# OPERATION AND RECENT DEVELOPMENTS AT THE ESRF

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*Abstract*

The ESRF has been operating for fourteen years and is now looking towards an ambitious upgrade programme for the coming years. This paper reports on the performances achieved today with the ESRF storage ring, as well as developments accomplished. These include a new time-structured filling mode, the evolution of insertion devices, developments to improve beam stability, in particular transverse and longitudinal multibunch feedbacks. The upgrade of the lattice to accommodate longer straight sections and the new High Quality Power Supply system will also be presented. The machine reliability and the most important failures will be discussed.

## THE ESRF IN 2007-2008

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 is in routine operation since 1994, delivers 5500 hours of beam per year to 43 beamlines simultaneously.

A large variety of insertion devices are installed in the 28 available straight sections. The present configuration of the ring includes 70 segments of insertion devices shared as follows: 53 in-air undulators, 6 wigglers, 11 in-vacuum undulators (2 metre-long) including 1 prototype cryogenic in-vacuum undulator [1]. Bending magnet radiation is used by 15 beamlines.

Table 1: ESRF storage ring main parameters

| | | |
|---|---|---|
| Energy | [GeV] | 6.03 |
| Maximum current | [mA] | 200 |
| Horizontal emittance | [nm] | 4 |
| Vertical emittance (minimum achieved) | [nm] | 0.025 |
| Revolution frequency | [kHz] | 355 |
| Number of bunches | | 1 to 992 |
| Time between bunches | [ns] | 2.82 to 2816 |

## OPERATION 2007-2008

### *Statistics*

In 2007, 5455 hours of beam were initially scheduled. Of these 5455 hours, 5343 were effectively delivered (including 56 hours of refill). This represents a beam availability of 97.9 %, which is slightly less compared to the previous year, mainly due to a single major failure of a stripline chamber (see below). Dead time due to failures accounts for the remaining 2.06%. The number of failures is however comparable to the previous year, thus leading to a Mean Time Between Failures of 56.8 hours (fig.1). Thirteen long delivery periods (*i.e.* more than 100 hours) without a single interruption took place in 2007, two of those weeks even lasted 168 hours!.

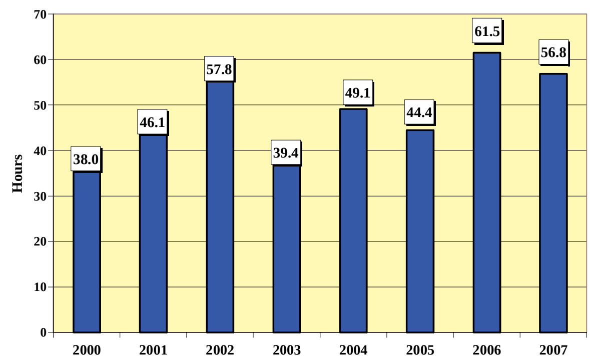


Figure 1: Evolution of the Mean Time Between Failures.

### *The Main Disturbing Events*

In July 2007, a major vacuum leak developed in the feedthrough of a stripline vacuum chamber used for beam diagnostics. As a result, two cells (~ 50 m) of the ring circumference reached atmospheric pressure requiring full vacuum processing with baking. Seventy-six hours of user time (user service mode, USM) were lost following this incident. The autumn operation schedule was subsequently revised and it was possible to gain two days within the user program to compensate for the lost beamtime.

The non functioning of the High Quality Power Supply (HQPS) [2] during certain periods of 2007 was the second cause of disruption this year. There were a total of 22 beam losses caused by electrical mains drops which could not be covered by HQPS. Those failures were concentrated after the definitive shutdown of HQPS in September 2007. In 2007, electrical main drops resulted in a total loss of 23 hours !

### *Filling Pattern*

In 2007-2008, multibunch modes remained dominant, making up 71 % of the shifts. However, in the multibunch mode family, the so-called “7/8 + 1” was a newcomer.

This mode was first delivered in 2007. It is now considered to be a good compromise for all Users: those needing time-structure and those needing high current and long lifetime (see figure 2). The unfilled gap in the time structure (1/8 of the circumference) stabilises the electron beam against ion instabilities. The filling pattern is delivered with an emittance of 25 pm or smaller in the vertical plane. A single bunch of 2 mA, placed in the middle of the gap, is delivered with a contrast ratio of $10^{-9}$ between filled and unfilled bunches.

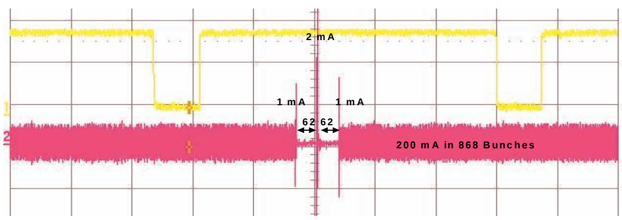


Figure 2: The new 7/8 + 1 hybrid mode

## DEVELOPMENTS INTO OPERATION

### *Lattice*

The installation of canted undulators in some straight sections of the storage ring is envisaged as part of the upcoming upgrade. This involves the installation of 2 undulators in a single straight section with an angle between them to allow the physical separation of the two undulator beams downstream in the beamline. To maximize the flux and brilliance of each undulator segment, as well as those of a normal uncanted beamline, the possibility of increasing the available space for insertion devices in straight sections beyond the 5 m currently available has been investigated. Investigations have been carried out into a new lattice without current in the 2 quadrupole families adjacent to the straight sections which would allow all ID straight sections to be increased to 6 m (fig.3) [4]. However the lifetime of that lattice which was put into operation in 2006 suffered a reduction of the order of 20 %. New investigations were carried out in 2007 to improve this situation: a new lattice keeping zero current in the same families with a beta function of 3 m in the middle of the straight section (as opposed to 2.5 m from 1998 to 2006 and 3.5 m from 2006 to 2007). This lattice shown identical or better lifetime than the original one used before 2006 and was put into operation in 2007.

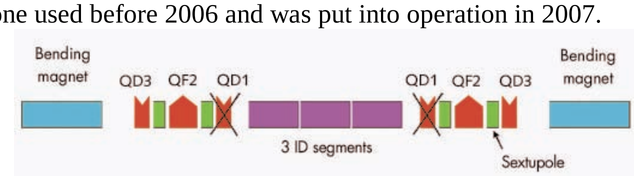


Figure 3: sketch of the new long high beta straight section.

### *Transverse and Longitudinal Feedbacks*

Bunch by bunch feedback systems making use of fast digital electronics based on field programmable gate arrays (FPGA) have been commissioned [3].

The longitudinal one has been developed to damp the beam instabilities driven by the higher order mode of the RF cavities. For operation, such instabilities are avoided by a careful tuning of the temperature of the cavities. But this method is not sufficient at higher current and the use of the longitudinal feedback was mandatory to ramp for test the current to 300 mA.

The horizontal and vertical feedback systems allowing to damp transverse resistive wall instabilities and ion driven instabilities have been used to operate the machine at zero chromaticity in multibunch. Thanks to a lifetime larger than 60 hours, the damping of such instabilities with an increased chromaticity is still used for normal operation, instead of the newly possibilities offered by the feedbacks. Nevertheless, at the end of 2007, the vertical feedback was operated regularly in user time (USM) to reduce the beam blow up produced by ion driven instabilities in uniform mode. Figure 4 presents the image of the beam as seen through a pinhole camera without (left hand-side) and with (right hand-side) feedback. The effect of the feedback systems is particularly noticeable after the shutdown following the venting to air of vacuum vessels resulting in an ion driven instability which excite the beam.

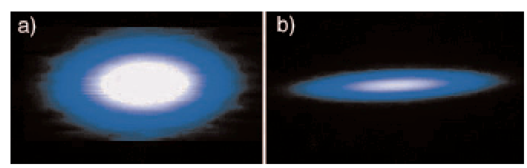


Figure 4: The electron beam in a bending magnet
a) No vertical feedback; b) Vertical feedback in use

The ramping to 300 mA performed during the test severely increase the vertical emittance and necessitated the usage of the vertical bunch by bunch feedback. Bunch by bunch feedbacks have also been tested to cure single bunch transverse instabilities. It allowed to reduce the chromaticity but not to operate at zero chromaticity.

### *High Quality Power System Version II*

The previous High Quality Power System (HQPS) has been in operation since July 1995. It was made up of a set of 10 rotating electrical accumulators coupled to an alternator and a diesel engine. Its function was to protect the machine by avoiding an electron beam dump following a voltage or phase drop which can occur during stormy. Repetitive failures of the Diesel engines started in 2002. A number of repairs and interventions were carried out between 2003 and 2007 which each year allowed the HQPS system to be restarted for the spring and summer seasons when the main drops are frequent and deep. The high number of interventions and repairs to the diesel engines resulted in a premature aging of the system and numerous shutdowns in summer 2007. Following these difficulties, a new system called HQPS II was ordered an put in operation. Its power has been extended from 8 to 9.3 MW in anticipation of the future 300 mA operation.. The new HQPS system has no diesel engine or clutch which were the main source of the problems encountered on the HQPS I system. The dismantling of the HQPS I system and installation of HQPS II started in October 2007. The HQPS II system has been put in Operation in May 2008.

### *Cryogenic in-Vacuum Undulator [1]*

In order to reach a higher field for the same gap and period, one direction consists of cooling the NdFeB material of an in-vacuum undulator to about 150 deg K. At such a temperature both the coercitive field and the remanence increase. It was decided to develop this technology in two steps. The first step consists of an undulator the magnets of which can be baked at 120° C therefore guaranteeing its usability at room temperature on any ESRF beamline ; the price to pay for this is a peak field increase limited to 10% instead of 35 %. With this prototype, efforts were focused on the development of the cryogenic engineering aspect and the development of the field measurement at cryogenic temperature compatible with an accurate phase error re-construction. Following a successful magnetic field measurement campaign, the undulator was installed on the ID6 beamline and has operated at cryogenic temperature since January 2008. The uncorrected measured closed orbit distortion is within 10% of the rms size as expected from the magnetic measurements.

### *Vacuum System*

Following the major failure of a crotch absorber in March 2005 which resulted in 5 days of USM being lost, it was realised that all 62 crotches located downstream of all the bending magnets in the storage ring were developing the same defect which is linked to corrosion induced by Xrays propagating in water in a copper tube. As a result, the design of the crotch was modified in order to further attenuate the Xray beam in the most critical area. A new set of crotch absorbers was ordered and were installed at regular intervals during the scheduled ring shutdowns. As of February 2008, 58 crotches have been replaced. The remaining 4 original crotches will be replaced in summer 2008.

### *E-logbook Linked to Tango Control System[9]*

Our commercial electronic logbook has been interfaced to the Tango control system. This gives new powerful features like automatically generate messages on specific events and retrieve historical data from Tango database. To perform such automatic data access, we use the logbook as a subscriber for Tango events. When Tango sends events, the logbook is able to generate automatic logs and record them in its own database.

## FUTURE

In the context of the ESRF upgrade for the next 10 years [8], the storage ring lattice will be modified to provide space for longer as well as a larger number of insertion devices [4]. New insertion devices will be developed possibly based on in-vacuum permanent magnets at cryogenic temperature [1]. The electron beam positioning system will be rebuilt to provide a higher photon beam stability, using the Libera technology [5]. The RF system will face a major reconstruction with a new type of RF transmitters and HOM damped cavities allowing stable operation at a ring current of 300 mA without feedback [6]. 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 a higher photon beam stability [7].

## CONCLUSION

The accelerator availability reached almost 98 % for a Mean Time Between Failures of 57 hours whilst new devices were commissioned and put into operation. The upgrade program for the next 10 years will even increase the potential of the storage ring.

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