OPERATION AND RECENT DEVELOPMENT AT THE ESRF

J-L. Revol, J-C. Biasci, J-F. Bouteille, J. Chavanne, P. Elleaume, L. Farvacque, L. Hardy, J. Jacob, G. Naylor, E. Plouviez, A. Ropert, B. K. Scheidt, ESRF, Grenoble, France.

Abstract

We report on the performances achieved by the ESRF storage ring as well as developments accomplished or underway. A new hybrid filling mode based on groups of bunches and a 4-bunch filling pattern are now delivered to the users. Following the increasing demand of users for beam stability, the fast global orbit feedback has been upgraded. The installation of 5 m-long, 8 mm vertical aperture NEG coated aluminium chambers is progressing at a rate of one chamber per shutdown. The increase in current from 200 to 300 mA is being prepared; however, operation in this mode is still impaired by HOM driven longitudinal instabilities. To overcome this difficulty, a longitudinal feedback is being commissioned. HOM damped cavities are also under study to possibly replace the existing five-cell cavities. The policy of preventive maintenance has been continued. Despite this policy, in 2005 the machine availability was slightly affected by water leaks occurring on front-end X-ray absorbers and on one dipole crotch absorber.

THE ESRF IN 2005

The European Synchrotron Radiation Facility (ESRF) located in Grenoble, 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 is installed in the 28 available straight sections. The present configuration of the ring includes: 60 in-air undulators (up to three 1.7 metre-long segments per straight section), 6 wigglers and 8 in-vacuum undulators (2 metre-long) [2]. Bending magnet radiation is used by 15 beamlines.

Although giving priority to user service, the Machine Division continued its efforts to improve performance whilst carrying out developments.

Energy **Particles**	**6.03** ***Electrons***	*GeV*		
Circumference	**844**	*m*		
Horizontal emittance	**4**	*nm.rad*		
Vertical emittance	**30**	*pm.rad*		
Modes	*Current*		*Lifetime*	
Multibunch	**200**	*mA*	**80**	*Hours*
16 Bunch	**90**	*mA*	**12**	*Hours*
4 bunch	**40**	*mA*	**6**	*Hours*
Hybrid (24*8+1)	**196+4**	*mA*	**30**	*Hours*

Table 1: Main parameters

OPERATION 2000-2005

Statistics

The figures of merit for operation, namely the mean time between failure (MTBF) and availability, were maintained at the same level in the last years despite the ageing of the components and the implementation of new developments. Last year, out of the 5466 hours scheduled for beam delivery to the Users (USM), 5296 hours were delivered, including refill time. The X-ray beam was available to users 97.6 %. of the scheduled time. The time lost due to failures represented 131 hours (i.e. 2.4% of the time). With 123 beam interruptions, the MTBF reached 44.5 hours in 2005. This figure has remained steady over the years in the range of 2 days without a beam loss (see Fig 1). The efforts by all groups toward preventive maintenance and failure analysis has largely contributed to maintaining the MTBF and availability these last few years. In addition, it should also be noted that a lot of efforts have been made to control and maintain the main beam parameters (filling pattern, lifetime, emittances, beam position).

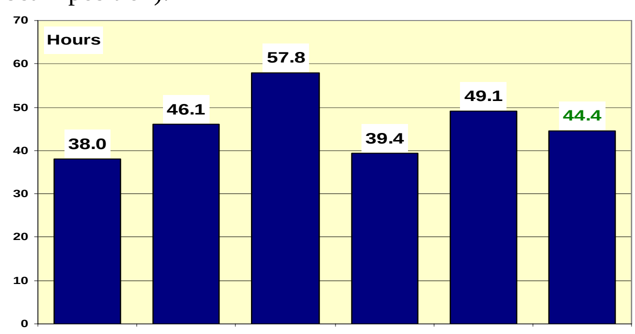

Fig. 1: Evolution of the Mean Time Between Failures.

Ageing of Machine Components

2005 was particularly marked by a number of water leaks linked to ageing. Water leaks-to-air developed on the photon beam moveable absorbers of a number of bending magnets and insertion device beamlines. These leaks affected only the oldest units, in operation since 1992-1993. Remedies were found to limit the impact on user operation. A number of spare absorbers were ordered and delivered, enabling the replacement and repair of the defective absorbers during machine shutdowns. The process leading to this leak has been understood and is linked to the high pressure water flow which generates cavitation followed by erosion of the wall material in some sharp edge elbows made of copper. The most severe failure, in terms of impact on user operation, was the water leak-to-vacuum of a crotch absorber, which resulted in the venting of two cells of the ring. The investigation showed that an annular cavity with narrow vertical height (~ 0.5 mm) had developed in the wall of the first tubes of the crotch, at the location of hard X-ray beam from the bending magnet traversing the copper. A further thorough investigation showed that this process also affects the 64 other crotches. In consequence, all crotches have been displaced vertically by 2 mm in such a way that the X-ray beam falls outside the existing cavities. Meanwhile, it is planned to replace all crotches with a modified design.

Filling pattern

Multibunch filling pattern, which represents (in 2005) 71 % of the total user time, was mostly delivered in uniform filling with a lifetime greater than 70 hours at 200 mA. The rest is shared between the 16 bunch, 4bunch and hybrid modes. Although in the past it was possible to deliver an intensity of 20 mA in single bunch, this is no longer possible, due to the increasing number of low gap chambers installed in the ID straight sections. The maximum current is now limited by horizontal beam instabilities and incoherent tune shift, which saturate the injection process. Consequently, in 2003, single bunch delivery at 15 mA was replaced by a 4 bunch mode with a total current of 40 mA. The hybrid mode has also been upgraded to 24 groups of 8 bunches with a single bunch of 4 mA in a gap.

The increasing demand of time structure leads to the conception of new multibunch filling patterns. With chromaticities identical to present multibunch modes, the lifetime is in the order of 72 hours at 200mA. The presence of a gap (1/8 of the circumference) avoids beam-ion instabilities, thus maintaining the vertical emittance at the lowest value of 25 pmrad. The width of the gap is reduced to the minimum value required by the most demanding beamline so to minimize the current by bunch and maximize the lifetime. 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. To optimize the use of this mode, the last bunch of the train is also filled at 2 mA. This new mode, which has been tested by a few beamlines during machine dedicated time, is ready for operation.

DEVELOPMENTS IN OPERATION

Upgrade of the orbit feedback

Until the end of 2004, the damping of the fast beam orbit distortions was done in the vertical plane by a global feedback system using 16 BPM and 16 correctors while in the horizontal plane local feedback systems were used to stabilize the beam in the 4 most sensitive ID straight sections. A global feedback system using 32 BPMs and 24 correctors is now in operation in the horizontal and vertical planes to compute and apply corrections at a rate of 4.4 KHz from .1 to 150Hz [1]. This new system which greatly improved the damping of the orbit distortion up to 100Hz, also provides data logging capabilities. This fast orbit correction is working in parallel with a slower correction system using 224 BPM and 96 correctors which perform 2 corrections per minute with accuracy and long term reproducibility.

	β (m)	RMS motion (μm)		Motion/ Beam size
		Feedback OFF	Feedback ON	
H	36	5	1.5	.006
V	6.5	1.5	0.7	.1

Table 2: Orbit feedback performance in straight sections.

Upgrade of insertion devices and front ends

The largest increase of brilliance in the last years was mostly provided by the upgrade of insertion devices and their associated beamline front-ends[2]. A large number of 10mm–high/5m-long aluminium chambers have replaced the existing 16mm-high ID chambers. To benefit from the smaller gap, most of the existing magnet arrays have been replaced by arrays with shorter periods. New in-vacuum undulators and revolver structures have also been installed. Revolver carriages accommodate two sets of undulator magnet arrays. One is typically a fully tuneable undulator, the other is optimised for a specific photon energy range with brilliance and flux 2 to 3 times larger than that at the tuneable undulator. An upgrade of the insertion device beamline front-ends has become necessary to handle the heat load from the simultaneous operation of three in-air undulator segments or two in-vacuum undulators at the present current of 200 mA and up to 300 mA in the near future. The front-end upgrade started in 2000 and will be completed end 2006. Exchange is performed at a rate of 4 front-ends per year.

Vacuum chambers and NEG coating

Bremsstrahlung radiation created by the collision of the electron beam with the residual gas inside the ID vacuum chambers is a serious issue for small aperture chambers in which the small conductance results in high pressure. Bremsstrahlung scattered off-axis by the optical component (monochromator, mirror…) is measured downstream of the beamline. In order to improve the situation, Non Evaporable Getter (NEG) thin film (0.5-1.0 microns) is sputtered on the wall of the vacuum chamber in a coating facility at ESRF[3]. Following activation of the NEG material (made of titanium, zirconium and vanadium) at 180°C, the NEG coated surface provides pumping and the photo-induced desorption is largely reduced, thereby accelerating the vacuum conditioning time under beam. Newly prepared 8mm aperture/5 m long constant cross-section NEG coated Aluminium chambers are first installed in the machine dedicated straight section at each shutdown. The chamber is then conditioned for 6 to 8 weeks until the following shutdown when it is moved to the final ID beamline destination. The chamber then only needs a few days of re-conditioning allowing the user operation to start almost immediately after the shutdown. This refurbishment process, with a maximum of 5 beamlines upgraded per year, allows a smooth transition for the beamline, with no loss of beam time. At the end of 2005 nineteen NEG coated ID chambers were in operation. Most of them are made of extruded aluminium 5m long with a constant elliptical cross-section and an internal aperture of 57x8 mm^2.

DEVELOPMENTS UNDER PROGRESS

Topping up

Implementation of injection with front end open in 2003 greatly improved the stability of the beam for users, with a continuous availability of the X-ray source. Thanks to a lifetime in multibunch close to 80 hours, only two short refills are performed each day. Between each refill the beam is delivered for 12 hours, without any stability perturbation, with a smooth current variation of 15 %. For the moment, no topping-up is envisaged in this mode. In contrast, the more frequent the refills, the larger the current variation during decay and the associated beam parameter fluctuations make topping-up (or more frequent injection) interesting in time structure mode of operation. The extreme contrast requested in these modes between filled and unfilled buckets requests a cleaning process. For the moment, the cleaning process performed in the storage ring makes the beam unstable for 30 sec at each refill, making it incompatible with an increased injection frequency. A process to clean the injected beam in the booster is under development. The extreme purity requested by the most demanding beamline makes this process very challenging for routine operation. With a refill every five minutes, improved stability will be immediately visible. However, beam position instabilities induced in the storage ring by the kickers will make the beam unusable during injection, imposing gating of the data acquisition. This effect is under evaluation in collaboration with the beamline scientists. Topping-up in time structure modes will be proposed to users when the cleaning process in the injector is ready.

Increase of the storage ring current

At the ESRF, HOM driven longitudinal coupled bunch instabilities are currently avoided up to the nominal beam current of 200 mA by precisely controlling the cavity temperatures and thereby the HOM frequencies of the existing five-cell copper cavities. However, for an increase in current from 200 to 300 mA (currently in preparation) longitudinal feedback is being commissioned. The design of the system is based on the bunch by bunch processing of a beam phase error signal and correction using a low Q kicker driven by a QPSK modulator. This development benefits from the latest technology available for signal processing electronics with high resolution, high sampling rate ADC and DAC, and FPGA DSP[4]. The use of a single FPGA, programmed at high level using a graphical environment substantially reduced the complexity of the project. In addition, thanks to the modest kicker strength, most of the tests performed during the development of this system could be done with a stable beam during user service mode without visible perturbation. HOM driven instabilities have already been damped during machine dedicated time, firstly using a stable 200mA beam and forcing the oscillation of a mode by a continuous signal of a test generator while the feedback is turned on and off and, secondly, with the damping of an unstable beam above 200 mA.

A transverse multibunch feedback system, built using the same FPGA system, is also under development for both horizontal and vertical planes. It will first be used for diagnostics during machine dedicated time and then for operation for new machine tuning.

In parallel to the feedback developments, normal conducting strongly HOM-damped cavities are under study in the perspective of replacing the five-cell cavities[5]. A cylindrically shaped 352.2 MHz HOM damped cavity prototype has been numerically optimized, taking into account technological restraints, especially cavity and ferrite shapes. An aluminium prototype with kit functions has been designed to compare numerical results and measures for low power. At term, the target for the ESRF is to reach 500 mA with the installation of 18 such cavities and the redesign of the vacuum chambers.

A new lattice with increased ID section length

To increase the number of independent instruments in some beamlines, it is proposed in the future to split the insertion device in a straight section into two shorter IDs generating radiation at different angles, resulting in a "canted undulator" geometry. In order to free maximum space in the straight sections and compensate the reduction in length of the ID due to canting, a new lattice, in which the straight section quadrupole triplets are replaced by doublets, is being tested[6]. The operational performances of this lattice and the associated beam parameters should be close to the present ones.

CONCLUSION

An essential element for the ESRF's success is the continuous refurbishment programme associated to an optimized and stable beam quality for user operation. The developments under progress or planned in the coming years will further increase the potential of the facility.

REFERENCES

[1] E. Plouviez and al., "Upgrade of the global feedback of the ESRF storage ring", DIPAC'05, Lyon.

[2] J Chavanne, P Elleaume "Latest Developments on Insertion Devices", This conference.

[3] R. Kersevan and al., "Status Report on the Performance of NEG-coated Chambers at the ESRF", This conference

[4] E. Plouviez and al., "Broadband bunch by bunch feedback for the ESRF using a single high resolution and fast sampling FPGA DSP", This conference.

[5] N. Guillotin, J. Jacob, V. Serrière, "Development of a HOM damped copper cavity for the ESRF", This conference.

[6] A Ropert, L Farvacque., "Optimisation of a New Lattice for the ESRF Storage Ring", This conference.