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OPERATION AND DEVELOPMENTS AT THE ESRF-EBS LIGHT SOURCE

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Abstract

The European Synchrotron Radiation Facility - Extremely Brilliant Source (ESRF-EBS) is a facility upgrade allowing its scientific users to take advantage of the first high-energy 4th generation storage ring light source. In December 2018, after 30 years of operation, the beam stopped for a 12-month shutdown to dismantle the old storage ring and to install the new X-ray source. On 25th August 2020, the user program restarted with beam parameters very close to nominal values. Since then beam is back for the users at full operation performance and with an excellent reliability. This paper reports on the last year operation performance of the source, highlighting the ongoing and planned developments and the sustainability efforts.

INTRODUCTION

The ESRF, located in Grenoble, France, is a facility supported and shared by 21 partner nations currently. This light source, in operation since 1994 [1], keeps delivering 5500 hours of beam time per year. The chain of accelerators consists of a 200 MeV Linac, a 4 Hz full-energy booster synchrotron and a 6 GeV storage ring (SR) with 844 m circumference.

In 2009, the ESRF has embarked on an upgrade programme of its infrastructure, beamlines and accelerators. The second phase (2015-2022), saw the design and the installation of a new storage ring based on a hybrid multi-bend achromat (HMBA) replacing the double-bend lattice [2, 3, 4, 5]. Reducing the horizontal emittance from 4 nm·rad down to 133 pm·rad (Table 1) allowed a dramatic increase in brilliance and coherence.

After 6 months of commissioning, the beam was back to users on 25th August 2020, the initially targeted date [6, 7, 8, 9, 10, 11].

Today, a large variety of insertion devices (44 in-air, 6 in-vacuum and 8 cryo-in-vacuum undulators, as well as 4 wigglers) are installed along the 28 available straight sections to give X-rays to 31 independent end-stations (some beamline have separate operating end-stations). Bending-magnet radiation, now produced by short bends and 2 or 3-pole wigglers, is used by another 17 beamlines.

USER-MODE OPERATION

After the commissioning and the Covid-19 periods, the yearly operation schedule is back to standard since 2022, i.e. 5 runs of User Service Mode (USM) separated by 5 shutdowns periods.

Table 1: Main Parameters of the Old and New SR

	Units	ESRF	ESRF-EBS
Energy	GeV	6	6
Circumference	m	844.4	844
Lattice		DBA	HMBA
Current	mA	200	200
Lifetime	hr	50	23
Emittance H	pm rad	4000	133
Emittance V	pm rad	4	10*

(*) Vertical emittance increased from 1 to 10 pm rad.

Filling Modes

During 2023, five different filling patterns were delivered: 7/8 + 1, uniform, 16-bunch, 4-bunch and hybrid 28x12+1 modes (see Fig.1).

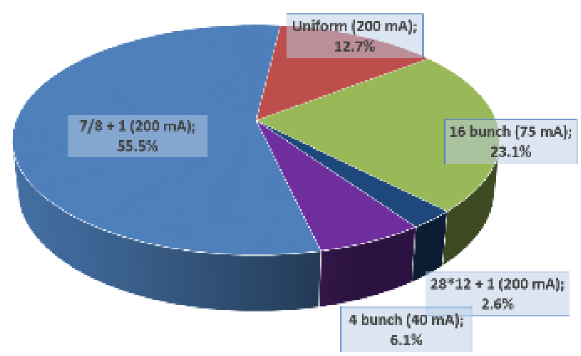

Figure 1: Distribution of beam modes in 2023.

The 16-bunch mode is still provided with an intensity limited to 75 mA due to the heating problem on the kickers' ceramic chambers. A new design of those chambers that significantly reduces its heating has been completed. The first of these 4 chambers has been installed in March 2024 but very first results are not fully satisfactory, likely due to a lack of Ti-coating on the junctions (under investigation). This chamber will be exchanged in summer 2024 with a new one. Two more chambers should be installed in autumn 2024 and the last one in Winter. Provided no hiccup occurs, this should enable us to deliver the nominal beam current of 90 mA early 2025.

Concerning the 7/8+1 and uniform modes, all nominal parameters have been successfully reached and delivered, i.e. an intensity of 200 mA with the single bunch current of 8 mA, a beam lifetime greater than 23 hours and an artificially stabilized vertical emittance of 10 pm·rad. Still, the injection efficiency remains below the nominal design

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(90%) with an average of ~ 70 % ± 10 % over the last months. The top-up occurs every hour for all beam modes.

For the time structure modes, the vertical emittance blow-up is fixed at 20 pm rad of 16-bunch and 40 pm rad of 4-bunch mode, respectively, in order to keep a reasonable lifetime and maintain 1-hour top-up. All the time-structured modes have been delivered with a purity of more than 10^{-9} between the filled and empty buckets with a cleaning process applied in the booster and occasionally in the SR.

RELIABILITY AND STATISTICS

The reliability of the new accelerator complex is comparable to that of the previous machine in its last years (see Table 2 and Fig. 2). 2023 is the second year with a standard operation schedule since the launch of EBS. 2022 was already an exceptional year, with 99.06% availability and 88.5 hours of Mean Time Between Failures (MTBF). Compared to 2022, the number of beam failures in 2023 decreased from 62 to 52, thanks to high quality maintenance.

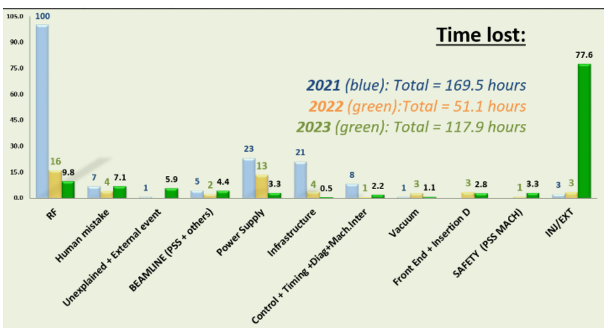

Figure 2: Distribution of failures in number and time.

The performance of the accelerators was excellent (99.2%) until November 2023, when the longest beam interruption of the year occurred. A copper cooling-water tube in the S3 septum magnet (used to inject the beam into the storage ring) broke, causing a severe water leak (Fig. 3). Fortunately, the water did not reach the parts under vacuum. The septum repair and vacuum restoration was limited to 78 hours thanks to experts working 24/24 to minimize the downtime. In November and December, the Machine-Dedicated Time (MDT) days were reorganised to give back 78 hours of beam to users to compensate for the time loss and allow them to perform or finish experiments that were affected by the failure. Taking this compensation into account, the machine availability of 2023 reached 99.28%. Without this time compensation, this single failure would have justified a year's beam availability of 97.85%, with a good MTBF of 105 hours.

In February 2023, an external event caused a long interruption when a glitch on the 20 KV electrical network forced the high-quality power supply (HQPS) to trigger the blackout protection system, tripping the power supplies, the RF and reducing the water flow. This event happened outside working hours and led to a beam interruption of 4 hours.

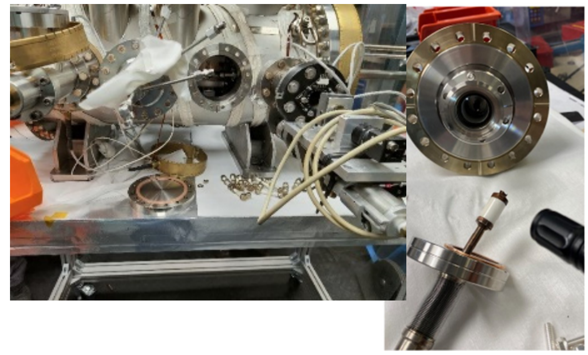

Figure 3: Broken copper cooling-water tube in the septum magnet.

In August, the Personal Safety System (PSS) of the Storage Ring triggered, due to premature ageing of the cables and emergency push buttons inducing false or spurious contacts. Indeed, this cabling was the only parts which had not been replaced during the EBS reconstruction. Consequently, all cables and buttons of half the Storage Ring areas were replaced in 2023. Remaining zones will be completed in 2024.

From January 2023 to December 2023, over the 5409 refills, only 64 were skipped (1.2%). This good result should be mitigated by the fact that with 1 hour toping up frequency, the operator is able to follow the refills and intervene on the fly to solve problems.

Statistics

Table 2: Machine Statistics (until December 2023)

	2021	2022	2023
Availability (%)	96.4	99.1	99.3
Mean time between failures (hrs)	66.4	88.5	107.1
Mean duration of a failure (hrs)	2.42	0.83	0.77
Number of refills		5414	5409
Number of skipped refills		87	64

OPERATION-RELATED DEVELOPMENT

Hot-Swap system for Power Supplies

The 864 electromagnets (512 quadrupoles, 192 sextupoles, 96 dipole-quadrupoles, 64 octupoles) are fed by individual DC-DC converters associated with a 360 V DC distribution network. Despite the increased amount of equipment and the complexity of the layout, the reliability of the system has been remarkable since the early days of operation. In the first days, it had mostly suffered from low-level control access weakness and from interfacing with the communication network. This is now solved. The hot-swap function, which goal is to increase the reliability by switching from a faulty PS channel to another in a few ms (when a specified ΔI is detected) has been successfully tested and put in operation. Today, all quadrupoles and DQ magnets are fully covered by the Hot Swap system. By the end of 2024, sextupoles and octupoles will also be covered

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(MOSplate cards have been delivered and are now being tested in lab). As an ironic fact, this system has not yet demonstrated its potential in increasing the availability in the sense that all Statum PS racks are so reliable that not a single channel failed during User Service Mode in 2023!

Solid-State Amplifiers (SSA)

Presently, out of a total of 13 RF cavities, 10 are fed by a single klystron transmitter [12], with a spare ready to take over. Three others cavities are each fed by one SSA tower. Due to the obsolescence of klystrons and in order to improve the redundancy and flexibility to repair, we plan to replace all klystrons by ten 110-kW SSAs. The implementation was supposed to start last year but difficulties to meet the specifications (mainly the efficiency of the RF pallet and of the AC/DC converter) resulted in a serious delay. We estimate today that the first SSA which will meet the specifications should be delivered in March 2025 and connected to the Storage Ring during summer 2025. Two SSAs should be installed at every long shutdown, until summer 2027 when this implementation will be completed.

Mini-beta Optics

High-energy experiments (i.e. using high-undulator harmonics) could benefit from an improved brilliance achieved with low-gap short undulators installed in the middle of a straight section, associated to reduced beta functions. A test bench has been installed in ID31 for this purpose. The mini-beta optics was validated experimentally and performance matches theoretical expectations with a lifetime reduction of approximately 20%. Last tests were done in April 2024 at the beamline and data, which look promising, are still being processed [13].

Injector Upgrade

Some upgrades of the injector are under-going in order to reduce the perturbations at injection and to improve the injection efficiency in view to accommodate future development of the storage ring.

First the injection septum in the SR will be moved closer to the beam in order to minimize the perturbations with a reduced bump. Then, the development of a multipole kicker has started and prototype should be available soon. In parallel, the SLS stripline kicker has been tested on the ESRF storage ring.

An upgrade of the present 200 MeV Linac has been initiated. Some components will be exchanged and a complete revision of the control system should take place in order to get more modularity in case of failures. A risk analysis of the injector also requires the upgrade or spare procurement of some critical components.

In parallel the study and design of a new Linac based on new technology allowing increased accelerating gradient has started.

A new booster lattice or a full energy Linac could also be envisaged in the long term, but it will require a much larger investment and downtime of the facility.

CONCLUSION

Three years after EBS produced its first beam to the Users, almost all specifications have been reached, except the nominal intensity in the 16-bunch mode. All new equipment built or bought for EBS look to be particularly reliable. The few failures which affected the beam availability mainly come from the equipment or design kept from the previous machine. The only bad surprise came from a faster degradation of cables due to radiations. This was solved as soon as it had been identified, such that only a few hours of beam interruptions were attributed to this issue. Today the main guidelines are: reducing even further the perturbations at injection, implementing the SSA RF-tower and define a strategy to upgrade the injector.

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