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THE ELETTRA 2.0 PROJECT

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Abstract

The project status of the future Italian 2.4 GeV fourth generation light source Elettra 2.0 that will replace the third-generation light source Elettra is presented. Elettra 2.0 will be the ultra-low emittance light source that will provide ultra-high brilliance and coherence and at the same time aims to provide very short pulses for time resolved experiments.

INTRODUCTION

Located on the outskirts of Trieste, Italy, Elettra operates for users since 1994 being the first third generation light source for soft X-rays in Europe. During those 27 years, many improvements were made in order to keep the machine updated and therefore competitive with the other more recent and modern light sources already designed to operate in top-up. Following the successful set in operation of the full energy injector in 2008, after 14 years of energy ramping, Elettra established top-up operations [1] in spring 2010, although not originally designed for it. Operating in top-up proved to be, and still is, very beneficial for the machine [2].

Although Elettra performs very well and is serving the user community with excellent results, in order to keep the light source competitive for synchrotron research and enable new science and new technology developments, after 28 years of operation the diffraction limited storage ring Elettra 2.0 is going to replace Elettra.

ELETTRA STATUS

Elettra operates 24 hours/day, seven days a week delivering more than 5000 hours/year of synchrotron light from infrared (IR) to hard x-rays to 28 beam lines. Ten of them are served by bending magnets. Two beam-lines use light from a superconducting 49-pole, 64-mm period, 3.5 T wiggler.

Many types of insertion devices are installed such as planar, polarizing, electromagnetic, superconducting including canted APPLE II type undulators occupying all the eleven available long straights while the dispersive short straights are also used for short insertion devices such as the 1 m long double APU (Adjustable Phase Undulator) device serving the TwinMic beam line.

The machine consists of a 100-MeV linac, a 2.5 GeV booster and a 2.0/2.4 GeV storage ring. For about 75% of user-dedicated time Elettra operates at 2 GeV while for the remaining 25% it operates at 2.4 GeV, being the only facility to operate at two energies (both in top-up). The main operating modes are multi-bunch with a dark gap of 42 ns and hybrid i.e. multi-bunch with one (for time resolved experiments) or two single bunches (distant 40 ns in a dark gap of 120 ns for pump and probe experiments). In 2021, hybrid mode user beam time amounted to 30 % of the total user beam time. The operating intensities are 310 mA at 2 GeV and 160 mA at 2.4 GeV with 5 mA single bunch(es) added when in hybrid mode.

The total availability, i.e. including the power outages, is 97% and the Mean Time between Failures (MTBF) is higher than 75 hours. The mean maximum time between failures is currently at about 321 hours with peaks at 451 hours. The top-up availability to the total user scheduled time for 2021 was 99 %.

ELETTRA 2.0: OVERVIEW

Already since 2014 discussions with beamline responsibles, users and partners started in order to define the requirements of the new machine described in a series of papers [3-9] resulting to a preliminary but otherwise complete Conceptual Design Report (CDR) [8]. Since 2017 a series of workshops with the users and partners established some new and final requirements. Thus, it has been decided to operate mainly at 2.4 GeV while letting open the possibility to operate for some time and for a limited percentage of user time also at 2 GeV. It has also been requested to let open the possibility of creating short pulses as small as 0.5-1 ps (fwhm) for time resolved experiments using vertically deflecting (crab) cavities that are planned to be installed in section 2 of the ring. All other long straight sections will be occupied by insertion devices with the exception of the injection straight (section 12). It has been also requested to increase the intensity to 400 mA, the available slots for insertion devices and to install super-bends and in vacuum undulators. The constraints were to keep the same circumference, to keep the present injection scheme and to minimize the dark time to 18 months.

The Elettra 2.0 project was approved by the Italian Government in 2019 and according to the current schedule the new machine will start serving the users at the end of 2026. Since some of the original requirements, as appeared in the CDR, have changed, based on the new revised requirements an enhanced version of our S6BA (symmetric six bend achromat) was produced namely S6BA-E (symmetric six bend achromat-enhanced), see Fig. 1, by using longitudinal gradient (LG) dipoles (Fig. 2) and reverse bends. Although most of the CDR part is still valid, a new Technical Design Report (TDR) was produced and is available since June 2021 [10].

ELETTRA 2.0: CHARACTERISTICS

The enhanced symmetric six bend achromat (S6BA-E) lattice (Fig. 1) has a total length equal to that of the present Elettra, i.e. 259.2 m and is made of 24 symmetric arcs, 12 long straights and 12 short straights sections, it has a 12-fold symmetry and is invariant under relative position shifts between them. Thus, the short straight sections in the

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arcs are created without appreciable change of the optics functions, increasing thus the slots available for insertion devices. Each arc consists of 3-unit cells of the TME (theoretical minimum emittance) type i.e. :

- 3 dipoles, of which one at 0.8 T with vertical field gradient and two with combined transverse (< 22 T/m), and longitudinal gradient (1 and 1.46 T) (Fig. 2),
- 8 quadrupoles (< 50 T/m) four of which are shifted at 5.16 mm to give the required reverse-bend angle of -0.4 deg each and
- 10 combined sextupoles (< 4500 T/m^2) (4 with correctors, 2 harmonic with correctors and 2 with skew quadrupole coils) and
- 2 combined multipoles (octupoles with correctors).

The working point is (33.25, 9.2-9.4) and the natural chromaticity (-71, -68) corrected to +2 in both.

The two arcs are separated in the middle by a short straight section of 1.26 m free space for installing the rf cavities, equipment or short undulators or wigglers while the free space of the long straights connecting the sections is 4.85 m long for installing insertion devices. With that choice of lengths, the transverse position of the Elettra 2.0 beam lines on the long straight sections compared to the ones in the present Elettra is almost coincident.

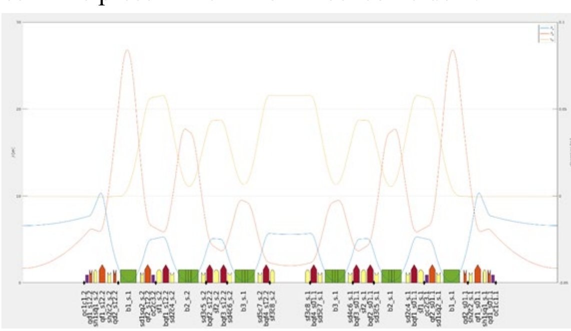

Figure 1: Elettra 2.0 S6BA-E lattice.

The total number of magnets is 552 with 192 corrector coils and 171 BPMs. For the fast correction (fast orbit feedback) 96 additional coils will be used.

The magnets will be powered independently, although they may be grouped in families and are mostly water cooled.

The bare emittance is 212 nm-rad (149 pm-rad at 2 GeV) at 1% coupling i.e. a factor of 50 reduction from the present machine and will increase the brilliance up to 2-3 orders of magnitude at 10 keV and about 36 times at 1 keV compared to that of the present machine. Also, the coherence level will be increased by a factor of 60 at 1 keV. The twiss functions of the lattice are shown in Fig. 1.

At full coupling, the emittances become respectively 100 and 70 pm-rad however there is no need or request to operate at full coupling.

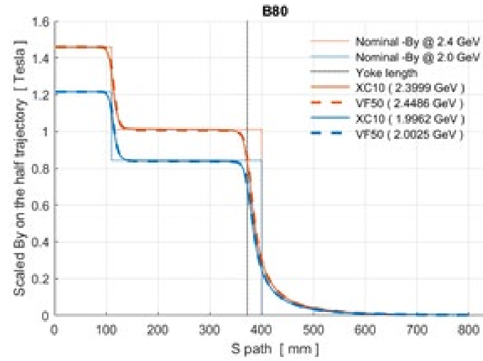

Figure 2: LG half-dipole magnet profile.

Another interesting point of the lattice is that, due to its low momentum compaction of 1.3e-4, it can naturally provide a short stable electron bunch below 10 ps (fwhm) for 100 mA total current and acceptable lifetime of 12 h. However, the use of crab cavities will allow both long pulses at 400 mA for the majority of the users plus short photon pulses of few tilted bunches for the beamlines that request time resolved capability [11].

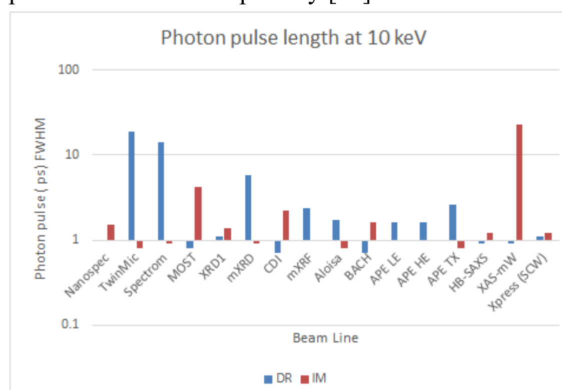

Figure 3: Pulse length at each beamline.

In Fig. 3 the shortest photon pulse duration and single pulse relative flux are summarized, for 10 keV photon energy. DR and IM mean drift optics and imaging optics respectively. For many beamlines the pulse durations is ≤ 3.5 ps fwhm. The minimum slit half-aperture is 5 µm in drift mode and 2 µm in imaging mode.

Elettra 2.0 will have three new micro-spot beam lines that the present machine cannot support, namely the µXRD, µXRF and HB-SAXS beam lines. To meet the requested performance, in-vacuum undulators (IVU) of at most 5 mm aperture will be used. Simulations show that IVUs with k_{max}=2 and 20 mm period at 2.4 GeV will provide the 7th, 9th, 11th and 13th harmonics with the required flux of 10^{14} ph/s/0.1%bw on the sample and energy range, while the brilliance is > 10^{21} ph/s/mm^2/mrad^2/0.1% BW (Fig. 4) at 10 keV. Some already existing IDs will be reused including the super conducting 3.5 T wiggler and additionally 5 short straight sections will be occupied by short wigglers (2) and short undulators (3).

The hard X-ray imaging (life and material science) requires 10^{13} ph/s at 50 keV while the absorption x-ray fluorescence requires the same flux at 35 keV, and can be

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satisfied using three super-bends (SB) of peak field at 6 T. When all insertion devices and SBs are included the emittance at 2.4 GeV reads 214 pm-rad and the energy loss due to radiation is 620 keV which for 400 mA translates to 248 kW power lost to radiation. Moving any ID field from zero to maximum changes the beam dimension by less than 1%.

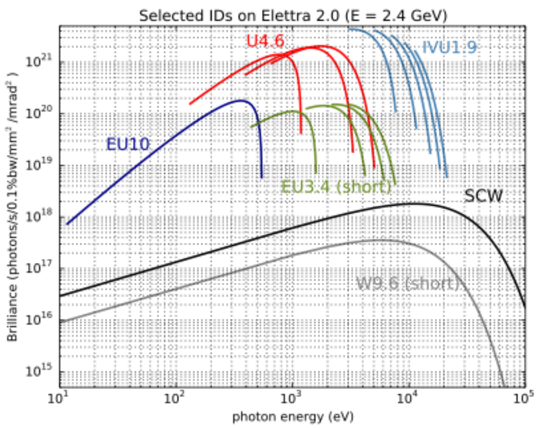

Figure 4: Old and new IDs brilliance.

The dynamic aperture (DA) including all (errors, chambers, ids) is about ±5 mm horizontally and ±2 mm vertically permitting off axis injection and at the same time permitting the tilted bunches having a vertical projection of ±1.2 mm. Simulations have shown that efficient orbit corrections are achieved with < 1 mrad kick of the correction coils.

A passive superconductive third harmonic cavity (S-3HC) lengthens the bunch for stability and lifetime. The intra-beam scattering without the effect of the S-3HC at 400 mA will increase the emittance from 212 to 275 pm-rad (30% increase) while including the effect of the S-3HC the emittance will increase to 235 pm-rad (11% increase). No ion trapping instabilities are expected.

The vacuum chamber will be rhomboidal with 20x30 mm external dimensions mainly made of copper with some parts in aluminum (long straights) and also stainless steel (dipole chambers). Most parts of the chamber will be covered with 500 nm NEG. The impedance budget is comparable to that of the present machine, being about 0.85 Ohm longitudinal (0.24 Ohm effective) and 564 kOhm/m transverse giving a tune shift of about -0.8 kHz/mA (present Elettra gives -0.6 kHz/mA). The longitudinal loss factor is 21 V/pC giving a parasitic power loss at about 7 kW when the effect of the third harmonic cavity is included. The single bunch microwave threshold is about 0.25 mA and the TMCI (Transverse Mode Coupling Instability) about 6 mA.

The average Touschek lifetime including errors and all is about 6 h at 2 MV total rf voltage and 3% coupling while including the effect of S-3HC it becomes 18 h.

FURTHER DETAILS

The 3-D detailed design including all insertion devices and front ends is almost completed. In Fig. 5 the view of an arc is shown. On the left of the picture a rf cavity is shown installed in a short straight section.

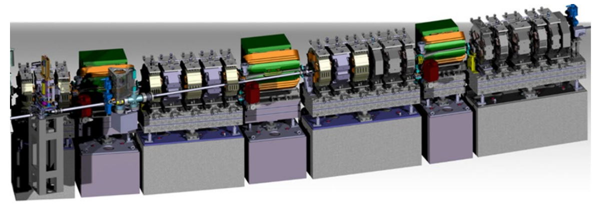

Figure 5: Elettra 2.0 arc view.

Almost all parts of the machine are defined. All types of magnets have been specified, designed and ready for the call for tender. The power supplies are reduced into 3 families:

- A: 300 A unipolar units: 80 units (including spares), COTS (commercial of the shelf),
- B: 100 A unipolar units: 500 including spares, in-house design + COTS power part,
- C: 20 A bipolar units: 480 including spares in-house design and special unipolar/bipolar units: 250+ units, in-house controller, Dipole B80 Trim coil, fast feedback correctors.

Prototypes for vacuum chambers, girders and many other parts are ordered expecting calls for tender next year. Each section will have 8 girders consisting of granite slabs long from 1.2 to 1.5 m, 0.6 m large and 0.3 m thick. Front-ends are defined. Prototyping is ongoing as well as discussions with potential manufacturers. The injection system will use 2 kickers, 2 septa and 1 anti-septum. The emittance swap technique will be used.

For the RF system [12], the four Elettra 500 MHz rf cavities presently in operation will be re-used. Each cavity will be installed in a short straight section and each one will be powered by a new130 kW solid state amplifier (SSA). The four SSAs have been already outsourced to industry and the first one is now already in operation in Elettra. As for the low-level rf, a digital system will be implemented.

The actual Elettra will stop running in July 2025 and Elettra 2.0 will start giving light to the users in November 2026.

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