LATEST DEVELOPMENTS AT THE ESRF

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Abstract

After nine years of operation for users, the ESRF reliability reached a record uptime of 96.8% in 2001. In parallel to the effort to improve the operation, the upgrade of machine performances is being pursued. This paper will present an overview of the on-going developments. Tests to increase the current from 200 mA to 300 mA have been successfully initiated. Beam position stability has been further refined using a feedback and the installation of damping links on the magnet girders. Increased brilliance and extended tunability of undulators to higher energies are achieved with the operation of 4 in-vacuum undulators at gaps of 6 mm. Front-ends are being upgraded to withstand the power generated by 5 m long, 11 mm gap undulators. The test of the super-conducting SOLEIL type RF cavity is in full swing. The feasibility study of the Ultimate Storage Ring Light Source is under way.

1 OPERATION DATA IN 2001

1.1 Statistics

Year 2000 was already a year with records of availability and Mean Time Between Failures. In 2001, once again, these records were surpassed. A total of 5400 hours were scheduled for beam delivery to the Users, out of which 5224 hours were really delivered, which represents a record of availability of 96.8 % (to be compared with 96.4 % in 2000)! The remaining hours are to be shared between the inescapable dead time for refills (1.4 % of the User time) and failures (1.8 % of the User time for 117 beam interruptions). This gives an unbeaten MTBF of 46.1 hours (to be compared with 38 hours in 2000). The improvement of these two important figures of merit reflects a decrease in both repetitive failures and ‘long’ failures.

It is to be noted that there were 22 periods with more than 72 hours of delivery without a single failure, amongst which 9 periods greater than 100 hours!

1.2 Active maintenance policy

The ESRF maintenance policy has been reinforced for more than 2 years. Repetitive failures, which would spoil the MTBF, are thoroughly traced. As one typical example, RF arc detections were a major contributor to MTBF limitation: in 2000, the Machine was stopped 38 times due to this kind of failure, representing an MTBF of 146 hours for this ‘equipment’. After a careful study of triggered signals and an appropriate retuning of arc detectors, the MTBF for this device presently reaches 404 hours! As an example of preventive maintenance applied to long failures, radio-gammagraphies are now systematically carried out after each vacuum intervention, at the locations of the RF fingers so as to detect early problems in the mounting procedure. We have had no more RF fingers melting on the path of the beam since this procedure has been applied and we can estimate that about 1 % of availability has been gained since then.

1.3 Single bunch evolution

In the past, single bunch operation was mainly governed by vertical beam instabilities. It is now affected by an increase in the horizontal impedance following the installation of narrow gap vessels and by the incoherent horizontal detuning induced by the asymmetry of the vacuum chamber [1].

2 TOWARDS 300 mA

2.1 Intensity ramping

Since 1996, the storage ring has been routinely operated with an intensity of 200 mA in the multibunch mode, i.e. twice the design current. Tests to increase the intensity to 300 mA have been recently initiated with a view to identifying possible experimental limitations and to defining the necessary R&D program with a long-term goal of delivering this current to Users.

Since HOM driven instabilities would very likely prevent 300 mA from being reached in uniform filling, tests were performed when filling only 1/3 of the ring. The periodic beam loading of the cavities induces a spread in synchrotron frequencies in the bunch train that prevents the constructive built-up of the instability. To guard against resistive wall instabilities, the chromaticity (ξ_x=6.7, ξ_z=9.5) was increased above the routine multibunch values. With these precautions, the first attempt to ramp the intensity above 200 mA was rather easy. No abnormal pressure rise or temperature increase on critical components (crotch absorbers, RF windows) was observed. Fugitive HOMs were cured by a slight retuning of cavity temperature. However, at 250 mA the radiation induced outside the shielding exceeded the authorised level and the tests were temporarily interrupted.

The lifetime was rather moderate: 17 hours as compared to 80 h at 200 mA in uniform filling mode. This is due to the increased Touschek lifetime contribution induced by the 1/3 filling pattern, to the higher than necessary chromaticity applied and to the higher pressure in the ring chamber induced by the extra synchrotron radiation power incident on all absorbers.

2.2 Heat load

From the heat load and thermal stress point of view, the crotch absorber is the most critical component in the storage ring. Since the actual crotch absorber made of glidcop is operated at the elastic limit of the material at 200 mA, a safe operation at higher current has to be questioned. In order to assess the temperature and stress limits for the copper absorber, tests have been carried out on a test beamline. An OFHC copper crotch absorber was placed 16 m from the source point and exposed to the power emitted by one segment of a U34 undulator during about 1 month, and two segments during 2 to 3 hours. The OFHC copper absorber safely withstood the high heat load without any notable damage. The temperature on the absorber surface measured by using an infrared pyrometer was consistent with finite element simulations. These results confirm that the thermal stress induced by very concentrated synchrotron radiation power is less harmful than pure mechanical stress.

3 FRONT-ENDS

Due to the upgrade of machine performances (stored current increase, low gap 5 m long chambers, in-vacuum undulators…) a new high power front-end [2] has been developed to withstand the power density generated by 5 m long, 11 mm gap undulators. An upstream pre-slit and a compact high heat load absorber have replaced the x-ray absorber. A CVD diamond window has replaced the Beryllium window and graphite filters usually employed.

Commissioning was successfully performed in 2000 on ID23 test front-end at a total power density of 300 kW/mrad^2. Four front-ends are upgraded every year. At the end of 2002, a total of 13 front-ends will be upgraded.

Intensive tests are in progress with several companies, to improve brazing procedures and also develop other joining techniques for Glidcop AL15, OFHC copper and stainless steel material.

4 INSERTION DEVICES

The construction of in-vacuum undulators started in 2000. Four devices with spatial periods of 17, 18, 21 and 23 mm have been completed. The nominal length of in-vacuum undulators is presently 2 m. Three undulators are in operation while the installation of the last device (period 18 mm) will take place in summer 2002. Their operation at 6 mm gaps shows a limited reduction of the beam lifetime (≤10 %). The in-vacuum undulator technology is the only reliable way to reduce gaps below 11 mm. Compared to conventional in-air IDs, ESRF in-vacuum undulators give improved photon fluxes in a limited energy range below 40 keV, using the fundamental and third harmonic (periods 17 and 18 mm) and above 40 keV with tunable devices (period 21 and 23 mm). The latter case is considered as the most important figure of merit for the upgrade of a number of beamlines operating a significant portion of their time at high photon energy (50 keV to 100 keV). Fig. 1 compares the flux collected in an aperture of 0.5*0.5 mm^2 at 30 m from an in-vacuum undulator (λ=23 mm, L=2 m, g=6mm, K=1.6), a standard (in-air) conventional undulator (λ=35mm, L=1.6 m, g=11 mm, K=2.2) and a wiggler (λ=125 mm, L=1.6 m, g=20 mm, K=14), when assuming standard ESRF beam parameters in a low beta straight section. It reveals the advantage of in-vacuum undulators operating on high harmonics of the spectrum (harmonics 9 to 15). Note that spectrum shimming is applied on the in-vacuum undulator giving a residual r.m.s optical phase errors below 2 degrees.

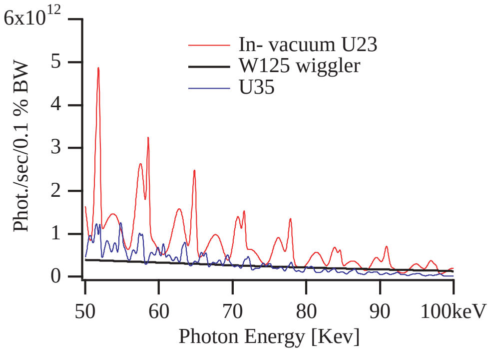

Figure 1: Computed flux for 3 ESRF IDs

Three new in-vacuum undulators (periods 22 and 23 mm) are presently being built for the ID11 and ID30 beamlines. Both high-energy beamlines will be fully equipped with in-vacuum undulators in the near future.

5 BEAM STABILITY

A major improvement in beam stability was achieved after the installation of two damping links on each of the 96 quadrupole girders. These links are designed to damp the main vibration mode of the girders (horizontal translation of the girder at 7 Hz) by using visco-elastic material. The main improvement is obtained in the horizontal plane, in the frequency range 4-12 Hz, but as shown in Table 1 and 2, a significant improvement can also be seen in broad-band (4-200 Hz) and in the vertical plane.

Though the beam vibrations in the horizontal plane are reduced by the damping links to an acceptable level (1 % of the beam size), some users are still requiring a better stability. For this purpose, local feedback systems have been installed on 4 straight sections.

Table 1: Horizontal r.m.s.beam motion in the middle of a high-β straight section (β_x = 35.4 m)

	4-12 Hz	4-200 Hz
no damping links (µm)	10	12
with damping links (µm)	2.7	4
damping links + feedback	0.28	1

We are now upgrading the system with a global horizontal feedback using 32 BPMs and 24 correctors.

The damping links also provide some damping in the vertical plane, so that the vertical beam motion is now close to the resolution of the BPMs. The improvement due to the vertical global feedback is now moderate.

Table 2: Vertical r.m.s.beam motion in the middle of a high-β straight section (β_z = 2,5 m)

	4-12 Hz	4-200 Hz
with damping links (µm)	0.5	1
damping links+feedback	0.17	0.6

6 TESTS OF THE SC CAVITY

A cryo-module prototype housing two superconducting 352MHz-cavities was developed within the framework of the SOLEIL project design study phase. It is currently installed on the ESRF storage ring until the end of year 2002, in order to qualify the HOM-free operation. It is being tested with beam in the accelerating regime at 4° K with the cavities cooled by liquid helium poured from Dewars. Four test periods are programmed over the year, at the end of ESRF scheduled shutdowns. In order not to disturb the ESRF machine performances during User time, the cavities are maintained detuned at room temperature in a passive regime. The heat generated by the beam is then evacuated by a helium gas flow cooled by a heat exchanger.

At room temperature, due to thermal expansion, the cavity is naturally tuned $3.5 \times f_{revolution}$ below the main RF frequency, keeping low the power deposited by the beam into the accelerating mode. Less than 100 W have been measured for any standard ESRF fill pattern, including HOM power. Also no interaction with any HOM of the structure has been observed. As expected, the cavity is transparent to the beam in this passive regime at 300° K.

Nominal 200 mA of beam could also be stored without any problem, with the passive, slightly detuned, SC cavity at 4° K. Beam acceleration using this prototype SC HOM free cavity is the subject of the 2nd test window presently under way. Detailed results are presented in a dedicated report at this conference [3].

7 INJECTION WITH FRONT-ENDS OPEN

An injection with front-ends opened is envisaged to minimise the heat load variation on beamline optics. Several feasibility tests were made in 2001 to assess the added radiation dose. First tests are scheduled for 2003 after installation of an interlocked radiation monitoring system close to the optics hutches.

8 THE ULTIMATE STORAGE RING

The feasibility study of the Ultimate Storage Ring based X-ray Light Source [4] is under way. A consistent set of parameters has been established (Table 3).

The technical feasibility of the main sub-systems is presently being reviewed. The status is the following:

Preliminary considerations on the design of the vacuum system are based on the operational experience at ESRF and other facilities and on the evolution of the relevant machine parameters (machine energy, beam current and dipole characteristics). Presently, the best solution for the vacuum system would be a bakeable, NEG-coated single chamber vacuum vessel, made of extruded aluminium with massive pumping at the crotch and absorber location.

The beam quality should not be spoilt by multibunch instabilities. On the RF side, this calls for strongly HOM damped cavities. A possible RF acceleration scheme using 6 SC SOLEIL type 352 MHz cavity modules occupying 3 straight sections is considered. One key feature for the RF system will be the number of closed Insertion Device gaps. They will strongly influence the RF working point (voltage, power, optimum coupling) since the energy loss per turn will vary by more than a factor of 2, depending on the number of IDs in operation.

The machine impedance is one of the critical issues for transverse instabilities. Even if the machine is operated with a large number of bunches and low bunch current, the evolution of the instability related parameters with the lowering of the emittance (smaller momentum compaction, smaller synchrotron tune, shorter bunch length, longer damping times) is expected to have a severe impact on thresholds. The use of feedback systems and the minimisation of the impedance look mandatory for achieving the intensity target goal. Compared to the ESRF impedance, the impedance would have to be reduced by a factor 3 to 5 (and even ultimately by a factor of 10). This imposes innovative solutions for the number and design of critical vacuum chamber components that will be worked out in the forthcoming months.

Table 3: Parameters of the USRLS

Energy (GeV)	7
Circumference (m)	2000
Lattice type	4-bend achromat
Emittances H /V (nm)	0.2 / 0.008
Momentum compaction	3.5×10^{-5}
Tunes H / V	92.36 / 58.30
Beam current (mA)	500
Number of cells	50 (40 ID beamlines)
β-functions at ID (m)	50 (H), 3.5 (V)
ID length (m)	7
ID gap (mm)	4 (in-vacuum) - 11
Flux @1 Å (ph/s/0.1 %)	6.5×10^{15} (11 mm gap) 1.7×10^{16} (6 mm gap)
Brilliance @1 Å (ph/s/0.1%BW/mm^2/mrad^2)	1.5×10^{22} (11 mm gap) 3.7×10^{22} (6 mm gap)

9 REFERENCES

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