STATUS OF THE ESRF-EXTREMELY BRILLIANT SOURCE PROJECT

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Abstract

The ESRF - the European Synchrotron Radiation Facility - is a user facility in Grenoble, France, and the source of intense high-energy (6 GeV) X-rays. In 2019, the existing storage ring will be removed and a new lattice will be installed in its place, dramatically reducing the equilibrium horizontal emittance. This 'fourth-generation' synchrotron will produce an X-ray beam 100 times more brilliant and coherent than the ESRF source today. The Extremely Brilliant Source (EBS) project was launched in 2015 and is now well underway, on track for its scheduled completion in 2020. The design is completed, the procurement in full swing, the assembly has started, and critical installation activities are being prepared. The current status, three years into the project, will be revealed, along with the expected performance of the accelerator and the technical challenges involved. This paper will focus on the implementation of the project.

THE EBS-PROJECT

The ESRF is a European facility supported and shared by 22 partner nations. This third generation light source, in routine operation since 1994, delivers 5500 hours of beam per year to 42 beamlines with an availability close to 99 %. The accelerator complex consists of a 200 MeV linac, a 4 Hz full energy Booster synchrotron and a 6 GeV Storage Ring (SR) of 844 m circumference. The 32 cell Double Bend Achromat lattice of the SR provides a 4 nm.rad horizontal emittance electron beam. After correction, the vertical emittance is routinely maintained in the order of 7 pm.rad. A large variety of insertion devices (in-air undulators, wigglers, in-vacuum undulators, cryogenic in-vacuum undulators) are installed in the 28 available straight sections. Bending magnet radiation is used by 12 beamlines.

Since 2009, the ESRF has embarked on an ambitious upgrade programme of the machine and beamline infrastructures. Phase 2 of the upgrade, called Extremely Brilliant Source (ESRF-EBS), has been founded and started in January 2015 with a budget of 150M€. A new storage ring will replace the existing one in 2019, with the aim of reducing the horizontal emittance to less than 140 pmrad. It will allow a drastic increase of the brilliance and coherence [1]. The facility should be back to user operation in August 2020. An ambitious beamline portfolio to exploit the enhanced performance of the EBS includes also the construction of four completely new beamlines from 2018-2022.

MASTER SCHEDULE

The milestones and phases of the master planning are:

- 07/2017: Decision on shutdown dates
- 2015-2017: Design & procurement
- 01/17 to 06/18: Delivery of components
- 10/17 to 10/18: Assembly phase
- 10/12/2018: **End of User Service Mode**. Start dismantling
- 03/2018: Start installation
- 12/2019: SR commissioning
- 03/2020: Beamline commissioning
- 25/08/2020: **Back to User Service Mode**

THE TECHNICAL CHALLENGES

In the context of R&D on the Ultimate Storage Ring, the ESRF has developed a Hybrid Multi-Bend Achromat (HMBA) lattice with the following features [1]:

- Multi-bend and longitudinal gradient in the dipole for lower emittance
- Dispersion bump for efficient chromaticity correction, and thus weaker sextupoles
- Fewer sextupoles than in DBA
- No need for "large" dispersion on the inner dipoles, giving small invariant and thus small emittance.

The lattice (Fig. 1) provides a natural horizontal emittance of Ex= 133 pm.rad, tunes working point at (76.21, 27.34) and natural chromaticity (-99, -82) [2].

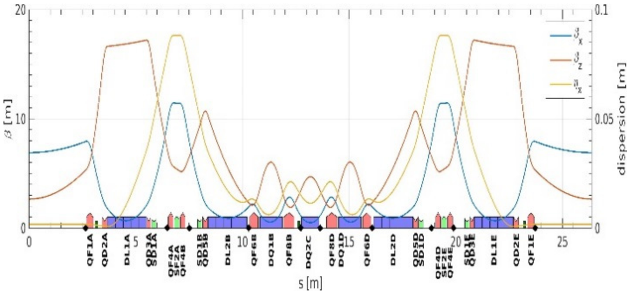

Figure 1: The ESRF Hybrid Multi Bend Achromat.

The corresponding magnet system [3] requires:

- 128 permanent magnet (Sm_2Co_{17}) dipoles with field between 0.16T and 0.65 T
- 384 quadrupoles with gradients about 52 Tm^{-1}
- 128 high gradient quadrupoles 90 Tm^{-1}
- 96 combined dipole-quadrupoles, 0.54 T and 34 Tm^{-1}

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- 192 sextupoles with strength about 1500 T/m^2, including correcting coils
- 64 octupoles, strength 30 kT/m^3
- 96 additional correctors, for horizontal and vertical steering and coupling correction.

In order to optimise the magnets and the vacuum system engineering, three beam stay-clear regions have been considered. In the central part, the beta functions are small and consequently the beam stay-clear could be reduced, making the magnet design easier in order to reach the required high gradients. The vacuum system is composed of more than 450 chambers. There are 14 main families for the arc cells, and several specific chambers. An antichamber provides space and access for discrete ultra-high vacuum pumps and cooled lumped absorbers. The central low profile vertical cross section is 13 mm while the remaining part is fixed at 20 mm. All chambers are made of stainless steel except the dipole chambers which are made from aluminium. The insertion device chambers consist of the 5 m aluminium extruded profile NEG-coated vacuum chambers already installed and conditioned in the existing storage ring. To further decrease the average vacuum pressure and the gas-bremsstrahlung in the straight section, the two chambers on each side of the straight section chambers will be NEG coated as well.

As the horizontal beta-function in the standard straight section is only 6.9 m, a special injection section has been designed with $\beta x=18.6$ m at the septum. Symmetry breaking is limited because the phase advance in each plane is identical to the standard cell, as well as the optical functions across the sextupoles. On both sides of the injection straight section, space is available for two kickers, allowing an injection scheme similar to the present one. The techniques to reduce the perturbation at injection will be further developed.

DESIGN & PROCUREMENT

The design is now completely finished, including the special cells for injection. All contracts have been placed and are now in the series production. The dipole magnets, assembled and calibrated in house, are all available. The delivery of the electromagnets is close to completion. Girders and supports supply is also nearly finished. Aluminium vacuum chambers are on schedule. Due to the complexity of the manufacturing process, the delivery of the stainless steel chambers are the elements which drive the assembly process. Absorbers, RF fingers, transition and specific chambers are almost all available. The components for the injection cells are the last to be manufactured. At this stage of the project, the storage space and logistics are a critical issue in a facility in operation.

A major milestone was reached in September 2017 with the successful completion of a mock-up of a standard cell to be used for the new machine (Fig. 2). All magnets are installed and aligned, all vacuum chambers have been connected together and inserted into the magnets, including front end vacuum lines, and have been put under vacuum. The mock-up assembly allowed the identification of many necessary corrections, which have been incorporated into the series production and to prepare the integration in the tunnel. Due to the compactness of the new machine, the engineering is challenging. Checking the integration and mounting procedures was essential.

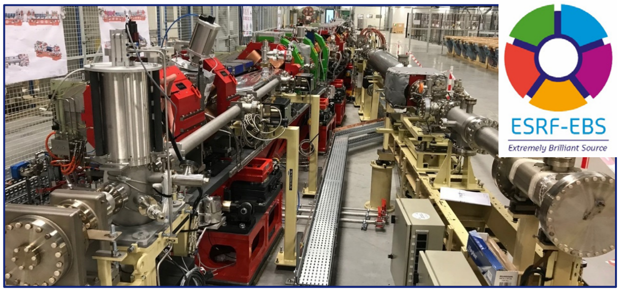

Figure 2: Mock-up cell of the new SR.

ASSEMBLY & PREPARATION

The delivery of the ESRF01 assembly building in September 2017 allowed the assembly phase of the EBS project to commence. This period, lasting from November 2017 to the end of 2018, will see 128 girders mounted with magnets, vacuum chambers and instrumentation, ready to be installed in the storage ring tunnel. The work takes place on three assembly lines, each dedicated to a specific task; mounting and aligning the magnets, placing the vacuum chambers inside the magnets, and finally closing the magnets for final precise alignment (Fig. 3). Each process lasts around a week. Then the finished girders are placed in storage, awaiting the installation phase. At the end of April 2018, 37 girders will be fully prepared.

Figure 3: The assembly lines in ESRF01.

To replace the existing 5cell cavities, 12 HOM damped cavities have been delivered and successfully RF conditioned to 750 kV. The challenging brazing of the absorbing ferrite plates of the HOM absorbers is now solved and they are expected to be delivered during 2018 and then installed.

DISMANTLING AND PREPARATION OF THE TUNNEL

Replacing an existing accelerator in operation makes the project very different to that of constructing an accelerator from scratch. Immediately after stopping the existing SR, the tunnel must be fully emptied and prepared prior to installing the new girders. This work is planned to take place

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over three months, working in two shifts per day. The removal of the SR equipment and services from the tunnel will be done using the three cranes with the tunnel roof slabs open. Almost only the equipment of the straight section will be re-used for the new SR, with some refurbishment. Each piece taken out, that will not be re-used, will be controlled by the radioprotection experts prior to disposal. Dedicated temporary buildings have been erected for this purpose. No large civil works or infrastructure modifications are needed for the new ring. Nevertheless, a few floor adaptations and some cleaning of the tunnel are foreseen. The installation of precisely aligned floor plates for the girders and support are foreseen in this phase.

INSTALLATION OF THE NEW SR

In order to minimise the coactivity and to optimise resources, the overall installation will be organized in eight groups of four cells in which similar activities will take place. Close to 12 T weight, exceeding largely the capacity of the cranes, each of the 128 girders must be lifted over the SR wall using three dedicated gantries. They will then be moved to the required location in each cell using a special moving system. It is planned to enter and position 4 to 8 girders per day.

The four girders of a cell and the DQ2 chamber in the middle will then be inter-connected and pumped. The reconstruction of the 28 straight sections dedicated to insertion devices will require significant effort to return to operational configuration. In addition, the 45 front ends must be rebuilt including a large set of new components. The three straight sections hosting the 13 single cell cavities and the injection zone will require much more time due to the presence of many nonstandard components. They are specially treated in the planning. Piping and cabling are two central activities performed by external companies driving the planning architecture and constrains.

SETUP & COMMISSIONING

The new SR will largely benefit from existing knowledge and technology developed for the present machine in terms of instrumentation and control (Tango). Many developments have been specifically made in previous years in preparation for EBS [4] in parallel to operation. In particular, the injector has been upgraded with the implementation of Top-up operation. However, a full realignment should take place for the reduction of the circumference, requiring the booster to be vented [5].

The RF power sources of the SR will be reduced from four to three stations thanks to the lower power required. Two stations will remain using klystrons, the third one will be re-constructed using the existing solid state amplifiers. The magnet power supply system will undergo the largest change in terms of architecture. Each magnet will be powered individually instead of being grouped by families like today. DC-DC converters powered by 360VDC and 48 VDC will be installed. The present AC/DC power supplies will be modified to provide the DC voltage distribution. The converters of the electromagnets of each cell will be grouped in a single cubicle including an additional converter able to replace any of them in case of failure, thanks to an intelligent hot swap system. This should help obtain the required mean time between failures. The implementation of the power supply system needs specific developments and will require a lot of tests. A simulator of the whole machine has been developed in order to test of the high level applications. The vacuum instrumentation will require additional equipment but the overall architecture will remain the same. The specific diagnostics vacuum chambers will be completely renewed, but the electronics and associated applications will mostly be reused. In particular, the present Libera BPM electronics and software will remain. The newly required electronics for the three additional BPM per cells will also been integrated and tested with beam prior to the shutdown [4]. This approach gives us confidence for the use of the turn by turn BPM configuration at the restart. Additionally, the specially developed beam loss detectors are calibrated and tested on the present SR. The two collimators, designed to locate the Touschek losses, will be a new type of device to be integrated in the operation of the SR. Design is now finished and procurement in progress.

Time will be dedicated at the end of the installation phase for power tests and final alignment. A total of three months is foreseen for beam commissioning, including vacuum conditioning. Five further months are required for the beamlines to return to operation with users. The short bend magnets replacing the dipole sources for the existing bending magnet beamlines will be installed after start-up during short shutdowns dedicated to interventions.

CONCLUSION

The project is on time and within budget thus far, with no show stoppers delaying the long shutdown. The design has been validated by the construction of a full mock-up cell. The procurement of the critical components is close to completion. The assembly of the 128 girders is in full swing and should be finished before the shutdown begins. The organisation and contracts for external support for the dismantling and installation is prepared. Installation and commissioning of the source remains the great challenge ahead. The technical and scientific community is looking forward to EBS completion with high expectations.

The present ESRF machine will be definitively stopped on 10 December 2018 after 25 years of user service. The EBS project has had no impact on user operation. The statistics remain high and still reflect the excellent reliability. The source has even benefitted from improvements due to the R&D projects, carried out in relation to EBS [4].

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