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ESRF OPERATION STATUS

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Abstract

The European Synchrotron Radiation Facility (ESRF) is undergoing the second phase (2015-2022) of an Upgrade, which concerns its infrastructure, beamlines and X-ray source. This paper reports on the present operational source performance, highlighting the most recent developments, and the preparation of the Extremely Brilliant Source (EBS) project. The renovation of the injector and the recent operation in top-up mode are also detailed.

HIGHLIGHTS

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 (Table 1). The 32 cell Double Bend Achromat lattice of the SR provides 4 nm·rad horizontal emittance electron beam. After correction, the vertical emittance is reduced up by to 4 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. The second phase (2015-2022), called Extremely Brilliant Source (ESRF-EBS), will see the implementation of a new storage ring based on a hybrid 7 bend achromat, replacing the existing one in 2019 [1]. Reducing the horizontal emittance to less than 140 pm·rad will allow a drastic increase in brilliance and coherence. The long shutdown for installation is planned to take place over 12 months. The facility should be back in user operation in August 2020.

Table 1: Main Parameters of the Present SR

Parameter	Unit	Value
Energy	[GeV]	6.04
Circumference	[m]	844
Nominal current	[mA]	200
Horizontal emittance	[nm.rad]	4
Vertical emittance	[pm.rad]	4

Much of the recent development work has been focused on the ESRF-EBS, and major progress has been made in procurement and assembly, with the arrival of many components on site. While facing the challenges of the increased workload for the project, the ESRF has also continued to ensure excellent machine availability and reliability throughout 2017, including running preventative maintenance campaigns to replace ageing equipment, developing new diagnostics devices, and installing a new ramped injection power supply (RIPS) for the booster. Meanwhile, a lot of preparatory work has been undertaken for the new SR.

OPERATION

As a result of these efforts, one year to go before the dismantling of the storage ring, the operation statistics for 2017 are very good (Table 2). A total of 5407 hours of beam were delivered out of 5502 scheduled hours, representing an availability of 98.28% with a Mean Time Between Failures (MTBF) of 64.7 hours. The ESRF's all-time records were respectively 99.11% (2014) and 107.8 hours (2011).

Table 2: Machine Statistics

	2014	**2015**	**2016**	**2017**
Availability (%)	99.11	98.53	99.06	**98.28**
Mean time between failures (hrs)	105.5	93.6	93.8	**64.7**
Mean duration of a failure (hrs)	0.94	1.37	0.88	**1.12**

The statistics were dominated in 2017 by a few long-lasting failures and some recurrent problems with kickers. The longest beam interruption lasted more than 12 hours and occurred during the last run of the year, when a faulty valve in the water cooling system of a beamline allowed compressed air to enter the water. The second longest failure occurred the following week when a series of radio frequency arcs prevented a refill. Severe permanent damage on some parts of the waveguides were discovered. The third longest failure, lasting six hours, occurred when the circuit breaker of a full zone of the technical gallery tripped during the night, switching off all electronic devices in this area. Problems with the kickers in the injection system caused 10 beam interruptions due to a faulty thyratron and 15 trips from an erratic side effect of the synchronisation timing system, when the injection rate was switched from 10 Hz to 4 Hz after the commissioning of the new booster power supply. Aside from this, the injectors have proved their excellent reliability: more than 4000 refills took place in all modes over the year (95% of these refills were done in top-up mode). Only 3% of the refills were skipped due to minor injector problems that could be reset straight away.

In preparation for Top-up, the injector underwent major upgrades:

- New Libera Beam Position Monitor electronics
- Quadrupole movers allowing correction of the orbit at high energy

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- New orbit correction algorithm
- Two additional RF cavities for redundancy
- Linac: New gun, pre-buncher, buncher, third modulator (for redundancy)
- A new booster Ramped Injection Power Supply
- New power supplies for the septum magnets
- Bunch cleaning system

The most significant improvement was made in May 2017 when the new Ramped Injection Power Supply [RIPS] was put into operation, replacing the former resonant booster magnet power supply system. Among many advantages the RIPS system does not depend upon external temperature, making it much more stable and reproducible for the electron cleaning procedure that is carried out in the booster. The new equipment has provided the ESRF with a back-up power supply in case of failure, and has reduced the energy consumption for injection, avoiding lengthy start-up warming.

The distribution of the filling modes did not change significantly over the years, with a large preference for the 7/8 + 1 mode (Fig. 1). Today, all 4*10 mA and 16-bunch deliveries are carried out in top-up mode, with a refill every 20 minutes, allowing a very small and permanent vertical emittance in the range of 7 pm·rad.

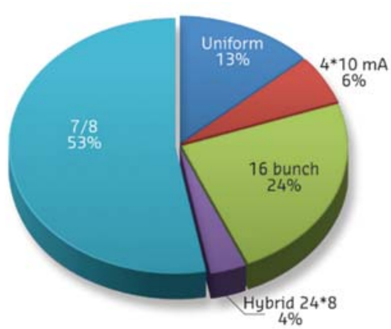

Figure 1: Distribution of the filling modes in 2017.

TOP-UP

Back in April 2016, injection in top-up mode was officially launched to users, and throughout 2017 it has been fully operational in 16- and 4-bunch modes (Fig. 2). The new mode sees the accelerators refilled with electrons every 20 minutes rather than every four to 12 hours. This results in a much higher integrated current over a 24-hour period, meaning more photons for the users and better beam stability due to smaller current variations. It also allows operating with a low vertical emittance in all filling modes. Previously, the vertical emittance would be artificially increased in some modes in order to increase the lifetime, but the nearly constant beam current provided by top-up mode means that the emittance – and the resulting brilliance and resolution for users – no longer has to be sacrificed. The top-up procedure is now well established, the sequencer fully operational, and the injection disturbance has been significantly reduced. Feedback from the beamlines is extremely positive.

In time structure mode of operation, the ESRF committed to deliver each single bunch with a purity better than 10^{-9} between the main bunch and the side parasitic bunches. A cleaning process based on a vertical resonance excitation is routinely applied in the SR. Nevertheless, despite efforts to mask the excitation on the main bunch, a residual blow-up of the beam could be observed for 20 seconds of the process. A cleaning system has been implemented in the booster based on a horizontal resonant excitation using a stripline associated to a reduction of the aperture using a scraper [2]. The cleaning is cancelled at the passage of the main bunch using a fast phase inversion of the betatron frequency excitation signal. Cleaning is applied at low energy at the beginning of the booster cycle. This technique is now routinely used with high reliability. Nevertheless, a preventive cleaning is performed in the SR once a day.

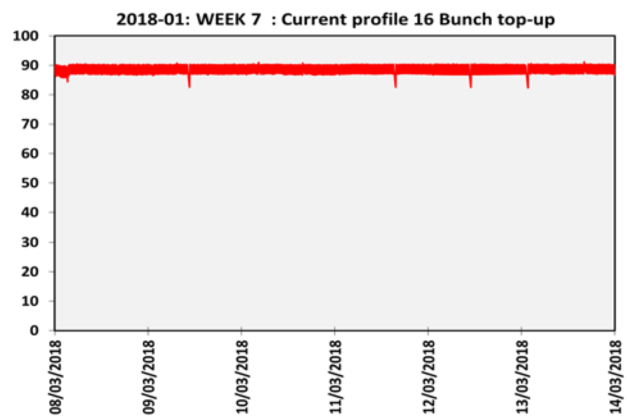

Figure 2: One week of delivery in top-up mode without a single failure, (1% missed injections).

In the context of the top-up project, the disturbance of the beam trajectory during injection has been drastically reduced thanks to the improvement of the injection kicker system and the addition of several active disturbance cancellation systems [3]. The most severe perturbation is caused by the presence of sextupole magnets inside the injection bump generated during the 2.8 μs injection revolution; these sextupoles apply extra dipole and quadrupole parasitic kicks to the beam during the rise and fall of the bump amplitude. The dipole parasitic kick has been reduced to half of its initial amplitude by the addition of conductive shims inside the kicker magnets, introducing a non- linear field component to the normal dipole field of the kickers that partially cancels the parasitic effect of the sextupoles. The remaining parasitic horizontal kick is further reduced by the application of a set of correction kicks produced by an auxiliary kicker able to produce arbitrary shape kicks matching the residual perturbation. An octupole has also been installed in the injection bump in order to compensate the quadrupole parasitic kick. A vertical parasitic kick is also present, caused by some misalignment of the injection kickers. This vertical kick has been reduced by the addition of skew quadrupole magnets inside the bump and a vertical correction kicker driven by an arbitrary shape correction signal generator. The septum magnets

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fired at injection also affect the stored electron beam. The fast orbit feedback has been modified by implementing a feed- forward feature. This feedforward, triggered at each injection, applies a set of correction kicks to cancel the orbit distortion. The techniques developed and the expertise gained during this work will be useful for the new machine.

In view of the implementation of top-up in 7/8+1 filling mode, foreseen for 2018, tests were performed in collaboration with users in November 2017 (Fig. 3) and April 2018. The tests evaluated the impact of injection on the more demanding beamlines, exploiting the coherence.

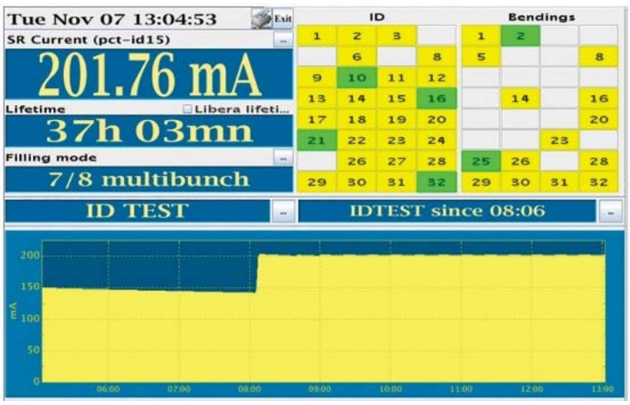

Figure 3: The control room synopsis during tests of top-up operation in 7/8+1 filling mode in Nov 2017.

PREPARATION OF THE UPGRADE

During machine operation and shutdowns many activities were being performed in parallel, in preparation for the EBS project [1, 4]:

- Insertion Device vacuum vessel conditioning in the free straight section of cell 14 of the storage ring. New chambers are installed each shutdown. All ID vessels should be conditioned before the long shutdown in order to reduce the level of bremsstrahlung.
- Test with beam of new RF finger design and new sector valve design.
- The magnet power supply system will be one of the subsystems which will undergo the largest modification changing from family power supplies to individual power supplies feed by a VDC network. The upgrade of the present power supplies to be used as the common sources for the DC-DC converters has started. Cables have already been laid along the technical gallery for the new system.
- New beam loss detectors (BLDs) have been developed and procured for EBS. The 128 BLDs have been calibrated, installed and commissioned on the present storage ring. They now replace the old system for operation. BLDs will be crucial diagnostics for the start-up of EBS. The experience gained on the system will be very valuable.
- The number of BPMs will increase from 7 to 10 per cell for the new SR. Additional BPM electronics using more recent technology have been procured. All modules will be installed and tested with beam on the present SR, in order to debug the mix of two type of Libera electronics.
- A new tune monitor based on Libera Spark electronics has replaced the obsolete system.
- A new bunch by bunch feedback developed at Diamond Light Source will be tested in parallel of the existing system before the shutdown [5].
- An upgrade of the klystron transmitter's local control is almost complete.
- New arc detection electronics are progressively replacing the old systems to improve reliability.
- New one micron filters have been installed on the deionized water cooling network. It has improved the reliability of the flowmeters of the present storage ring, and will help to keep the new cooling network clean at start-up.
- Installation of a liquid nitrogen loop in the technical gallery for the cryogenic cooling of in-vacuum devices. The loop will replace the existing individual cooling system, allowing an easier installation of additional devices in the future.
- EBS will benefit from the present up to date Tango control system. Software development are continuing with the refurbishment of old applications and the preparation of the integration of new device.
- A new machine interlock system is under development
- A new timing system is being implemented [6]. The refurbishment of the obsolete accelerator synchronisation system is based on the White Rabbit technology developed at CERN. A specific module, WHIST, has been designed for that purpose. The first tests, including connection to the real machine, are very satisfactory and the goal is to be ready with the core of the new system in user mode before the shutdown.
- In addition to the work performed for Top-up operation, the booster underwent specific activities in preparation of EBS. In particular, additional plates were installed under equipment in the booster in view of the circumference reduction to enable the increase by 170 kHz of the RF frequency imposed for the new SR.

CONCLUSION

The present ESRF machine will be definitively stopped on the 10th December 2018, after 25 years of user service. Since the beginning the source has benefitted from large investments for maintenance and development. Until today, the performance of the machine has steadily been improved while guaranteeing excellent operation statistics. This effort has not been impacted by the challenges of procuring, pre-assembling the new EBS storage ring and preparing its installation in 2019.

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