Towards an increased brilliance at the ESRF

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Abstract

After having achieved and even surpassed design performances in the course of the 1992 commissioning, the ESRF has been operated for synchrotron radiation users since January 1993. In parallel to securing routine operation at target performances, progress is continually being sought with regards to the peak performance of the machine. In this respect, the brilliance is certainly the true figure of merit for a high energy light source like the ESRF. This paper will review the different possibilities which are currently being investigated with the ESRF project team to increase the brilliance of the source. Decreasing the nominal 10 % coupling is the easiest way in terms of the gain-to-effort ratio. A coupling in the % range has been achieved by a proper tuning of skew quadrupoles. Studies are under way to make this mode the routine one for operation. The problems raised by an increase of the stored current from 100 mA to 200 mA (excitation of instabilities, impact on the RF system, engineering repercussions due to the extra heat load resulting from the increase of current) will be discussed. A further factor of about 2 can be gained by introducing some dispersion in the insertion device straight sections. A modified optics has been optimized to meet this requirement and will be tested at the beginning of 1994. In the short term, this series of upgradings should provide a gain in brilliance by one order of magnitude.

1. INTRODUCTION

The European Synchrotron Radiation Facility is a third generation synchrotron light source, optimized to provide high brilliance X-rays in the Å range, mostly from undulators and wigglers installed in a large number of straight sections. The actual operation of the machine in the User Service Mode effectively started at the beginning of 1993 [1]. The first year of operation at target performance (see Table 1) has demonstrated the existence of a potential for significant upgrading of the source performances.

Table 1: Storage ring specifications

	design goals	achieved during commissioning
Intensity	100 mA	114 mA
Horizontal emittance	6.3 nm	8.4 nm
Coupling	10 %	10 %
Brilliance at 1 Å from a 1.6 m long undulator in phot/s/0.1%/mm^2/mrad^2	1.0 10^{18}	4.0 10^{17}

In this respect, the brilliance is the figure of merit the most referred to. As shown from the formula below, one can act on several parameters to increase the brilliance (current I, horizontal emittance ε_x, coupling κ, insertion device gap g).

$$B \sim \frac{I}{\kappa\ \varepsilon^2_x} f(g, E)$$

Four topics are currently being concentrated on in the aim of increasing the design brilliance of the source: increase of the stored beam current to 200 mA, test of other versions of the original Chasman-Green lattice with dispersion in the straight sections which would allow a factor of 2 on the minimum natural emittance to be gained, minimization of the horizontal-vertical coupling by means of an optimized skew quadrupole system, construction of a mini gap undulator [2]. This paper will review the results achieved so far.

2. INTENSITY

The design intensity in the multibunch mode of operation was achieved in June 1992. Initially this current was considered as a challenging target since intensity thresholds of the order of 60 mA had been predicted from transverse and longitudinal coupled bunch instabilities [3].

The source of the transverse coupled bunch instabilities is the long range wake field of the resistive wall impedance. To stabilize the corresponding modes of oscillation, we apply in both tranverse planes the standard over-compensation of the chromaticity which enables the spectrum of the unstable modes to have more overlap with the positive frequency region associated with the damping effect of the broad-band positive resistance. For 100 mA, a vertical chromaticity of up to 0.4 associated with the uniform filling of the storage ring circumference was frequently used in the early stage.

For all third generation light sources, Higher Order Modes of resonances in the RF cavities were considered as a major obstacle for reaching the design current with a uniform filling of the circumference. At the ESRF, with cavities similar to those of LEP and not at all optimized for a light source, simple solutions have been found to nevertheless overcome the predicted HOM limit and go significantly beyond the design current. In the longitudinal plane and again in the uniform mode of filling of the circumference, we are confronted with strong coupled bunch modes driven by HOMs around 500 MHz and 900 MHz. These instabilities occur between 60 and 100 mA in a non-systematic way. They can show up during the injection, in which case they appear as a saturation of the filling process. They can also show up during the current decay and lead to either significant lifetime accidents or even abrupt losses. Extensive investigations have been made to avoid the excitation of these HOMs by the stored beam. A temperature control of the cavities to keep the harmful HOM frequencies away from the beam eigen frequencies was successfully tested and enabled the initial threshold current of 60 mA to be doubled.

However, the best solution to avoid the above coherent instabilities consists in adopting a non uniform filling of the circumference. The beam is much more stable both longitudinally and transversally with respect to HOMs and the resistive wall, when the storage ring is filled leaving an empty gap corresponding to about 2/3 of the circumference.

In the transverse and mostly vertical plane, the coherent motion is driven by the wake field of the resistive wall impedance. This is a rather short range wake that decays significantly over a revolution period. With a gap of empty buckets extending over 2/3 of the circumference, a significant decay of the driving coherent field occurs between the passage of the tail of the bunch train and the next passage of the head. By so doing, one interrupts the possibility of transmission and built-up of the potentially destructive field by cross-talk between adjacent bunches and therefore avoids the growth of the instability.

In the longitudinal plane, we are essentially dealing with very narrow resonant HOMs. Consequently, the stabilizing effect cannot come from the decay of the wake field which lasts for more than a revolution period. In fact, the stabilization originates from the periodic beam loading of the cavities at every passage of the bunch train that produces a significant amplitude modulation of the RF voltage at the revolution frequency, typically 10 % peak to peak at 100 mA. The resulting spread in synchrotron frequencies of the bunches in the train prevents a constructive built-up of the instability by cross-talk between successive bunches.

As shown in Figure 1, peak intensity performances have been steadily increased over the past two years. In a first stage the intensity had been progressively ramped up to the maximum value of 150 mA permitted by the 1 MW klystron initially used to feed the four cavities. In the aim of accommodating a 200 mA beam, one of the 2 klystrons has been upgraded to 1.3 MW, thus enabling a stored current of 175 mA to be reached at the beginning of 1994 without any sign of HOM-induced or resistive wall coupled bunch instabilities despite the reduced vertical chromaticity (ξ_z = 0.24) with which the machine is presently run.

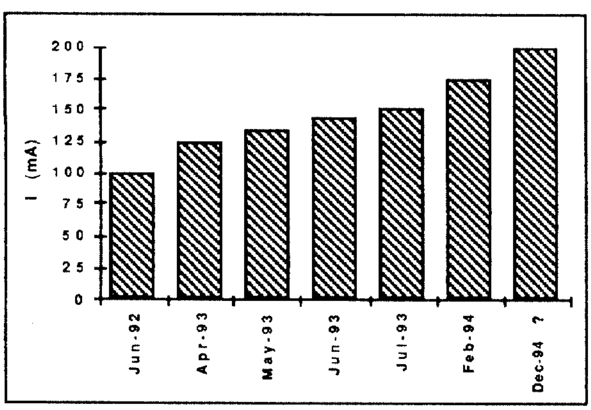

Figure 1

As a matter of fact, the large over-compensation of the chromaticity is no longer necessary for ensuring stable conditions at high intensity in the 1/3 mode of filling. This relaxed chromaticity compensation has very beneficial effects since it leads to both an increase in lifetime and in parallel a larger dynamic acceptance which in turns makes a high injection efficiency easier. However, given the fact that the resistive wall impedance is strongly dependent on the vacuum chamber height and that we are permanently increasing the number of flat insertion device vessels, larger values of the chromaticity might be required in the future. The maximum vertical chromaticity still compatible with reasonable lifetime and injection efficiency stands at around 0.75, which demonstrates that the lattice can accommodate larger chromaticities and damp a resistive wall effect significantly larger than the current one. No major tuning problem is therefore anticipated for reaching the 200 mA goal soon. When compared with the design target of 100 mA, this gain of a factor of 2 in intensity will automatically provide a factor 2 in the source flux and brilliance.

Third generation light sources are characterized by the extremely high power density of the photon beam from insertion devices. The increase of intensity also raises problems for defining the adequate components capable of absorbing the extra power resulting from the increase of current. We had therefore to change the copper absorbers at the end of each dipole on which most of the unwanted photons are dumped for more heat load resistant ones. The successful testing of a new configuration of the front-end with reinforced protection of the beryllium window also showed that modified front-ends could withstand the corresponding increased heat load. Finally, the upgrade in current would be of no interest if the beam position stability was spoilt. The improvement of the electronics of the BPM system has shown to solve the problem of partial saturation which was experienced mainly in the 1/3 filling mode with errors of 0.1 mm at 100 mA. This upgraded electronics is effective up to 150 mA and is expected to work up to 200 mA.

3. COUPLING

The storage ring is routinely run on a working point close to the coupling resonance (υ_x = 36.44, υ_z =11.39). Despite these unfavourable conditions, the measured coupling ($\kappa = \varepsilon_z / \varepsilon_x$) is of the order of 10 %, i.e. close to the design value. Moving the tunes far enough from the coupling resonance $\upsilon_x - \upsilon_z = 25$ leads to a natural coupling in the 2 % range. The main contribution to the coupling is obviously due to the betatron coupling with a dominant effect coming from the residual vertical closed orbit in the sextupoles. The measured vertical spurious dispersion is of the order of 2 mm, which gives a negligible contribution to the coupling (less than 10^{-3}).

Decreasing the coupling is a relatively easy and economical way of increasing the brilliance of the source. The skew quadrupole scheme implemented at the ESRF is based on the compensation of the two coupling resonances in the vicinity of the working point ($\upsilon_x - \upsilon_z = 25$, $\upsilon_x + \upsilon_z = 48$). The machine is equipped with 2 pairs of 4 skew quadrupole correctors for each of the two resonances concerned. The skew quadrupole fields are generated by powering the backleg coils equipping the sextupoles with adequate polarities.

The traditional method of minimizing the split between the transverse tunes at the coupling resonance is used (Figure 2). In addition, the on-line measurement of the electron beam emittances from the imaging of the central cone of an undulator enables the effectiveness of the correction to be checked. Coupling in the 1 % range, which is at the limit of precision of such a method, is currently measured when the correction is switched on. The settings of the skew quadrupoles are very reproducible, which indicates an intrinsic skew component independent of the tune and orbit of the day.

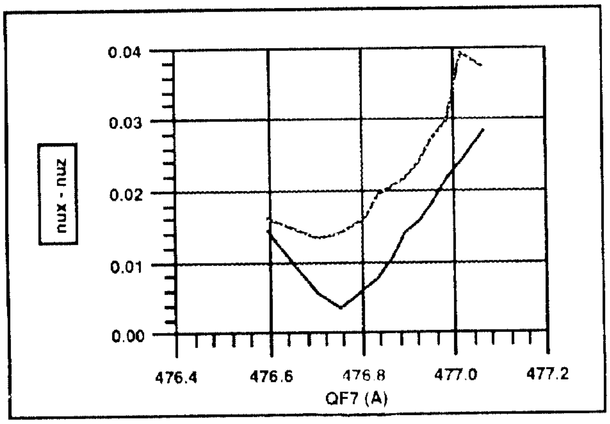

Figure 2

4. HORIZONTAL EMITTANCE

The present optics of the storage ring corresponds to an expanded Chasman-Green lattice with zero-dispersion at the insertion device source points. In order to keep reasonable horizontal beta functions in the quadrupoles and to minimize the detrimental effects induced by the correspondingly increased chromaticity, the natural horizontal emittance had been increased from the theoretical value of 3.4 nm to 6.9 nm. Some possibilities of lowering the natural emittance by allowing for non-zero dispersion in the straight sections are being investigated. Simulations of a new optics [4] indicate that the effective emittance when taking into account the effects contributing to the emittance increase (momentum spread, radiation emitted from insertion devices,...) could be reduced down to the 4 nm range. Figure 3 gives the optical functions of this low emittance optics.

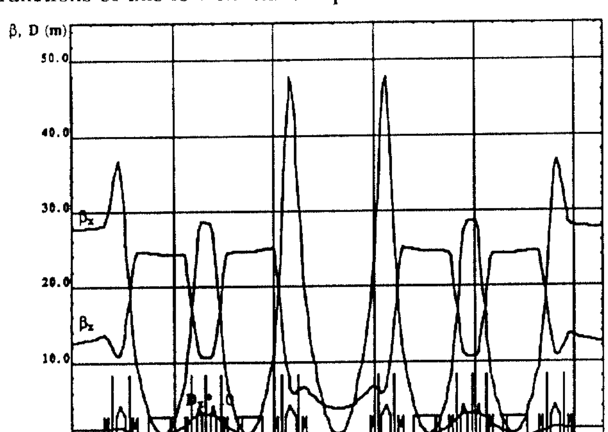

Figure 3

The vertical emittance will follow by maintaining the coupling factor constant. Therefore, on top of the gain associated with the small coupling, a further gain in brilliance of about 3 is likely to be obtained by lowering the horizontal emittance.

With the exception of the upgrading of some sextupole power supplies, the experimental tuning of this modified optics does not require any major modification of hardware. Preliminary tests started at the outset of 1994 and will be one of the major machine physics objectives till the end of the year. In order to simplify the passage from the modelling of the lattice to experimental settings, initial tests first concentrated on the 32-fold symmetry version of such a low emittance lattice tuned to a working point of 30.2, 9.85. Promising results agreeing well with predicitions were obtained with emittances in the low 4 nanometer range being recorded. However, we are confronted with a striking divergence with the modelling due to the dispersion behaviour. The measured dispersion shows a strong modulation along the machine corresponding to 2 periods. Investigations are currently under way to find the sources of this pertubation. This could result from a beat between the main harmonic of the closed orbit (30) and the harmonic of the dispersion and sextupoles (periodicity 32). Focusing errors could also be responsible for the observed modulation. Although these assumptions are supported by simulations, they have not yet been confirmed experimentally.

The tuning of the 16-fold symmetry lattice which is a variant of the previous one and corresponds to higher tunes (36 and 11) is the next priority objective. The easiest way to evolve from the present 16-fold lattice to a low emittance one without being confronted with uncertainties on quadrupole calibration consists in mismatching the achromat by detuning the focusing quadrupoles. Again, as far as emittances are concerned, the machine reacted like the simulations. Promising results were obtained: horizontal emittance of 5 nm associated with a very low coupling thanks to the tuning far from the coupling, excellent injection efficiency, stable ramping to 100 mA. This indicates that both the dynamic acceptance and the chromaticity corrections are correct, despite a more complicated scheme where all sextupoles contribute to the chromaticity correction and enlargement of the dynamic aperture. Further optimization of the lattice will proceed in the forthcoming months.

5 CONCLUSION

The ESRF brilliance would be multiplied by a factor of between 40 and 400 by combining all possible gains on the target performances. This means that there is certainly room for a factor of at least 10, which would already place the ESRF half way between the third and fourth generations.

6. REFERENCES

[1] J. M. Filhol, "Status of the ESRF", These proceedings

[2] Brainstorming on minigap undulator, ESRF internal report

[3] J. Jacob, C. David and J. L. Revol, "RF system developments for high current accumulation in the ESRF storage ring", These proceedings

[4] L. Farvacque et al., "Possible retuning of the ESRF storage ring lattice for reducing the beam emittance", These proceedings

7. AKNOWLEDGMENTS

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