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ELETTRA 2.0 - THE NEXT MACHINE

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Abstract

A next generation light source (ULS) to replace Elettra, the third generation Italian light source is presented 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. During those 20 years many improvements were made in order to keep the machine updated and competitive with the other more recent and modern light sources. Although Elettra will continue serving the scientific community for some more years, it was felt that the right time has come to prepare her successor and therefore studies were performed on this issue [1].

After the 4th generation light sources came to operation, it became evident that free electron lasers (FEL) cannot replace storage rings (SR) (therefore the term 4th generation is not reflecting the reality since each generation replaces the previous one) but rather are complementary. There are many reasons for that such as the SR high repetition rate and the fact SRs can serve a very large number of experiments whereas FELs serve only few (usually one).

SR light sources clearly cannot compete with FELs on the pulse length (ps against fs) at least at comparable intensities but there is a big margin of improvement on other beam characteristics. Already in the 90's people were speculating on diffraction limited light sources [2, 3] although the times were not yet ripe.

In general a ULS compared to a 3rd generation must have a much higher brilliance (at least one order of magnitude at low photon energies e.g. 1 keV) a high level of coherence in both planes (the 3rd generation has only high vertical coherence) smaller spot size and divergence, higher flux and variety of insertion devices.

Certainly all those beam properties, highly desirable for many experiments, have a great impact on the design and operability of those machines. Reducing the emittance by more than an order of magnitude may result in using higher gradients therefore higher chromaticities, smaller dynamic apertures and stronger non-linear effects. If on this one adds other requirements as for example installing the new machine in the same tunnel in replacement of the old one the degree of complication may increase exponentially.

REQUIREMENTS FOR ELETTRA 2.0

In a previous paper [1] an exhaustive analysis of emittances, beam sizes and free available space for realistic lattices from 4 to 9 bend achromats was made. How Elettra2.0 should be came by merging that analysis with the requirements of the users as expressed during a workshop on the Future of Elettra in April 2014 and summarized below:

- Energy 2 GeV
- Same building, same ring circumference (259-260m)
- Maintain the existing ID beam lines, same position
- Maintain the existing bending magnet beam lines
- 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.)
- Free space available for IDs not less than that of Elettra
- Use the existing injectors i.e. off-axis injection
- 6+6 months downtime for installation and commissioning

The above user requirements and the analysis made in [1] led us to adopt the 6-bend achromat as best solution.

ELETTRA 2.0 LATTICES

The 6-bend achromat optics, shown in Figure 1 (using OPA [4]), has an emittance of 0.25 nm-rad with WP (33.2, 9.3) and natural chromaticities (-63,-50). The corresponding horizontal beam size at the straight sections is 40 μm for the horizontal and 3 μm for the vertical one at 1% coupling (however higher coupling i.e. towards round beams to avoid resistive wall effects is preferable) and the divergence is 6 μrad. The dipoles have now a field of 0.8 T (compared with 1.2 T at 2 GeV of Elettra) and their maximum quadrupole component is 17 T/m (compared with 2.8 T/m in Elettra). The quadrupoles have a maximum gradient of 53 T/m (compared with 15 T/m in Elettra).

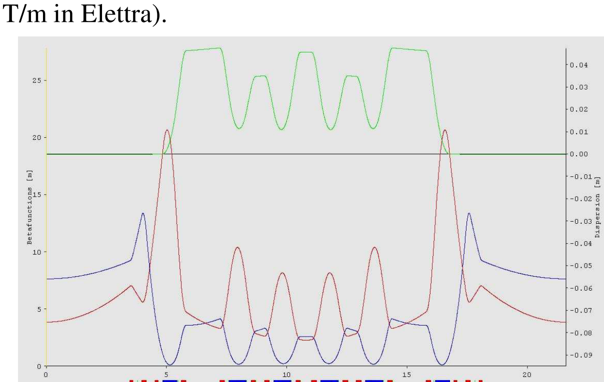

Figure 1: Elettra2.0 lattice 1.

The dispersion in the arcs is low (40 mm compared with 400 mm in Elettra) meaning that also the short straight sections (1.4 m long) situated in the arcs before the outer dipoles can be used for insertion devices with

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performance similar to ones in the zero dispersion regions.

However the low dipole fields of this lattice cannot be used for the bending magnets based bean lines. One possible solution is to install a short wiggler in the short section on the right. This however implies that the whole beam line will be shifted by 7 degrees, a rather large shift that might create space problems. To circumvent this problem another lattice was created using a short strong permanent magnet of 1.3 T with a bending angle of 5.6 deg to replace the second and fifth dipole as shown in the next Figure 2. With this lattice the bending magnet based beam lines will get their light from the 1.3 T dipoles and need not shift almost at all, while the short wiggler solution mentioned above stays still valid.

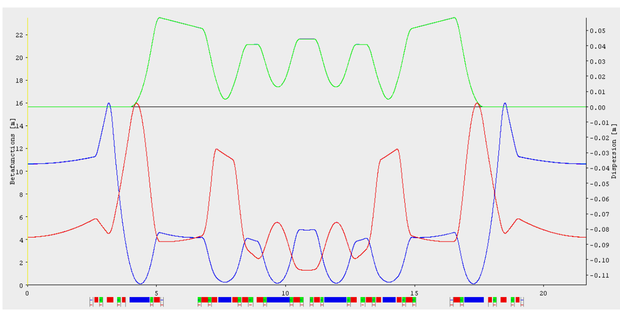

Figure 2: Elettra2.0 lattice 2 with 2 permanent magnets.

The emittance of this lattice 2 is 0.28 nm-rad, same working point while the natural chromaticities are (-79,-47). The maximum horizontal beam size becomes 55 and the vertical one 3.5 μm.

The energy loss per turn is 38 % less for lattice 1 and 23% less for lattice 2 compared with that of the actual Elettra. The momentum compaction is $3x10^{-4}$ while the natural energy spread stays as before $7x10^{-4}$.

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 very strong gradients in all magnets with a high impact on the dynamic aperture. In the next Figure 3 the dynamic aperture (to be further optimised) is shown:

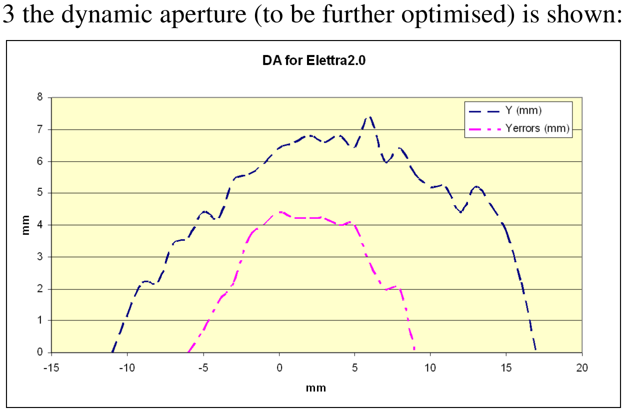

Figure 3: DA of the lattice with and without errors.

Although the dynamic aperture without errors is very comfortable when alignment errors are included (about 50 μm in position and 100 μrad in angle) a 40% reduction is observed. Certainly it may be laborious to inject off-axis to a ±7 mm horizontal aperture, especially as far as top-up efficiency is concerned, but this is not rendering the optics unfeasible because once the injected beam is stored the dynamic aperture still corresponds to 200 σ of the beam size (compared with 100 in Elettra).

For coupling control some families of skew quadrupoles are to be included. Touschek lifetime when using the actual Elettra rf-system is about 6-8 hours for 300 mA with the natural bunch length of 12 ps.

BRILLIANCE AND COHERENCE

With Elettra2.0 the brilliance increases by a factor of 15 at 1 keV as can be seen from the next Figure 4 for the 4.5 m long, 46 mm period undulator in the SuperEsca beam line.

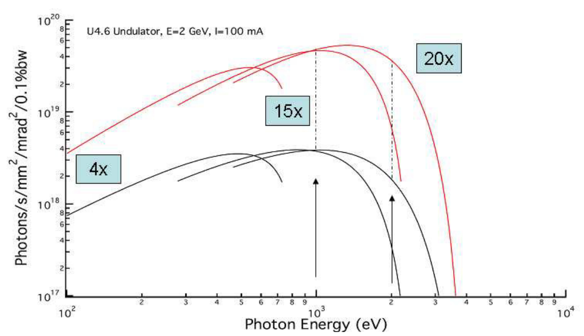

Figure 4: Brilliance increase between the actual machine and Elettra2.0.

Furthermore the ring will be horizontally diffraction limited for photon energies up to 100 eV whereas the coherence fraction at 1 keV becomes now at 38% from 2% with the actual machine. In Figure 5 the coherence fraction is shown for both machines.

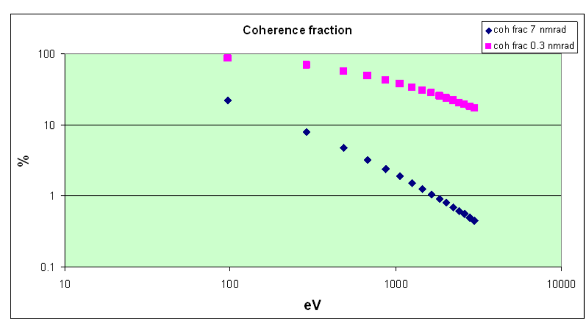

Figure 5: Coherence fraction for Elettra and Elettra2.0.

CHALLENGES AND DISCUSSION

Diffraction limited rings require very strong focusing i.e. magnets with high gradient which require high precision engineering, a very challenging task. Since the circumference available for the new Elettra is about 260 m, the magnets have to be longitudinally short. We opted for 0.22 m maximum magnetic length for the quadrupoles and 0.85 m maximum length for the dipoles. The maximum integrated field for the quadrupole with 53 T/m is 12 T. To achieve such a field the pole opening should

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be ≤ 30 mm meaning that the vacuum chambers should be at about 25 mm or less internally, a certain challenge for vacuum pumping. New materials such as cobalt-iron alloys can give a 40% higher field and possibly allow increasing the distance between the poles. Preliminary design of the dipoles and quadrupoles [5] confirm their feasibility. In the next Figure 6 the profile of a dipole and a quadrupole is shown. Notice the asymmetry in the pole position of the quadrupole done on purpose to facilitate the extraction of radiation.

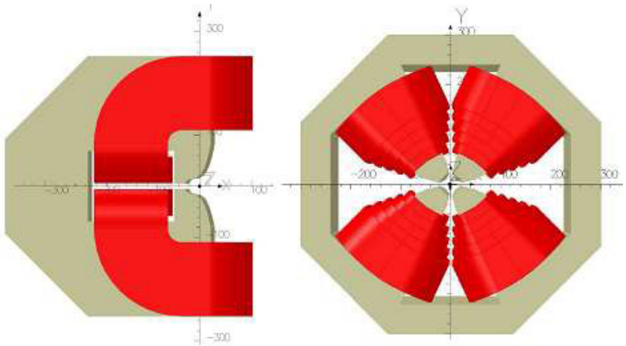

Figure 6: Dipole and quadrupole profiles.

Fitting the new machine on the existing girders it is possible as can be seen from the next Figure 7, since the maximum radial shift of the new machine is about 300 mm [6] and its total length 259.8 m.

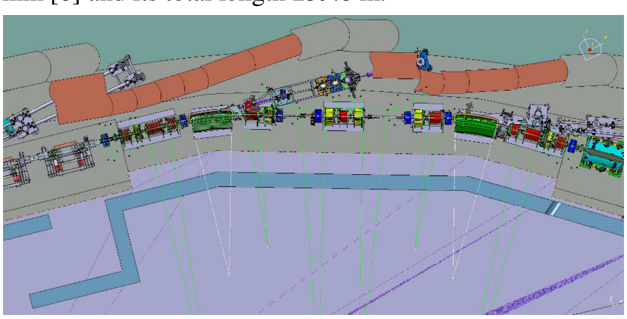

Figure 7: Elements of one sector Elettra2.0 (yellow lines) superimposed on an actual sector. Observe the short permanent magnet exactly before the actual dipole.

Beam dynamics studies including intra-beam scattering and collective effect analysis are in progress.

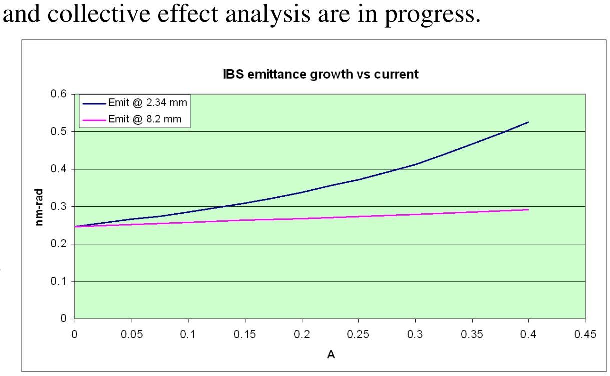

Figure 8: Emittance growth due to intra beam scattering for the natural and for a lengthened bunch due to the third harmonic cavity already in function at Elettra.

Some preliminary results on intra beam scattering (Figure 8) show that with the already existing third harmonic cavity there will be only a 20% emittance growth at 400 mA to be compared with a 100% growth in case of a non lengthened bunch.

CONCLUSIONS

Elettra2.0 will have a fixed energy of 2 GeV and will replace the old machine occupying the same tunnel. The machine lattice will be a 6-bend achromat with an emittance of 250 - 280 pm-rad (25-28 times reduction from that of the actual machine) and very small spot size and divergence (< 60 µm horizontal, 3 µm vertical, < 6 µrad). The insertion devices photon source points remain the same meaning there is no need to move the existing insertion devices beam lines. For the bending magnet beam lines two options are offered: either served from a short (0.48 m) permanent magnet dipole of 1.3 T for almost no positional shift or by short wigglers with a shift of their physical location of about 7 degrees.

The new machine will be diffraction limited in the horizontal plane for $\lambda \geq 15$Å while in the vertical for 1% coupling for $\lambda \geq 0.15$Å.

A project has already started aiming to produce the conceptual design report. Together with the report three prototypes will be constructed namely a fixed gap undulator (to be tested on the actual machine), a short permanent magnet dipole and a strong 0.22 m long quadrupole.

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