STATUS REPORT OF THE ESRF

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Abstract

The ESRF accelerators have been in full routine operation for more than four years. The source delivers 5600 hours of X-ray beam to nearly 40 beam lines simultaneously. Our first goal is to ensure good availability of the Machine as well as a satisfactory Mean Time Between Failures (MTBF). A third RF unit has been installed which, amongst other advantages, allows Landau damping from active modulation. A fast global feedback system to reduce the fast distortion of the closed orbit in the vertical plane has been put into operation and is giving results as expected. New filling patterns have been assessed and the Machine was successfully operated at 4 GeV (instead of the nominal energy of 6 GeV) in March 1999. Two years ago [1] several challenging short-term goals were defined. Most of them have been achieved or are actually in progress. The results are given below.

1 INTRODUCTION: THE ESRF TODAY

Three new associated members recently joined the ESRF (Portugal, Israel and Czech Republic) bringing to 15 the number of participating countries. The construction phase finished in December 1998 and the Operation phase then started. 37 beam lines (open to external Users) are now fully operational and three others are foreseen before year 2001. There are currently 54 insertion devices installed in the Storage Ring, which represent an integrated length of 85 metres. The number of shifts requested for experiments on the beamlines is approximately 2.5 times more than the ESRF can offer (5600 hours of beam time for Users in 1998). This justifies why the Machine Division's first goal is to ensure a high availability and Mean Time Between Failures whilst continuing challenging developments without disturbing the operation of the Machine.

2 MACHINE OPERATION

The number of hours in User Service Mode (USM) has gradually increased from 3000 hours in 1994 to 5600 hours in 1998. The major challenge over this four year period has been to increase the beam availability (percentage of scheduled time that beam is supplied for user operation) as well as the MTBF. We can consider that these goals have been achieved since the availability in 1998 reached 95.3 % (the highest score ever obtained at the ESRF) for a MTBF of 31 hours. Out of the remaining 4.7 %, only 3.7 % is due to faults and 1 % represents dead time due to refills. Great care is taken to maintain this good performance, implying both preventive maintenance and upgrading of equipment [2].

3 RECENT DEVELOPMENTS IMPROVING THE MACHINE PERFORMANCES

- Fast Global feedback

In November 1998 a fast global orbit correction system was put into operation. Its goal is to reduce, in the vertical plane, the fast distortions of the closed orbit due to mechanical vibrations of the girders supporting the quadrupole magnets of the Storage Ring. Indeed, the parasitic motion of the beam due to these vibrations must be kept at values as low as possible to avoid spoiling the good emittance figures so far achieved: ε_x= 4 nm rad and ε_z = 30 pm rad. The three main peaks of vibrations were observed at 7 Hz, 30 Hz and 60 Hz. This is why the bandwidth of this correction system has been set between 10^{-2} and 100 Hz. This system uses 16 BPMs and 16 correctors to correct the orbit at a 4.4 kHz rate. This proved to work successfully (it is mostly efficient on the lowest frequency orbit distortions which are the most harmful for the users) and is now fully operational. The damping factor is up to 10 at 7 Hz and 2.5 when averaging all frequencies up to 100 Hz. The feedback brings the amplitude of the fast beam vertical position down to 1 μm rms all around the ring, as measured by independent fast beam position monitors, to be compared to the 10 μm vertical beam size (rms). [4]

- Fast Local feedback

At the request of a beam line, a local fast horizontal beam position feedback was installed on one straight section of the Machine. This system uses two BPMs to measure the horizontal electron beam position at both ends of the ID24 straight section and four fast steerer dipole magnets to produce a local correction bump (a closed bump which does not change the closed orbit on the rest of the machine). The amplitude of the vibration was reduced from 13 μm (rms) to 1.1 μm, to be compared to the 400 μm horizontal beam size (rms).

- Installation of a third RF unit

In the second half of 1997, a new 1.3 MW transmitter, feeding a third pair of cavities, was put into operation on the ESRF storage ring. With this third transmitter the total accelerating voltage increased from 8 to 12 MV. In

addition, by modulating the RF voltage at the revolution frequency with this third unit it is possible to produce additional Landau damping of longitudinal multibunch oscillations. At the same time, this unit provides a redundancy to guarantee a smooth operation of the ESRF in case of a major intervention on one transmitter. A new associated control system was developed and commissioned in parallel.
Another great advantage of the redundancy is that one of the RF transmitters can be used to perform klystron testing on a dummy load (due to a system of wave-guide switches).

- Installation of 8 mm (inner vertical height) vacuum vessels

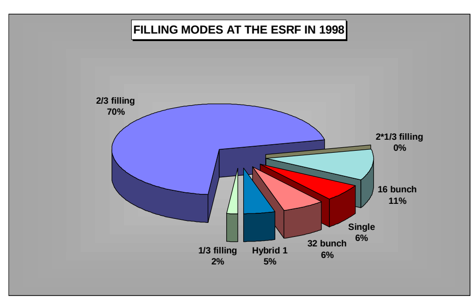
Following the reduction of the vertical β function in all straight sections, new vacuum vessels (5 metres long, 8 mm high) have been developed enabling the gap of the corresponding insertion devices to be closed down to 11 mm. These stainless steel vacuum vessels are copper-plated to minimize their contribution to the impedance of the Machine. Two of these vacuum vessels are now installed on the Storage Ring. First of all they are put in a dedicated straight section for several weeks to condition them after which time they are moved to the required straight section. Others will be installed in the forthcoming months.

- Longitudinal instabilities and fighting the HOMs.

Many efforts are being made to improve our understanding of HOMs and to avoid them developing in our cavities, mainly in multibunch mode at high intensity. One way of destroying the coherence of the participating particles is to spread out the synchrotron frequencies of the electrons of different bunches. This can be achieved by filling the ring in a non-uniform way (with fractional filling patterns). This is done to deliver high intensity in multibunch mode, where two thirds of the bunches are filled (2/3rd filling mode).
Another way is to produce Landau damping from active modulation. Owing to the new RF system, this is possible by driving one pair of RF cavities at $f_{RF} + f_0$, (one revolution frequency above the RF frequency). This method is now used to deliver the beam in multi-single bunch mode (16 or 32 bunches equally spaced).
New cooling devices were designed to regulate accurately the temperature of the RF cavities, thereby tuning away the HOMs. These devices are now in operation on the Machine and permit high intensity (200 mA) with uniform or symmetrical filling patterns.

4 BEAM MODES AND FILLING PATTERNS

The preferred mode for the Users is indisputably the 2/3 filling mode for which a high intensity of 200 mA with a good lifetime approaching 55 hours can be delivered. However, other time-structured modes such as the single bunch (16 mA with a lifetime of 5 hours) and the 16-bunch mode (90 mA with a lifetime of 8 hours) remain of great interest for a few beamlines. The compromise between the two kinds of modes (high intensity or time-structured) is the hybrid mode (200 mA, 1/3 filling + 1 single bunch opposite the bunch train). Two years ago, the drawback of this mode was the long refill time (about 20 minutes) due to the necessity to kill the parasitic bunches around the single bunch (cleaning process). Since then, a new cleaning method (selective) has been developed and even allows a topping-up in this mode which takes about 10 minutes. The quality of these time-structured modes remains very high with an excellent purity (no parasitic bunches) routinely measured below 10^{-7} and sometimes even down to 10^{-10}.
At the request of one beamline, which requires time structure, a new fractional filling pattern was tried: the two times 1/3 filling, i.e. 2 bunch trains (350 bunches) separated by 150 unfilled bunches. This mode, which is close to a uniform full filling, required pushing the intensity thresholds due to HOMs (longitudinal coupled bunch instability). As a result of the new cooling systems installed on the RF cavities this was easily achieved: 200 mA were reached without any sign of instability with the same lifetime as in 2/3rd filling mode (55 hours at that time). In agreement with the Users, several shifts were successfully delivered recently in this mode.
Investigations are, however, also being made into the possibility of achieving both a real time-structured mode and a high intensity (for the flux) whilst keeping a high level of purity. This means remaining far from instabilities but maintaining enough current per bunch to be able to discriminate and kill the unwanted parasitic bunches. Up to now, the best compromise which matches all the constraints was 32 groups of 4 bunches with 1.25 mA in each bunch (total intensity of 160 mA). The instabilities were avoided by driving one pair of RF cavities in active modulation mode (frequency $f_{RF} + f_0$) and a perfect cleaning was obtained. This mode will be proposed to our Users in the coming months.



- Operating the ESRF at 4 GeV

By reducing the energy of the storage ring from the nominal 6 GeV to 4 GeV, record emittance values were achieved : $\varepsilon_x = 1.7$ nm rad and $\varepsilon_z = 12$ pm rad .
Even if the corresponding photon flux is significantly reduced at an X-ray energy above 10 KeV, the gain in brilliance and the corresponding increased coherence

properties of the X-ray beam could be interesting for some specific experiments. It is for this reason that two days of beam delivery at 4 GeV at the beginning of March were proposed. To achieve reasonable performances at 4 GeV, careful machine tuning had to be made, and in particular to raise the HOMs threshold. 100 mA were achieved (in 2/3rd filling mode) with a lifetime of 10 hours (essentially limited by Touschek effect). A lot of beam line teams took advantage of the beam to perform experiments up to 30 KeV, operating their insertion devices on very high-ranking harmonics (up to the 21st). Although it is not intended to change the nominal energy of the ESRF storage ring, again this demonstrated the high flexibility of our accelerators.

5 NEXT GOALS

- RF fingers test bench

In multi-single bunch mode (16 bunch or 32 bunch mode), the maximum intensity of 90 mA is mainly limited by the overheating and the consequent outgassing of some of the RF liners of the vacuum chambers (due to damage). There is reason to believe that the design of the RF liners could be improved in order to push this limitation further. This is why in December 1998, one part of a straight section was equipped with an RF finger test bench. Two different RF fingers can be put on the bench at the same time and a thorough on-line check is possible by monitoring vacuum and RF parameters (temperature monitoring with infrared cameras, several thermocouples and RF pick-ups). The goal is to characterize experimentally the behaviour of our RF fingers. This will improve our understanding of the origin of the limitations of those damaged and enable us to define which need to be replaced and what improvements can be made. This test bench is very appealing since the RF fingers can be exchanged during a Machine Dedicated Day and therefore many tests can be done in a short period. Conclusive results are expected during 1999.

- RF waveguide extension

A project is in progress to extend the waveguide network so that one given RF klystron of the storage ring can replace its neighbouring RF unit or even feed the booster RF cavities. This will allow a high level of redundancy that will permit SR operation to be safeguarded even in case of a major failure on any single transmitter.

- Reduction of the coupling

Significant work has been carried out on a new method of correcting the coupling, based on the exploitation of the orbit cross-talk response matrix. According to simulations, it was found that by placing 16 skew correctors around the Machine at optimized positions, the actual coupling (1 %) can be reduced to as low as 0.05 %. Therefore, it was decided to install 16 additional skew correctors, symmetrically distributed. This gives a total of 32 skew correctors now installed on the Machine. With this method, a vertical emittance of about 20 pm.rad was reached (corresponding to a coupling of 0.6 %) [3].
Another method was developed, in parallel, based on an empirical minimization of the coupling by reading the vertical emittance on two pinhole cameras. A vertical emittance of 13 pm rad was reached (corresponding to a coupling of 0.3 %).
Further studies will be performed to understand the limitations which presently prevent us from achieving a lower coupling.

- New windows on Front ends

Some straight sections are equipped with three undulator segments (integrated length of 5 metres), and it is planned to close their gaps to the minimum (11mm) as soon as an 8-mm high vacuum chamber has been installed on their respective straight sections. This will result in a significant increase in the power density to be transmitted or stopped by the front-ends: 300 kW/mr^2, to be compared with the present 140 kW/mr^2. New X-ray absorbers and window configurations have been designed and will be tested during the year, at such a high power density.

6 SUMMARY AND CONCLUSIONS

Our main goal is to provide a reliable delivery of the X-ray beam. Year after year we can claim that this is the case. 1998 was the apogee since it ended with an availability of 95.3 % for a MTBF of 31 hours. At the same time the challenge is to continue developments on the Machine without disturbing operation. The goals are to both improve the beam characteristics and to upgrade the equipment. Through several examples we have demonstrated that this is possible and that a balance can be found between operation and developments. We have also seen that the developments have had a direct repercussion on the beam quality. Consequently, we plan to continue the same policy in the forthcoming years.

REFERENCES

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