UPGRADE OF THE ESRF ACCELERATOR COMPLEX

J-C. Biasci, J-F Bouteille, J-M Chaize, J. Chavanne, P. Elleaume, L. Farvacque, L. Goirand, M. Hahn, L. Hardy, J. Jacob, R. Kersevan, J-M. Marc Koch, J-M. Mercier, A. Panzarella, C. Penel, T. Perron, E. Plouviez, E. Rabeuf, J-L. Revol, A. Ropert, K. Scheidt, D. Schmied, V. Serriere, ESRF, BP 220, F-38043 Grenoble Cedex, France.

Abstract

The ESRF which is the first third generation synchrotron radiation source, opened its first beamline in 1994 and has been continuously developed since then to satisfy the user community. However, the need has arisen to make a major upgrade of the infrastructure and accelerator complex in order to fulfil the request for new scientific applications. The experimental Hall will be expanded and a number of beam lines will be reconstructed. The storage ring lattice will be modified to provide space for longer as well as a larger number of insertion devices. New insertion devices will be developed. The electron beam positioning system will be rebuilt to provide higher photon beam stability. The RF system will face a major reconstruction with a new type of RF transmitter and HOM damped cavities allowing stable operation at a ring current of 300 mA without feedback. The injector system will be upgraded to operate the 16 and 4 bunch fillings in the top-up mode in order to increase the average current and obtain higher photon beam stability.

INTRODUCTION

The European Synchrotron Radiation Facility (ESRF) located in France is a joint facility supported by 12 members and 8 associate countries. This third generation storage ring X-ray light source, which has been in routine operation since 1994, delivers 5500 hours of beam per year to 43 beamlines simultaneously. A major upgrade of the facilities is being negotiated with the contracting partners. It includes an expansion of the experimental Hall to accommodate longer beamlines as well as the reconstruction of the beamlines. The Upgrade Programme[1] aims to improve all areas of science represented in today's experimental programme at the ESRF. However, particular emphasis is given to the following fields which have been identified as the core of this Programme for the following decade namely Nanoscience and Nanotechnology, Structural and Functional Biology, Soft matter, Pump-and-Probe Experiments and Time Resolved Science, Science in extreme conditions and X-ray Imaging. As part of this upgrade, the ESRF X-ray source will be further enhanced over the coming years. These enhancements will provide X-ray beams of even higher brilliance and flux to permit new and better science to be carried out using the ESRF beamlines. Increased numbers of photons will also allow experiments to be performed faster, an important aspect for heavily flux-limited science where measurements can currently take days, thereby increasing ESRF flexibility and capacity. The proposed modifications of the X-ray source will provide higher brilliance and flux, increased capacity for further beam lines, higher photon beam stability, increased Insertion Device (ID) flexibility and enhanced durability of the accelerator complex. These improvements will come as the result of increasing the length of selected insertion device straight sections, canting undulators, increasing the stored electron current, operating in a "top-up" mode and upgrading obsolete components of the accelerator. Figure 1 presents the associated gain in brilliance. A factor 2 gain in spectral flux will be achieved. An important boundary condition for these developments has been strongly emphasised by the User Community, namely that improvements to the brilliance must not decrease the performance of the storage ring in terms of reliability and stability. Beam stability, a key to the success of the ESRF, is therefore an essential parameter for the upgrades of the storage ring.

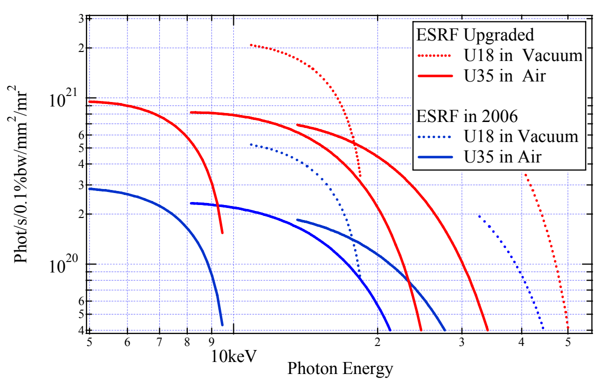

Figure 1: Brilliance of typical ESRF undulators before upgrades (blue curve) and after upgrades (increase in current to 300 mA, 7 m long insertion devices and lower vertical emittance) have been implemented (red curve).

Further increasing the brilliance by reducing the horizontal emittance has been a recurrent demand from a number of beamlines. Investigations of new storage ring magnet lattices fitting inside the existing tunnel have not yet produced a satisfactory technical solution. Any such change would also entail a considerable interruption of up to 2 years (shutdown and re-commissioning). In view of the many user communities relying on the ESRF to practice their science, such a period of time is considered to be too long. As a result, the upgrades to the ESRF accelerator and source will be made within a framework that avoids large-scale intervention on the storage ring in order to minimise disturbance to user operation, while still delivering significant increases in the quality of the source and the resulting X-ray beams.

7 M LONG INSERTION DEVICE STRAIGHT SECTIONS

The lattice of the ESRF storage ring is of the Double Bend Achromat (DBA) type with 32 cells of alternating horizontal high and low beta values. The lattice was designed with two sets of quadrupole triplets located on both sides of the 5 m long insertion device straight sections to provide maximum flexibility and to give the possibility of setting a wide range of beta values in the centre of the straight sections. This flexibility has never been used and it is possible to remove one quadrupole on each side and to use the corresponding space to enlarge the length available for insertion devices from 5 to 6 m. This has been tested and was implemented in the user mode from October 2006. A further increase in the length of the available space for insertion devices [2], from 6 to 7 m, is possible by replacing two quadrupoles on both sides of the insertion device with shorter magnets and by displacing the adjacent sextupole as shown in Figure 2.

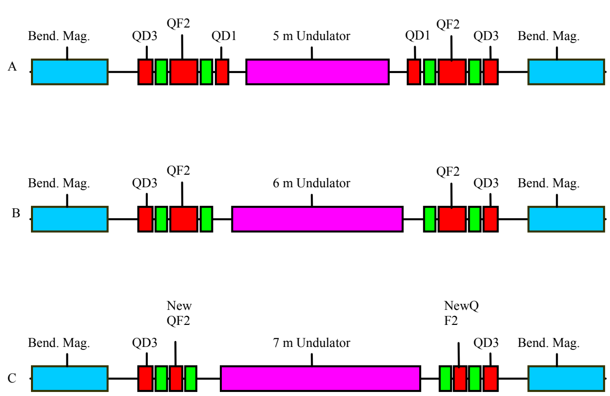

Figure 2: Schematic diagram of a high beta straight section. The blue, red and green elements are bending magnets, quadrupole and sextupole magnets, respectively. Case A represents the situation as in the first part of 2006 with a triplet of quadrupole magnets on both sides of a 5 m long undulator. Case B shows the first phase of modification consisting of the removal of the QD1 quadrupoles on both sides of the undulator, allowing the undulator length to be increased from 5 to 6 m. Case C shows the next step with the replacement of QF2 by a shorter quadrupole and the moving closer of the adjacent sextupoles giving a final available length of 7 m for undulator(s). Similar modifications can be implemented on a so-called low-beta straight section.

The alternating low and high beta undulator source points which are a highly appreciated feature of the ESRF lattice will be kept. The implementation of a number of such 7 m straight sections should be possible with minimal adverse effects on the lifetime and injection efficiency. The 7 m length available could either be used to install longer undulators and increase the available brilliance or to increase the flexibility of insertion devices. The undulators inside such a long straight section could be canted as shown in Figure 3.

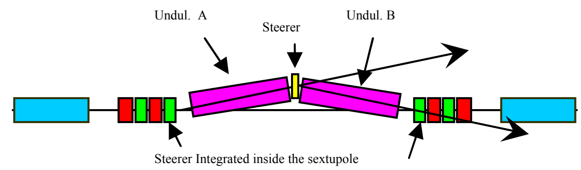

Figure 3: Schematic diagram of undulator canting. The angles in the figure are exaggerated to improve readability. The maximum angle between the beams from Undulator A and Undulator B will be close to 2 x 2.7 mrad. The canting is produced by means of three steerers located at the entrance, middle and end of the straight section. The entrance and end steerers will be implemented inside the existing sextupole magnets.

With such a set-up, two of the existing 1.65 m undulator segments (simple or of revolver type) or a 3 m long in-vacuum undulator may be installed on each of the two segments of the chicane. As has always been the case at the ESRF, specific insertion device segments optimised to the needs of each beamline (polarisation, photon energy range, harmonic content, etc.) will be developed and installed on the newly rebuilt straight sections. In particular the beamlines requiring high photon energy will make use of cryogenic in-vacuum undulators, the technology of which is in an advanced stage of development at the ESRF [3].

OPERATION WITH 300 mA

Initially, the ESRF storage ring was designed for 100 mA of electron beam. During machine commissioning the current was increased to 200 mA. A bunch-by-bunch feedback system [4], which is currently under commissioning, has allowed stable operation at 300 mA in uniform filling mode for short periods of time during machine tests. This mode of operation which still requires further tuning and optimisation will become the standard operation mode in the years to come. All multibunch modes will be delivered with a stored current of 300 mA, including uniform, 2 x 1/3 filling and the new 7/8+1 mode [5].

HIGH POWER SOLID-STATE RF AMPLIFIERS FOR THE ESRF

High power klystrons constitute the heart of the existing RF power transmitter system. As demonstrated during 15 years of operational experience, klystron instabilities constitute a large and the most unpredictable contributor to RF trips and RF down time. Confronted with these these difficulties concerning the klystrons, all of the new light sources developed in Europe (SOLEIL, DIAMOND, ALBA) as well as some existing sources (ELETTRA, SLS) have been or are developing alternatives RF power sources either based on Inductive Output Tubes (IOT) or high power solid-state amplifiers. IOTs are not available at the frequency of 352 MHz in use at the ESRF. Hence, the only alternative to klystrons is solid-state power amplifier technology. Following the pioneering results of SOLEIL, it is planned to follow the same line and gradually replace the klystron based transmitters with solid state amplifiers. The solid state power amplifiers will also be well adapted to ensure the required redundancy for the 300 mA ring current.

HOM DAMPED RADIO FREQUENCY CAVITIES

The reliability of day-to-day operations at 300 mA could suffer if it had to rely on the delicate combination of Higher Order Mode detuning of the Radio Frequency cavities through precise temperature regulation and optimum tuning of the longitudinal bunch by bunch feedback system. It is therefore planned to replace the existing 5-cell copper cavities with a sequence of single-cell HOM damped room-temperature cavities, which will provide longitudinal stability over the full range of current from 0 to 300 mA even without feedback. The new cavities will be optimised for high beam power transfer and will fit into the existing RF dedicated straight sections of the ring. A normal conducting 352.2 MHz cavity with Higher Order Mode damping is presently being designed at the ESRF [6]. The study is based on the BESSY and ALBA design with ridge waveguide HOM dampers [7].

TOP-UP OPERATION

The implementation of injection with open front ends in 2003 has improved the stability of the beamline optics due to the continuous availability of the X-ray beam. Thanks to the long life time in multibunch mode, only two short refills are performed per day with the present machine configuration. Between refills, the beam is delivered for 12 h, with a current change of 15-20 %. In contrast, the larger current variation during decay makes a frequent injection (top-up) attractive for the time-structured modes (16 and 4 bunch modes) as it will increase the average current as well as the X-ray beam stability .

These time-structured modes, as well as the hybrid mode, must be delivered with a high contrast of 10^9 between the filled bunches and the empty bunches. The process of removing the low populated bunches required for a 10^9 contrast is commonly referred to as “cleaning”. This is currently achieved in the storage ring immediately after injection by selectively exciting and intercepting the low current bunches in the vertical plane, making use of the variation of the vertical tune with the bunch current. Several solutions are under investigation to perform the cleaning process in the booster and to avoid such an undesirable excitation of the beam each time the refilling takes place in the storage ring.

OTHER DEVELOPMENTS

Several other developments and improvements to the accelerator complex will be carried-out within the proposed upgrade program. One concerns the reconstruction of the Linac pre-injector [8]. Another improvement is the replacement of the electron beam position monitoring system with a digital system. This will increase the precision of the measurement as well as the beam stability and allow a further optimisation of the lattice. The system will be designed in order to provide a continuous DC-AC correction scheme that will eliminate the closed orbit errors induced by gap changes of the Insertion Devices as has been demonstrated at DIAMOND [9]. Further studies will be carried out concerning longer term developments such as the production of short X-ray pulses as well as a lattice with ultra small emittance.

REFERENCES

[1] Science and Technology Programme 2008-2017, http://www.esrf.eu/AboutUs/Upgrade

[2] A. Ropert, L. Farvacque, “Upgrade Plans for the ESRF Storage Ring Lattice”, this conference.

[3] J. Chavanne et al., “Construction of a Cryogenic Permanent Magnet Undulator at ESRF”, this conference.

[4] E. Plouviez et al., “Bunch-by-bunch Transverse Feedback Development at ESRF”, this conference.

[5] L. Hardy et al., “Operation and Recent Developments at the ESRF”, this conference.

[6] V. Serriere et al., “Status of HOM Damped Room-temperature Cavities for the ESRF Storage Ring”, this conference.

[7] E. Weihreter, “Status of the European HOM Damped Normal Conducting Cavity”, this conference.

[8] T. Perron et al., “New Preinjector for the ESRF Linac”, this conference

[9] G. Rehm et al, “Digital E-BPMS at Diamond, operational experience and integration into a Fast Global Orbit Feedback”, DIPAC-2007.