STATUS REPORT OF THE ESRF

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Abstract

The ESRF is now in full routine operation with nearly 30 beamlines taking X-ray beam and opened to external Users. The performances of the Machine have been steadily improved during the last year : increase of the intensity up to 200 mA, reduction of the vertical emittance, lowering of the vertical β in the straight sections, reduction of the undulator minimum gap, all of these resulting in a significant gain on the achieved photon brilliance. In parallel to this net improvement, the routine operating standards have been largely improved with a Mean Time Between Failures larger than 40 hours and an availability better than 94 % over the 5000 hours of beam scheduled in 1996. In addition, the versatility of the Machine has been enlarged with an increasing number of operating modes so as to better satisfy the different Users' requirements (multibunch mode, single bunch mode, 16 bunch mode and various hybrid modes).

1 INTRODUCTION

The ESRF was the first of the third generation high energy synchrotron radiation sources to start User operation in 1994. The 10 years construction phase will end in 1998 with the completion of the last of the 30 ESRF beamlines. Today 27 beamlines (including 5 Collaboration Research Group beamlines) are open to the Users, and during the year 1996, a total of 518 experiments were carried out during 6563 shifts (of 8 hours) by 1777 external Users.

2 PERFORMANCES

Brilliance

At the same time the ESRF was starting User operation, a lot of developments were undertaken to increase the brilliance available to these Users [1]. The present situation is summarised in table 1.

Parameters	Units	FPR Design Goal	Routinely served in USM (April 1997)	Medium term objectives *
Current	mA	100	200	200
Associated lifetime	hours	8	50	60
Lifetime @ 100mA	hours	8	80	100
Horizontal Emittance ε_H	10^{-9} m.rad	6.2	4	3
Vertical Emittance ε_V	10^{-12} m.rad	620	40	10
ID minimum gap	mm	20	16	11
Brilliance @ 1• 1.6m undulator	ph/s/mm^2/mrad^2 /0.1%Bwidth	6 10^{17}	2.1 10^{19} (low βz)	8.3 10^{19} (low βz)
Brilliance @ 1• 5m undulator	ph/s/mm^2/mrad^2 /0.1%Bwidth	2 10^{18}	8.8 10^{19} (low βz)	3.8 10^{20} (low βz)

* End of 1997

Table 1 : Evolution of the brilliance at the ESRF.

Position stability

For the beamlines to fully benefit from this high brilliance, an excellent beam position stability has to be provided and figures less than 10% of beam sizes and divergences are routinely achieved thanks to the automatic closed orbit correction running every 5 minutes. With the very small vertical emittance, the required vertical position stability starts to be at the limit of the feasibility (a few µm) and all sources of errors or drifts have to be minimised [2]. To reduce the fast fluctuations of the vertical beam position, which exceed the 10% specifications, a fast AC position feedback is being developed. The goal is to reduce the amplitude of the beam oscillations in the vertical plane in the frequency range from 0.1 Hz to 100 Hz. The strategy will consist in applying a global correction over the full machine and not several local corrections on each ID straight section. This system will rely on 16 dedicated electron BPM's (located in the straight sections) and 16 fast steerer magnets. It will be controlled by a central DSP board communicating with local DSP boards via fast data links operating at a 44 kHz frequency.

Lifetime

After several years of operation, the ring vacuum vessels (stainless steel) have been fully conditioned and the average dynamic pressure is about 2.10^{-9} mbar at I=200 mA. Such a low pressure corresponds to a very large gas scattering lifetime. In fact, even on a 6 GeV machine, the main limitation of the lifetime comes from Touchek scattering due to the increased density in the bunch volume. This explains the moderate lifetime (8 hours) in single bunch and 16 bunch modes, but also shows up in multibunch mode, due to the high intensity (200 mA) and the low coupling (1%), A significant increase in lifetime was obtained at 200 mA by increasing the number of circulating bunches thereby reducing the current per bunch: From 40 hours in 1/3rd filling the lifetime jumped to more than 50 hours in 2/3rd filling, at 200 mA. When lengthening the bunch train, the machine gets more sensitive to HOMs developing in the RF cavities and this was overcome by a careful temperature control of these cavities [3]. An efficient way to increase the Touchek lifetime is to enlarge the energy acceptance. By moving the injection septum away from the stored beam (from 13 mm to 19 mm), a net gain of several hours was achieved on the lifetime in 16 bunch (from 7h up to 11h). However, a larger gain was expected and investigations are being pursued to enlarge the present ± 3% energy acceptance.

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3 OPERATION AT THE ESRF

Since 1993, when the beam was delivered for the commissioning of the first beamlines, until 1997, the number of hours dedicated for the Users (the User Service Mode) has been progressively increased: from 2984 hours in 1993 to 5359 hours in 1997. The ultimate goal is to deliver 6000 hours per year in USM, which should be reached before the year 2000. Throughout these years, our guidelines were always to improve the reliability of the Machine, its meantime between failures whilst increasing the beam performances. Four years after the first USM shift, we can state that these three goals have been met. In 1996, only 3% of the operation time was lost due to failures, the remaining 97% being composed of the time for the refills (2.5%) and the delivery (more than 94%). Not only is the availability important but the meantime between failures (MTBF) which is of major interest for the Users. This figure which was only 13 hours in 1994 has now been increased to more than 41 hours in 1996, i.e. 3 times better. The mean duration of one failure is now about one hour. These good results are not a matter of chance. Many actions have been undertaken to improve the reliability of the Machine, among others:

- Preventive maintenance on the water circuitry: a lot of beam losses occurred due to cooling interlocks following the blocking of some magnet cooling pipes by metallic dust circulating in the water circuits. Since 1995 when the preventive maintenance policy was initiated, very few failures have been recorded as far as this piece of equipment is concerned.
- High Quality Power Supply (HQPS): the Grenoble area is subject to violent storms during the summer the consequence of which are severe drops on the electrical mains resulting in beam losses. Since summer 1995, ten units (1 MW each) have been operational to take over any electrical mains drop. The HQPS has been operating for more than 1 year now and the conclusions to be drawn are very positive. Over the full year 96, more than 220 drops recorded on the input electrical mains have been smoothed, avoiding beam trips with all their possible direct and indirect consequences. It is clear that the very significant improvement in Mean Time Between Failures described above can be, for a large part, attributed to the unperturbed primary power delivered by the HQPS. At the same time this has enabled intrinsic faults in equipment to be clearly distinguished from actual outside perturbations. Moreover, the absolute low harmonic pollution engendered by the HQPS on site means that all power converters will have increased lifetimes.
- Radio-frequency system : Since May 1995, the machine has been running with 2 klystrons each of them feeding 2 cavities. The main advantage lies in the fact that each klystron works far below its designed maximum power thus reducing the rate of trips. The switching from 1-transmitter to 2-transmitter mode together with an efficient work of reduction of the sensitivity to EMC noises of the RF plants have resulted in a doubling of the MTBF of this touchy equipment. In order to increase the available accelerating voltage and to provide more flexibility to the RF operation, a third RF plant feeding 2 extra cavities will be commissioned and put into operation this year.

Super Spare Power Supply

Although power supply failures are rare, they can last a long time when they occur (replacement of a transformer or another major repair). To avoid a loss of time in these situations, a Super Spare Power Supply was built. Its role is to supply any magnet power supply which would fail. Furthermore a switching board was recently installed: it allows any magnet family from the Super Spare Power Supply to be supplied within less than one hour.

	1994	1995	1996	1997
USM scheduled hours	3800	4752	5193	5359
USM delivered hours	3372	4412	4901	5090*
Availability (%)	88.7	92.8	94.3	95 *
Time lost for refills (%)	2.7	2.9	2.4	2.5 *
Time lost for failures (%)	8.6	4.2	3.2	2.5 *
MTBF (hours)	13.5	21.5	41.2	> 40*

* expected

Insertion devices

The ESRF was designed to be essentially an Insertion Device based source. Out of the 28 available straight sections, 25 are already equipped with 1, 2 or 3 ID segments (1.6 m long), which can be either planar or helical undulators, or wigglers [4]. The very large variety of ID types enables experiments to be carried out simultaneously at X-ray energies ranging from 500 eV (on beamlines equipped with windowless front-ends) up to 500 keV (from a superconducting wiggler). 12 straight sections are equipped with 5m long 15mm high stainless steel vacuum vessels devoid of pumping, which authorises a 16mm minimum gap. We are presently developing 5m long 10mm high ID vacuum vessels which will enable the gap of the insertion devices to be closed down to 11mm. These stainless steel vessels will be copper plated so as to minimise their contribution to the impedance of the machine. Following the reduction of the vertical β function, 2 prototypes of 10mm high 2m long vacuum vessels were installed and successfully tested on the machine. The first 5m long 10mm high vessel will be installed during the summer of 97.

Beamline Front-Ends

There are presently 25 front-ends transmitting X-ray beam from insertions devices, and 6 from bending magnets. 6 ID front-ends are windowless. On some wiggler front-ends the total power in the X-ray beam can reach 15kW, whilst the power density approaches 750

W/mm^2 (normal incidence at 10m from the source) with 2 phased undulators at a 16mm gap. A specific carbon filters-Beryllium window assembly was developed which enables the transmission of such a high power density. To preserve the X-Ray beam coherence, some beamlines have been equipped with polished Be windows and sometimes with diamond filters. A noticeable point to be mentioned is the slightly increasing meantime between failures of the front-end equipment despite the increasing number of beamlines (and of front-ends) since 1994.

4 BEAM MODES

As a consequence of the great variety of experiments which are carried out at the ESRF, various filling patterns of the electron beam are now served to the Users. The Users community is divided into two parts, those who need a maximum intensity with the longest lifetime whatever the filling pattern is, and those who need a time-structured mode (for nuclear scattering or structural biology for instance). For the first part of the Users community, the machine is operated in multibunch mode (either ‘one third’ or ‘two third’ filling modes) at 200mA.

For the second part of the community, time structured modes have been developed. The single bunch mode is now delivered at an intensity of 15mA (with a 5 hours lifetime). A transverse feedback is under development and should enable higher intensity to be reached.

	2/3 filling	Single Bunch	16 bunch	Hybrid mode
Max. intensity (mA)	200	15	90	200
Associated Lifetime (hours)	50	5	8	30
% of time in operation	55 %	5 %	25 %	15 %

Modes routinely delivered at the ESRF

The 16 bunch mode was first developed as a compromise for all the Users and is still delivered now (25% of the shifts). The maximum intensity of 90mA is mainly limited by the overheating and consequent outgassing of the RF liners of the vacuum chamber. An R&D program on the RF liners is in progress to increase the maximum intensity.

To maintain the same brilliance per mA, the beam is delivered with the same low emittances (ε_x=4nm.rad and ε_z=40 pm.rad) in these modes which explains the associated moderate lifetime.

More recently, various hybrid modes have been developed to better satisfy the community of Users. They consist in a one third filling bunch train (typically 180mA) with one or several isolated bunches regularly spaced in the opposite gap (typically 5mA per bunch). Despite the fact that everyone can find their advantages in these hybrid modes, the drawback of these exotic modes is the reduced lifetime (30 hours) which is mainly driven by the lifetime of the single bunches and also the longer dead time for the refill (about 25 minutes instead of a couple of minutes for the other modes).

For the filling of the Storage Ring in single bunch, 16 bunch or hybrid modes, the Linac produces short pulses with a 2ns FWHM. It has been optimised in order to achieve an initial purity in the 10^{-3} range in the SR. Then a cleaning process is applied which consists in exciting the parasitic bunches in the vertical plane so as to kill them on a scraper.

The bunch purity (relative intensity of the parasitic bunches compared to the main bunch) is measured by an X-ray avalanche photodiode installed in the tunnel which has an excellent dynamic range (better than 10^8) and a good time resolution (10^{-6} at 2.8 nsec of the main bunch). The quality of all the time-structured modes is very high since a bunch purity better than 10^{-7} is routinely delivered.

Jitter free streak camera

A collaboration contract was signed in 1996 with the CUOS (Centre for Ultra-Fast Optical Science) in Michigan for the development of a state of the art streak camera. This streak camera, which will have a resolution less than 1 pico-second in accumulation mode, will be triggered by an ultra-short laser pulse (300 femto-second) in order to eliminate the jitter. The laser pulses will also be produced synchronised to the X-ray pulses with a jitter of much less than the width of the X-ray pulse. This set-up will demonstrate that even with a 100 pico-second X-ray pulse, it is possible to probe events on the sub pico-second scale.

5 SHORT TERM GOALS

The ESRF objective is to further develop its high potential while maintaining the excellence of its operation standards. The following major goals have been set for 1997:

- 5400 hours of scheduled USM time.
- An increased rate of availability with an objective of 95% (the last % is the most difficult to achieve).
- The commissioning of a third RF plant (transmitter) together with 2 additional cavities.
- The installation of a few 10 mm high insertion device vacuum vessels.
- A reduction of the horizontal emittance: A new version of the optics giving 3nm.rad (instead of the present 4) is being studied.
- A reduction of the coupling down to values in the 0.3% range, which is extremely challenging.
- A fast global AC position feedback which will operate in the vertical plane, using electron beam position monitors.

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