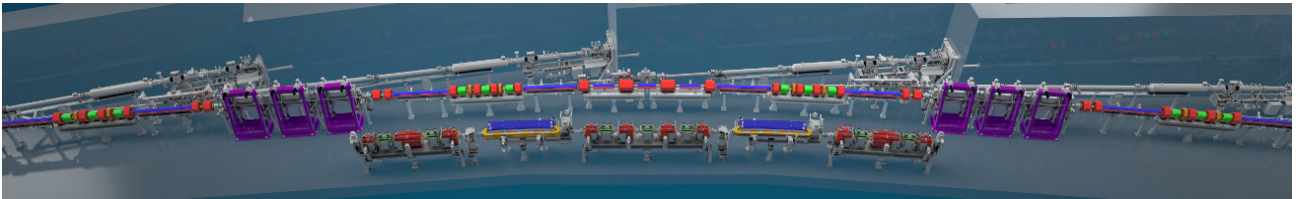


Figure 2: Artist impression of the new ESRF synchrotron. One of the 32 sectors to be replaced (present lattice function) is positioned next to the storage ring represented with the new design.

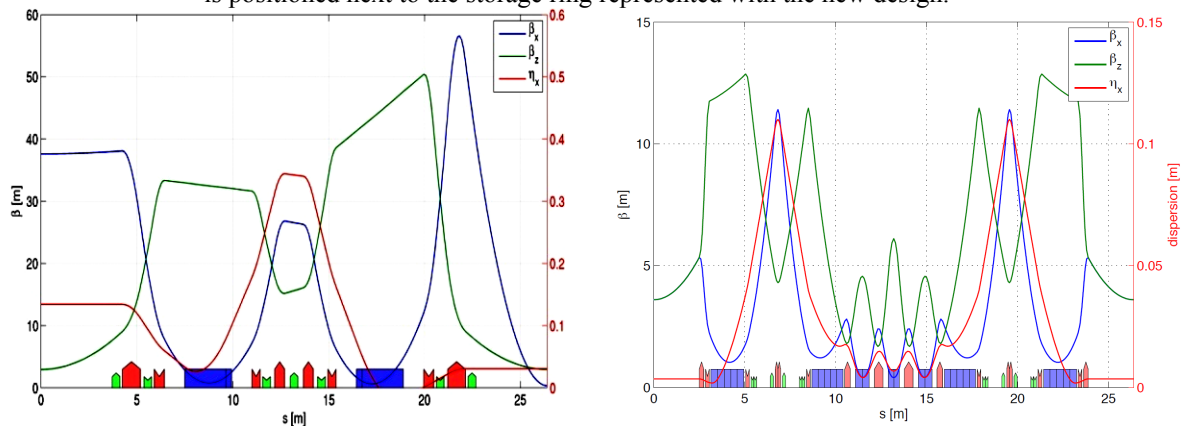


Figure 3: Lattice functions and layout for the existing storage ring (left) and the new design (right).

Table 1: Main Beam and Lattice Parameters.

Parameter	Existing Lattice	New Lattice
Energy, $E$ [GeV]	6.04	6.04
Circumference, $C$ [m]	844	844
RF frequency, $f_{RF}$ [MHz]	352	352
Beam current [mA]	200	200
Horizontal Emittance [pm · rad]	4000	150
Vertical Emittance [pm · rad]	4	3
Beta at ID center, $\beta_x, \beta_y$ [m]	37.6, 3.0 (high $\beta$ ) 0.35, 3.0 (low $\beta$ )	3.6, 3.6
Beam size at ID center, $\sigma_x, \sigma_y$ [ $\mu\text{m}$ ]	413, 3.9 (high $\beta$ ) 50, 3.9 (low $\beta$ )	24, 3.3
Beam div. at ID center, $\sigma_x', \sigma_y'$ [ $\mu\text{rad}$ ]	10, 1.3 (high $\beta$ ) 107, 1.3 (low $\beta$ )	6.4, 0.91