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ELETTRA AND ELETTRA 2.0

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Abstract

The status of the Italian 2.4/2.0 GeV third generation light source Elettra is presented together with the future upgrade concerning the new ultra-low emittance light source Elettra 2.0 that will provide ultra-high brilliance while the very short pulses feasibility study for time resolved experiments is in progress.

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 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]. Except the above-mentioned big upgrades, other minor ones took place aiming to the smooth and reliable operation of Elettra, and many possible scenarios were studied aiming in increasing the machine capabilities, as reported previously [3-6]. Those scenarios were not realized since it has been decided that the light source should undergo a massive upgrade that will render the machine competitive for the next 25 years by replacing Elettra with a new diffraction limited light source.

ELETTRA STATUS

Elettra operates 24 hours/day, seven days a week delivering more than 5000 hours/year of synchrotron light from IR to hard x-rays to 28 beam lines of which bending magnets serve ten. 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 some dispersive short straights are also used for short insertion devices such as the one of 1 m long serving the TwinMic.

The machine consists of a 100-MeV linac, a 2.5 GeV booster and a 2.0/2.4 GeV storage ring. At about 75% of user-dedicated time Elettra operates at 2 GeV while for the remaining 25% 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 (in 2020 at 31% of the total user beam time) 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). The operating intensities are 310 mA at 2 GeV and 160 mA at 2.4 GeV with 5 mA single bunch(es) is (are) added when in hybrid mode.

In Fig.1, the total availability i.e. including the power outages (green bars) is shown for the last ten years while in red bars the Mean Time between Failures (MTBF) is shown. The mean maximum time between failures is currently at about 321 hours with peaks at 451 hours.

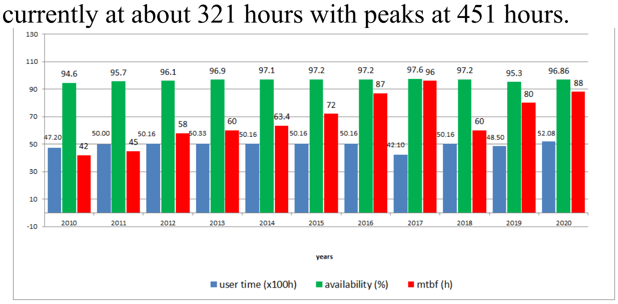

Figure 1: Combined graph of Electra availability (in %, green bars) and MTBF (in hours, red bars).

The downtime distribution amongst the subsystems of Elettra is shown in Fig. 2 for the last 3 years, main contributors for 2020 (red bars) are power outages, power supplies (unchanged since 1990) and the superconducting third harmonic cavity that due to covid-19 restrictions a critical repair needing intervention of external personnel and material was delayed.

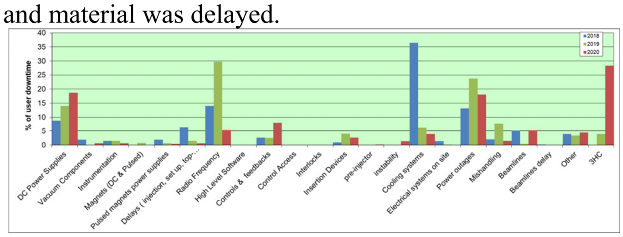

Figure 2: System failures as percentage of user downtime for 2018, 2019 and 2020.

The top-up availability to the total user scheduled time for 2020 was 99.2%. Top-up contributes also to a very good short and long-term beam orbit stability. When the air temperature stays constant within ±1 d C, the long term (2 to 5 days) orbit stability is at ±5 µm maximum while the short term (24 hours) at less than 10% of the beam size (1.7 µm horizontally and 1.2 µm vertically).

ELETTRA 2.0

After 27 years of serving the user community with excellent results, the diffraction limited storage ring Elettra 2.0 will replace Elettra in order to remain competitive for synchrotron research and enable new science and new technology developments.

Already since 2014 discussions with beamline responsibles, users and partners started in order to define the requirements of the machine described in a series of

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papers [7-13] resulting to a preliminary but otherwise complete CDR [12]. 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 percent 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, all other long straight sections will be occupied by insertion devices with the exception of the injection straight (section 12).

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 by using longitudinal gradient (LG) dipoles (Fig. 3) and reverse bends. Although most of the CDR part is still valid, a new TDR is produced and will be available by June 2021.

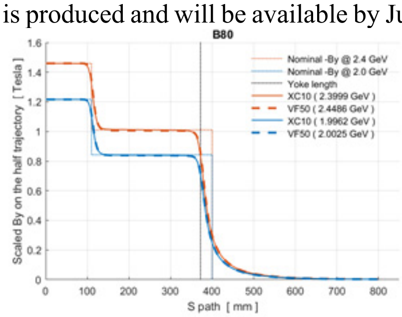

Figure 3: LG half-dipole magnet profile.

The symmetric six bend enhanced achromat (S6BA-E) lattice consists of six quad-dipole-quad cells per achromat creating an invariant optic under relative position shifts between them. Thus, short straight sections in the arcs are created without appreciable change of the optics functions, increasing thus the slots available for insertion devices. The lattice has a total length equal to that of the present Elettra, i.e. 259.2 m and is made of 24 arcs, 12 long straights and 12 short straights sections and has a 12-fold symmetry. Each arc consists of 3 unit cells of the TME type (theoretical minimum emittance) i.e. 3 dipoles, of which 1 at 0.8 T with vertical field gradient and 2 with combined transverse (< 22 T/m), and longitudinal gradient (1 and 1.46 T), 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 (< 45000 T/m^2) (4 with correctors, 2 harmonic with correctors and 2 with skew quadrupole coils) and 2 combined multipoles (octupoles with correctors) The harmonic sextupoles and octupoles are needed for controlling the tune shift with amplitude. Each section consists of 2 arcs separated in the middle by a short straight section of 1.26 m free space for installing the rf cavities, equipment or short Ids 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. The working point is (33.25, 9.2-9.4) and the natural chromaticity (-71, -68) corrected to +1 in both.

The total number of magnets is 552 with 192 corrector coils and 147 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 twiss functions of the lattice is shown in Fig. 4.

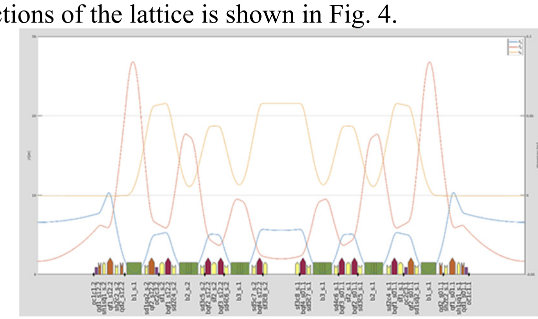

Figure 4: Our S6BA-E lattice.

Elettra 2.0 will operate mostly at 2.4 GeV and at 400 mA. Its 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.

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

Another interesting point of the lattice is that due to its low momentum compaction of 1.2e-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 (Fig. 5).

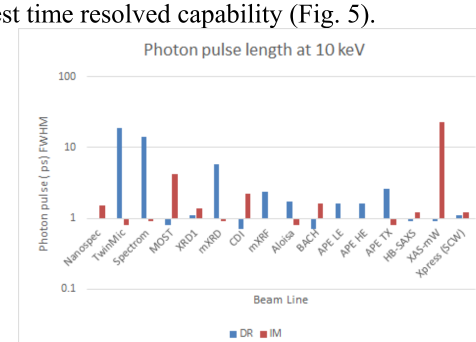

Figure 5: Pulse length at each beamline.

In Fig. 5 the shortest photon pulse duration and single pulse relative flux are summarized, for 10 keV photon energy while DR and IM mean drift optics and imaging optics respectively. For many beamlines the pulse

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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. 6) 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).

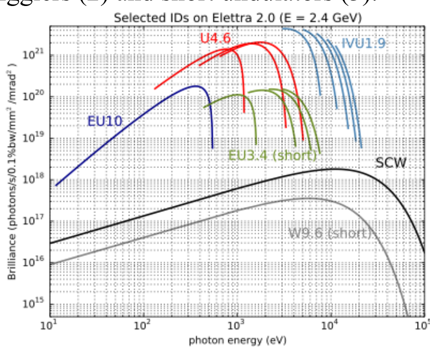

Figure 6: Old and new IDs brilliance.

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, both can be satisfied using two 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 for zero to maximum changes the beam dimension by less than 1%.

The dynamic aperture (DA) including all (errors, chambers, ids) is about ±5 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.

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 0.785 Ohm longitudinal (0.11 Ohm effective) and 523 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 74 V/pC giving a parasitic power loss at about 26 kW. The single bunch microwave threshold is about 0.3 mA and the TMCI about 5 mA.

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 average Touschek lifetime including errors and all is about 8.35 h at 2 MV total rf voltage and 3% coupling while including the effect of S-3HC it becomes 24 h.

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