LATTICE RELATED BRILLIANCE INCREASE AT THE ESRF

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Abstract

The ESRF brilliance is currently being increased by more than two orders of magnitude with respect to the original design target value of 1018 photons/sec/mm2/mrad2/0.1% relative bandwidth by acting on the stored beam current, the refinement of the insertion device technology and beam emittances. This paper will review the lattice-related contribution to the on-going improvements of the initial performances in brilliance of the source: modifications in the tuning of the basic Chasman-Green lattice enabling the reduction of the horizontal emittance from the design 7 nm down to 4 nm, strategy to control the coupling below 1 %, optimization of the beta functions in the insertion devices. This already brought a factor of 30 in brilliance. The potential for a further improvement in the brilliance by a factor of ten will be described.

1. INTRODUCTION

Brilliance is the figure of merit the most referred to for third generation light sources. At the ESRF, the initial brilliance performance has been upgraded by a factor of 100 by acting on the different parameters entering into the brilliance formula:

$$B = \frac{I}{\kappa \varepsilon_x^2} f(E, g, B)$$

- the stored beam current I has been increased from 100 mA to 200 mA by overcoming the HOM limit thanks to the partial filling of the circumference and to the detuning of the HOMs by temperature control of the cavities.

- on the insertion device side (gap g, field B), spectrum shimming techniques have pushed the highest useful undulator harmonic and increased the brilliance at all harmonics. Undulator gaps have been decreased from 20 mm down to 15 mm which allows a gain of a factor of 2 in brilliance in the fundamental via the associated reduction of the undulator period. Thanks to the reduced vertical beam stay-clear affordable with the new lattice optics, new insertion devices will have a gap of 11 mm.

- lattice-related parameters (the horizontal emittance ε_x and the coupling factor $\kappa = \frac{\varepsilon_z}{\varepsilon_x}$) have been significantly reduced with respect to the design values. This, together with a better matching of the optical functions at the source points, has brought an improvement in brilliance of a factor of 30, i.e. the major part of the quoted figure of 100.

2. REDUCTION OF THE HORIZONTAL EMITTANCE

In the Double Bend Achromat lattice used at the ESRF, the small emittance is achieved by lowering the horizontal β function inside the bending magnets, thus generating unacceptably high β values in the focusing structure outside the bending magnets and leading to large chromaticities, higher sensitivity to errors and reduced dynamic apertures. Our design value of 7 nm resulted from a compromise between these different effects [1].

In order to achieve a lower emittance nevertheless, a new version of lattice settings with a distributed dispersion has been implemented and has now been operated for 2 years. By detuning the quadrupoles in the achromat, the dispersion pattern is more balanced inside the bending magnets where the emittance is created [2]. This strategy enabled almost a factor of 2 to be gained on the horizontal emittance from 7 nm down to 4 nm. This gain is almost entirely transferred in brilliance increase since the non-zero dispersion combined with the internal beam energy spread contributes to the beam size in the straight sections very slightly.

3. COUPLING CONTROL

The X-ray pinhole camera [3] enables the photon beam emittances and accordingly the electron beam emittances to be permanently measured. Two of these devices are installed on different bending magnets. Their results are in good agreement, thus confirming the extremely low vertical emittance achieved at the ESRF. Since the image made with the second camera has a significant contribution from energy spread, it also provides an accurate diagnostic of the electron energy spread.

In comparison with initial objectives of a 10 % coupling, dramatic progress was made and the coupling routinely decreased to 1 %.

Until January 1996, the correction of coupling was based on the cancellation of the 2 coupling resonances $\upsilon_x - \upsilon_z = 25$ and $\upsilon_x + \upsilon_z = 48$ close to the working point ($\upsilon_x = 36.44$, $\upsilon_z = 11.39$) [4]. This was performed by using 2 pairs of skew quadrupole correctors for each resonance in order to adjust the amplitude and the phase of the correction while moving the tunes to the resonances. The residual coupling of 1 to 2 % obtained is due to other resonances which look difficult to minimize via the single resonance method.

The installation of an additional set of 8 skew

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quadrupoles now allows more advanced corrections [5]:

- measurement of the coupled response of the machine to steerer excitation and minimization of the cross-talk terms
- minimization of the spurious vertical dispersion

This procedure results in routinely achieved values of less than 1 % in all operating modes (as shown in Figure 1 during a two-week period alternating hybrid, single bunch, 16 bunch modes) and record values of 0.5 %.

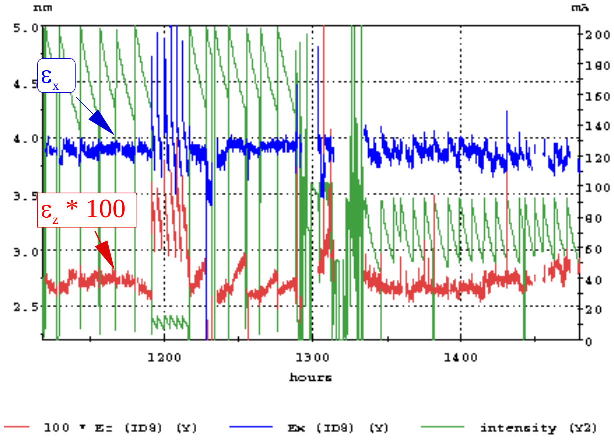

Figure 1

At this stage, the reduction of the vertical dispersion (given the small initial values as shown in Figure 2) does not give a noticeable improvement in coupling. However, the induced radiation in the presence of vertical dispersion will start to play a role when further refining the correction algorithm in order to achieve the future goal of an 0.3 % coupling. This upgrade also requires the discrepancy between modeling and calibration experiments on the effect of a single skew quadrupole to be clarified.

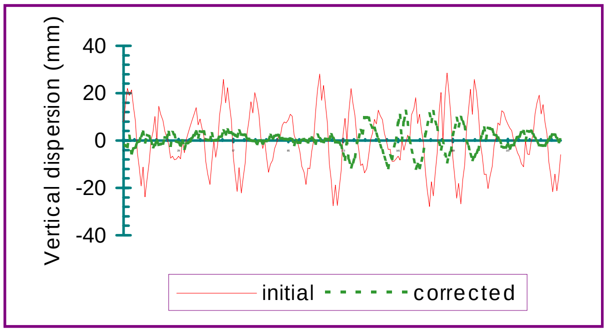

Figure 2

4. WINNING OVER DIFFRACTION WITH β

With the original 7 nm lattice and 10 % coupling, the brilliance of the photon beams was essentially dictated by the emittances of the electron beam. This is no longer the case with the presently achieved 40 pm vertical emittance, as shown in Figure 3. The effective dimensions result from the convolution of the electron beam emittances and the photon beam emittance associated with the single electron which can be expressed as $\varepsilon_R = \frac{\lambda}{2\pi}$ (λ being the wavelength of the radiation). For a given value of ε_R and ε_z (vertical electron beam emittance), the minimum photon beam emittance is obtained for a perfect matching ($\beta_z = \beta_R$, with $\beta_R = \frac{L}{\pi}$ and L being the length of the undulator) as illustrated in Figure 4. This corresponds to $\beta_z = 1.59$ m or $\beta_z = 0.53$ m, depending on the number of 1.6 m long insertion device segments (3 or 1), emitting at 14 keV. When the matching is imperfect, the reduction of the effective brilliance which would be only 12 % with 10 % coupling reaches 55 % with 1 % coupling. Any further reduction of the vertical emittance would be impaired by a greater relative reduction of the brilliance.

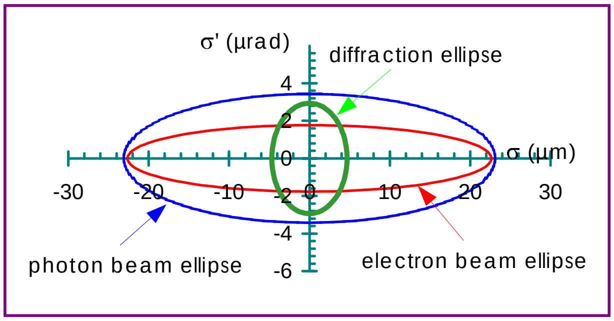

Figure 3

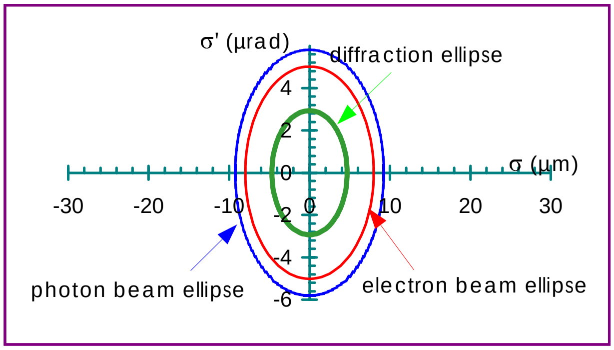

Figure 4

Going to β_z values of the order of 0.53 m looks very difficult to achieve in terms of machine tuning. Also given the parabolic increase of the β_z value at the 5 m undulator edge, the reduction of the insertion device gap from the present 15 mm to 11 mm would be inhibited. Since the tendency at the ESRF is to evolve towards the installation of 3 insertion device segments per straight section, $\beta_z = 1.59$ m would provide a perfect matching. However, other constraints (such as the evolution of the actual beam size of the X-ray beam drifted 30 m downstream the source point or beam position stability considerations) favour β_z values of the order of 2.5 m, which in terms of brilliance reduction is negligible in the case of 3 installed segments. In this new version of the optics [6] used in User Service Mode since November 1996, the vertical β in the undulator straight sections is therefore decreased from 13 m down to 2.5 m, thus leading to an increase of the vertical tune by three integers, from 11.39 to 14.39 (Figure 5).

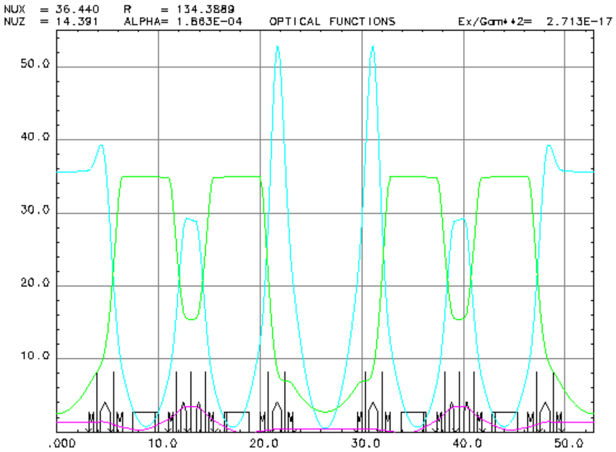

Figure 5

Reducing the vertical β was also a prerequisite for decreasing the insertion device gaps. Thanks to the smaller electron beam vertical sizes in the straight sections, beam scraping on the reduced beam stay-clear ID vacuum vessels (± 4 mm inner aperture) is less severe and consequently the beam gas scattering lifetime reduction and Bremsstrahlung emission on the beamlines minimized. Comparative studies with the high β and low β optics (Figure 6) show that a minimum beam stay-clear of 5 mm can now be accepted instead of 7 mm for the same 20 % reduction in beam lifetime. Two 2 meter long, 8 mm high vacuum vessels are now installed without significant impact on the lifetime. The first 5 meter long, 8 mm high vacuum vessel will be installed next summer.

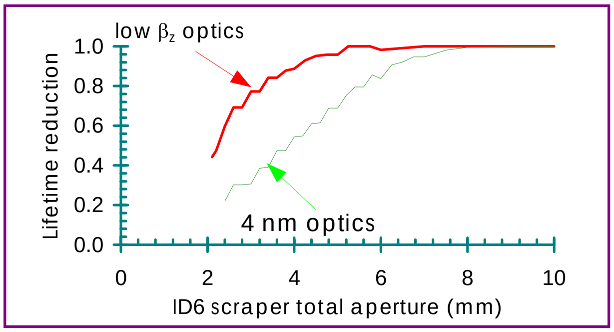

Figure 6

The low β_z optics also has other potential advantages:

- the reduced sensitivity to insertion device chamber wall impedance enables a relaxed chromaticity to be used in all filling modes. This is particularly visible in single bunch mode where the intensity threshold is strongly chromaticity dependent. The required vertical chromaticity (ξ_z = 0.67 instead of 0.9 for the high β_z optics) favours the obtaining of a larger energy acceptance and longer lifetimes.

- the reduced sensitivity to insertion device field imperfections minimizes the possible effects induced by gap changes such as modification of the coupling or orbit distortions.

- the beam at a cross-over tolerates larger scattering angles, therefore the lifetime is less sensitive to the vacuum in the insertion device straight sections.

5. FUTURE PLANS

The significant evolution of the lattice since the design stage with even stronger focusing and larger non-linearities via the chromaticity compensating sextupoles reinforces confidence in further possibilities of reducing the natural horizontal emittance. Tests on a new optics providing a 3 nm emittance will be initiated very soon. This upgrade, together with the reduction of coupling and the operation of 11 mm gap insertion devices will push the ESRF in the 10^{21} range in brilliance which is the maximum achievable figure with the present generation of storage rings.

The possibility of provoking dissymmetry of the electron beam horizontal envelope in the high β insertion device straight sections while operating the lattice with a non-zero alpha function in the straight section such that the emitted photon beam would focus about 30 m downstream the beamline at the sample location is also under consideration [7]. For a number of beamlines, the resulting increase in flux at the sample would be superior to a gain by a factor of 10 in brilliance. Necessary hardware allowing an assymmetrical powering of the quadrupoles of the straight section triplets is being purchased and the scheme will be tested first in one straight section during the second half of 1997.

6. REFERENCES

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