THE DIFFRACTION LIMITED LIGHT SOURCE ELETTRA 2.0

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Abstract

Elettra 2.0 is the name of the next generation light source to replace Elettra, the Italian third generation light source. The new machine will have a bare emittance of 0.25 nm-rad and coherent flux about two orders of magnitude higher than that of the present machine. In the paper the aspects of its feasibility are described and discussed.

INTRODUCTION

Located on the outskirts of Trieste, Elettra operates for users since 1994 being the first third generation light source for soft X-rays in Europe. After 23 years of faithfully serving the user community with excellent results, a major upgrade towards what it is called the "ultimate" light source is planned [1,2] to maintain its leadership for its energy range of synchrotron research and to enable new science and new technology developments to the general benefit.

The main characteristics of this new generation is a substantial increase of the photon source in brilliance and coherence as compared to today's X-ray beams achieved by a substantial emittance reduction of the stored electron beam at levels capable of providing a diffraction limited X-ray source also in the horizontal plane while such a limit has already been achieved at Elettra for the vertical plane. Elettra 2.0 thus, aims to provide intense beams in the range of VUV to X-rays for the analytical study of matter with very high spatial resolution.

Already in the 90's people were speculating on diffraction limited light sources [3] although the times were not yet ripe. Development in accelerator technologies during the last twenty years led to many important results featuring new magnet design, innovative vacuum and material technologies as well as important improvements in beam monitoring and feedback systems. Those new capabilities and technologies, which were not available or were at their infancy when the present Elettra storage ring was conceived, provide today a solid basis for the realization of the new machine.

Studies being carried out at Electra resulted in a new storage ring lattice design based on the multi-bend achromat concept and produced the first version of a conceptual design for the new machine [4].

REQUIREMENTS FOR ELETTRA 2.0

The requirements for the new machine are as follows:

- Energy 2 GeV
- Emittance reduction by more than 1 order of magnitude
- Electron horizontal beam size less than 60 um
- Intensity 400 mA, maintain the filling patterns as before (hybrid, single bunch etc.)
- Use the same building and almost the same ring circumference (~260 m)
- Free space available for insertion devices (ID) not less than that of the actual Elettra
- Maintain the existing ID beam lines at the same position
- Maintain the existing bending magnet beam lines
- Use the existing injector
- Minimize the "dark time"

An exhaustive analysis of emittances, beam sizes and free available space for realistic lattices from 4 to 9 bend achromats was made [1]. Combining the results of that study with the above listed requirements led us to adopt as best solution a special version of a six bend achromat coined S6BA. The new magnetic lattice will substitute the 12 arcs of the existing storage ring with 12 new arcs of almost identical length and will reduce the present horizontal emittance of 7 down to 0.25 nm-rad. This reduction will result in increasing the brilliance and coherence of the X-ray beam by a factor of 20 at 1keV.

For the emittance reduction higher gradients fields are used resulting in higher chromaticities, smaller dynamic apertures and stronger non-linear effects making the construction and operation of those machines rather challenging.

THE S6BA LATTICE

The lattice consists of 6 quad-dipole-quad cells per achromat creating an invariant optic under relative position shifts between them. Thus relative long straight section can be created in the arcs without appreciable change of the optics functions increasing thus the space available for insertion devices.

The S6BA optics, shown in Figure 1 has an emittance of 0.25 nm-rad with working point (33.3, 9.2) and natural chromaticities (-75,-51).

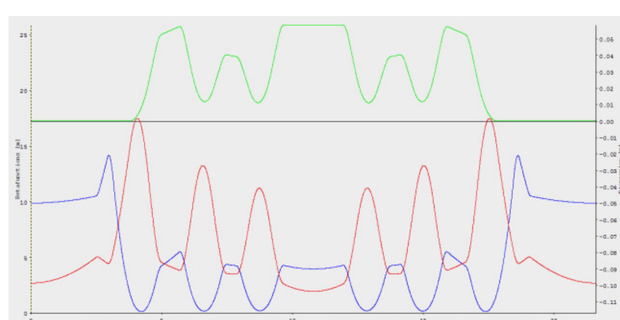

Figure 1: Electra 2.0 lattice.

The corresponding horizontal beam size at the straight sections is 40 μm in the horizontal and 3 μm in the vertical at 1% coupling (however higher coupling i.e.

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towards round beams to avoid resistive wall effects is preferable) and the divergence is 6 μrad. The dipoles will be combined having a dipole field of 0.8 T (compared with 1.2 T at 2 GeV of the actual Elettra) and their maximum gradient will be 17 T/m (compared with 2.8 T/m in Elettra). The quadrupoles have a maximum gradient of 50 T/m (compared with 15 T/m in Elettra).

The dispersion in the arcs is low (58 mm compared with 400 mm in the actual Elettra) meaning that also the short straight sections (1.8 m long or longer) situated in the middle of the arc can be used for insertion devices or even, due to the very small and similar beam dimensions in both long and short straight sections, in-vacuum insertion devices with a 6 mm gap can be easily installed without additional optic elements. Since the dipole fields of the lattice are now lower cannot be used for the dipole based beam lines but for the infrared beam line. Two possible solutions were considered: either to install a short wiggler in the short straight section or to install a super-bend. Both solutions may contribute to an emittance increase of the bare lattice depending upon their field and number.

DYNAMIC APERTURE

Reducing the emittance by a factor over 25 in a circumference of about 260 m (12 achromats) while requiring the available free space to be at least as before, results in having strong gradients in all magnets with a high impact on the dynamic aperture. To investigate the DA, 6-dimensional (6-D) particle tracking was performed (2000 turns), including both betatron and synchrotron oscillations in the presence of classical synchrotron radiation emission and radiofrequency (RF) acceleration using Elegant[5] including alignment and field errors. In the next Figure 2 the dynamic aperture (to be further optimised) is shown:

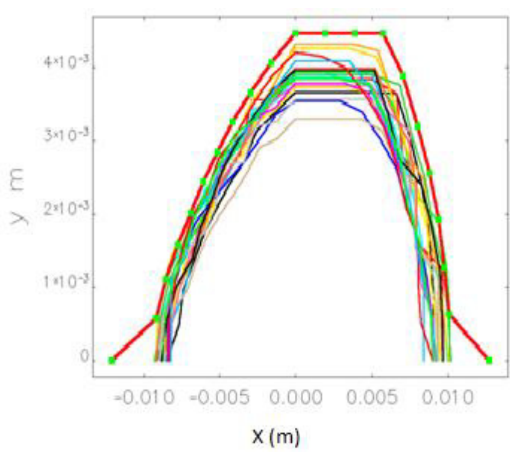

Figure 2: DA of the lattice with and without errors (red most external curve).

As position errors were taken, 20 μm between magnets in a girder, 100 μm between girders and 100 μrad in angle. Field errors were taken as 0.01%. Values refer to the standard deviation of a Gaussian distribution with 3-sigma cutoff.

As can be seen from Figure 2 the dynamic aperture is reduced to ±8.3 mm horizontally and ±3.5 mm vertically. This aperture allows off-axis injection and the use of the injectors as in the present machine. In Figure 3 the injection efficiency versus the horizontal bump is shown. With an injection bump of about 8 mm the predicted efficiency is about 95%.

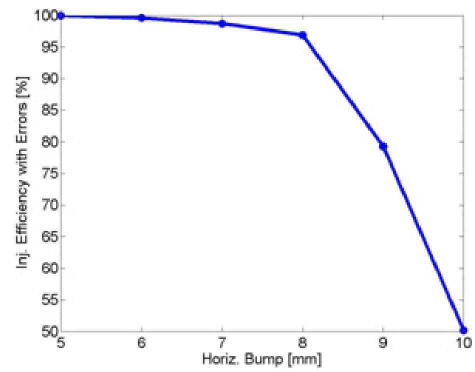

Figure 3: Injection efficiency versus the horizontal beam bump amplitude.

EFFECTS OF INSERTION DEVICES

The insertion devices (ID) modify the radiation equilibrium resulting in changes of the damping times, beam emittance and energy spread. IDs influence the linear and non-linear optics producing distortions of the optics functions (e.g. beta beats and tune shifts) and additional resonance excitations that can reduce the dynamic aperture. Those effects can be corrected using the dispersion-free quadrupoles and by careful choice of the working point. In general the emittance and energy spread will decrease with moderate ID fields. However for very strong fields and/or long period devices the small dispersion created may invert the effect. In the next Figure 4 the emittance, energy spread and energy loss per turn versus the number of insertion devices (taken the ones of the actual Electra) are shown.

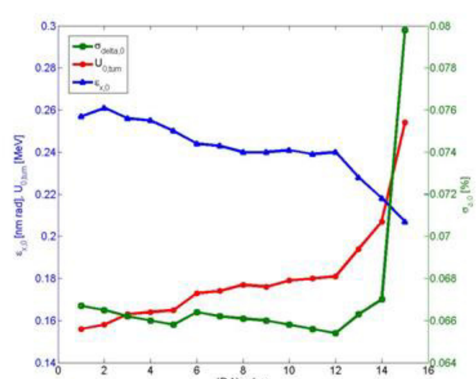

Figure 4: Emittance, energy spread and energy loss per turn versus the number of insertion devices at minimum gap / max phase.

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As can readily be seen the net effect is a reduction of emittance. However if short 2T wigglers in the short straights and/or super-bends are added the emittance increases depending upon their number and field. The short wigglers give 2.3 % increase per device however the effect is neutralized if combined with the effect of the other insertion devices in the long straights. Super-bends are having a bigger impact; a 3.5 T super-bend pair will increase the emittance by 4% if using a combined magnet whereby only a small portion is at 3.5T. The effect becomes stronger using a superconducting dipole emitting at a total bending magnet angle (5.7 deg). In that case the net emittance increase is 20% per dipole.

MAGNETS

Due to the demand for large free space available for IDs the magnets have to be longitudinally short and the distance between them is between 50-70 mm. Due to that the magnets are designed to have their magnetic length almost equal to their physical length. The maximum length of the dipoles is 0.84 m and of the quadrupoles 0.22 m with bore radius at 28 mm. All magnets will be air-cooled. There will be 72 dipoles, 192 quadrupoles, 240 sextupoles of which 120 will be combined for providing dipole (correctors) and skew quadrupole field. Additionally 72 pure correctors are foreseen.

In the next Figure 5 a quadrupole and its profile are shown. One can readily check that coils do not hang out the yoke. All magnets including correctors are designed and a quadrupole prototype is under construction.

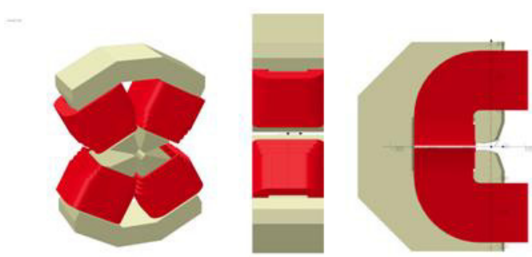

Figure 5: Quadrupole and dipole profiles.

LIFETIME ISSUES

In general we opt for a cylindrical vacuum chamber of 23 mm internal diameter (except for light exits and the low gap chambers) with some parts made out of stainless steel or copper and other parts of aluminium with NEG. Such configuration can give vacuum similar to the existing machine i.e. 3 nTorr of N_2 dynamic pressure. Assuming 1% coupling, 400 mA stored intensity and 2.4 MV effective RF voltage, the Touschek lifetime is 12 hours and including elastic (1286 h) and inelastic scattering (26 h) the total linear lifetime becomes 8 hours taken the "zero" current bunch length of 1.8 mm. However when performing 4-D tracking using OPA [6] whereby particles start on axis but with momentum deviation $\Delta p/p$, the total lifetime is reduced to 6 hours indicating also a momentum acceptance of 7%. The above investigation suggests that the new machine will be also Touschek dominated and using the third harmonic cavity (3HC) one expects a threefold increase in lifetime.

Due to small emittance intra-beam scattering becomes important. For the "zero" current bunch length (3HC off) a 92 % emittance increase at 400 mA is estimated whereas in the case of bunch lengthening (3HC on) the emittance increase is 46% as seen in figure 6. Hence, the already existing third harmonic cavity (3HC) should also be used for Elettra 2.0.

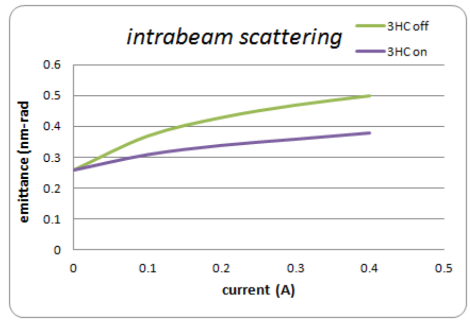

Figure 6: Emittance growth due to intra beam scattering for the natural and for a lengthened (3.5 times) bunch.

CONCLUSIONS

Electra 2.0 will operate at 2 GeV replacing the actual machine in the same tunnel. The lattice will be a special 6-bend achromat (S6BA) with an emittance of 250 pm-rad and very small spot size and divergence (< 60 μm horizontal, 3 μm vertical, < 6 μrad). The photon source points from the insertion devices will remain at the same position as at present. For the dipole beam lines various options are offered: either to be served from a short (0.48 m) permanent magnet dipole of 1.3 T or by a short 2 T wigglers or by installing super-bends. In all those cases the dipole beam lines have to be shifted accordingly. The project for Electra 2.0 is estimated to last 5 years and 9 months with a dark period (beam off – beam on) of 18 months.

The new machine will be diffraction limited in the horizontal plane for $\lambda \geq 15$Å while in the vertical at 1% coupling for $\lambda \geq 0.15$Å whereas its coherent fraction at 1keV will be 38%.

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