ELETTRA STATUS AND UPGRADES

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Abstract

The operational status of the Italian 2.4/2.0 GeV third generation light source Elettra is presented together with the possible future upgrades especially concerning the next ultra low emittance light source Elettra2.0.

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 22 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, 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 added to the smooth and reliable operation of Elettra as reported previously [3]. At the same time studies based on various upgrade scenarios that define the upgrade Phase I were made. This phase includes plans for upgrading the energy from 2.4 to 2.5 GeV, the possibility of decreasing the emittance [3], coupling control [4] and rearranging the space for a larger short straight section to be used for additional longer insertion devices. Looking into the future an ultra low emittance successor of Elettra was studied [8, 9] with an emittance of 250 pm-rad i.e. 28 times smaller than that of the actual machine.

ELETTRA STATUS

Elettra operates 24 hours/day, seven days a week delivering more than 5000 hours/year of synchrotron light from IR to soft x-rays to 28 beam lines of which 10 are served from dipoles. Two beam-lines use light from a superconducting [5] 49 pole 64 mm period 3.5 T wiggler.

Many types of insertion devices are installed such as planar, Figure 8, APPLE II, electromagnetic, superconducting while one beam line uses a canted set of APPLE II type undulators. All twelve long straights are occupied and dispersive short straights are used for insertion devices. Thus a short undulator serves the TweenMic beam-line while there are plans for another XAFS beam line served by a short 2 T wiggler.

The machine consists of a 100 MeV linac a 2.5 GeV booster and a 2/2.4 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 (at 20% of the total user beam time) with one or two single bunches in the dark gap. 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 Figure 1, the total availability (green bars) is shown during the three phases of operation; in fact before 2008 the storage ring ramped in energy, whereas after 2008 operates with a full energy injector and since 2010 in top-up. The numbers clearly show a continuous improvement of availability.

Another important number indicative of the reliability of a light source is the Mean Time between Failures (MTBF, figure 1, yellow bars). Also in that case a clear improvement after 2007 is observed. An increase of the maximum time between failures is also observed, currently about 300 hours with peaks at 424 hours.

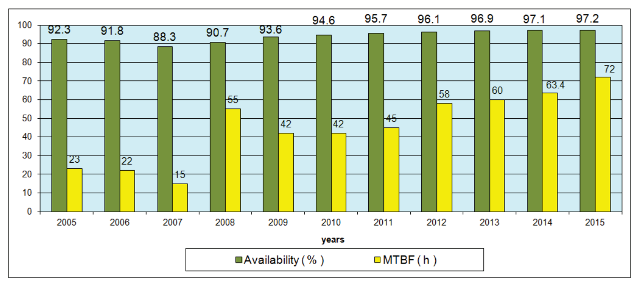

Figure 1: Combined graph of Electra availability (in %, green bars) and MTBF (in hours, yellow bars).

The downtime distribution amongst the subsystems of Elettra is shown in the next figure 2. As can be observed a large portion of the downtime is due to external causes like electric power surges.

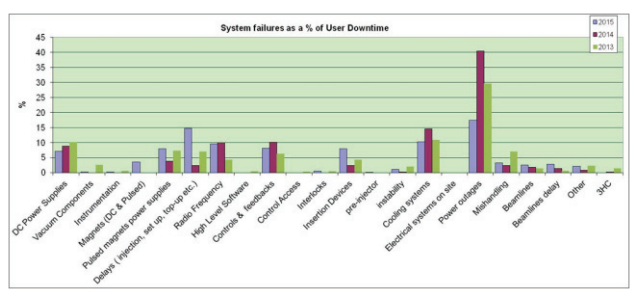

Figure 2: System failures as percent of user downtime for 2013, 2014 and 2015 .

The top-up was mainly invented for keeping source and experiments thermally/electronically stable. At the same time proved to be very beneficial for the availability being at the same time a very stable mode of operations. The top-up availability to the total user scheduled time since 2010 is between 97 and 99 %. The remaining 1-3% indicates functioning in the decay mode due to some failure which is considered downtime when below a

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certain threshold of intensity (270 mA at 2 GeV and 130 mA at 2.4 GeV).

Top-up contributes also to very good long and short term orbit stability. Currently the long term (2 to 5 days) is at ± 5μm maximum while the short term (24 hours) at 2% of the beam size (1.7 horizontally and 1.2 μm vertically).

NEAR FUTURE PLANS

Over the last few years many improvements were made aiming to update the machine and increase its stability, flexibility, limits and operability; at the same time studies were performed to evaluate possibilities of some machine upgrades as Phase I, described previously [3, 6].

Energy Upgrade

The magnets and power supplies of Elettra have a large margin and although initially the machine was designed to operate at 1.5 and in a second stage at 2 GeV it operated from the very beginning at 2 and since 1999 also at 2.4 GeV without problems or additional costs. Users of the 2.4 GeV beam time (25% of the total) have shown an interest to get higher energy.

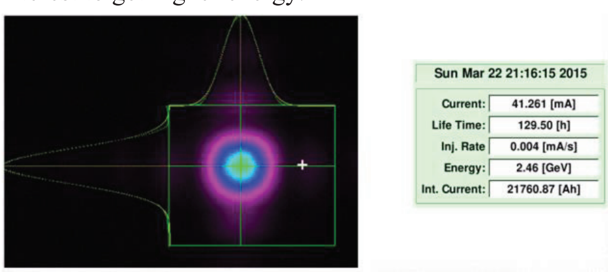

Figure 3: Beam at 2.4695 GeV.

Although the bending magnet at 2.4 GeV (1.4 T) is having already a 13% saturation it was possible to inject and accumulate at 2.4695 GeV (Figure 3) the limitation of not reaching 2.5 GeV is due to the dipole power supply.

Brilliance Increase

The emittance of Elettra (7 nm-rad) is one of the closest to the theoretical limit for a double bend achromat. This emittance can be further reduced if one abandons the achromat condition introducing thus dispersion in the straight sections. For Elettra an alternative theoretical optics is found (Figure 4) with an emittance of 2.6 nm-rad, a 30-60% reduction in spot size and an average factor of two in brilliance increase. The machine tunes are 15.3 and 8.2 whereas the dynamic aperture is reduced by 50%, still enough for beam injection and in fact it has been achieved injection and accumulation. The dispersion although distributed is now about 50% less than the maximum in the achromatic lattice.

Since the dispersion is distributed one has also to examine the effective emittance and at the same time the influence of the 3.5 T superconducting wiggler currently is operation. With the wiggler at full field the effective emittance is only 20% less than the nominal one indicating that the reduction must be based on the effective emittance while a net gain of a factor of 2 is obtained if the magnetic field is at zero.

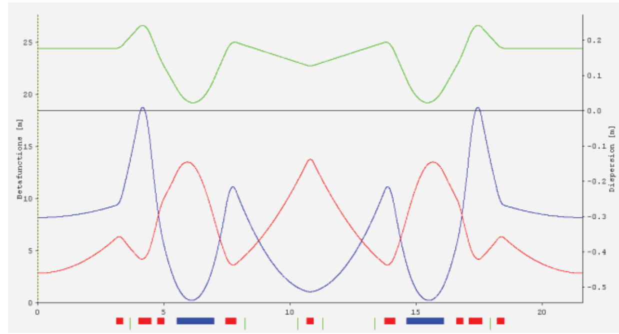

Figure 4: Elettra optics for reduced emittance. Graphics from OPA [7].

Magnet Splitting for Space Unification

All straight section of Elettra are occupied but still there is demand for new insertion device based beam lines. Elettra has twelve-fold symmetry with 3 straight sections per achromat: a long straight section of about 5 m with zero dispersion and two dispersive short ones in the arcs of 1 and 1.3 m long separated by a defocusing quadrupole. Those sections are used for instrumentation and for the rf-cavities while in one 1.3 m long section a 1 meter short undulator is installed serving the TweenMic beam line. This fragmented space can be unified by replacing the defocusing quadrupole by 2 other ones of reduced dimensions and shifted from the centre. This rearrangement gives a unified free space of 2.5 meters for installation of longer insertion devices while the optics is practically unchanged.

The fact that the insertion device will be in a dispersive region is not a problem as long as the field remains low i.e. ≤ 1 T as is usually the case for undulators and the experience with the already installed short undulator for TweenMic.

ELECTRA 2.0

In a previous paper [8] an exhaustive analysis of emittances, beam sizes and free available space for realistic lattices from 4 to 9 bend achromats was made. Elettra2.0 optics took shape from that analysis and the requirements of the users as expressed during a workshop on the Future of Elettra in April 2014 summarized below:

- Energy 2 GeV
- Maintain ring circumference (259-260 m)
- Emittance reduction by more than factor of 10
- Electron horizontal beam size less than 60 um
- Intensity 400 mA, maintain the filling patterns as before (hybrid, single bunch etc.)
- Maintain the existing ID beam lines position
- Maintain the existing bending magnet beam lines
- Free space available for IDs not less than at present
- Use the existing injectors i.e. off-axis injection

The above user requirements and the analysis made in [8] led us to adopt the 6-bend achromat as best solution [9].

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The 6-bend achromat optics, shown in Figure 5 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).

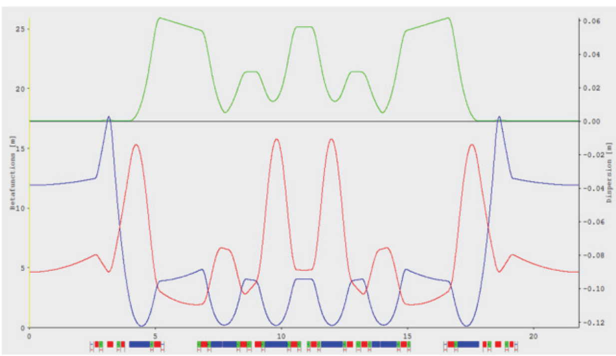

Figure 5: Elettra2.0 lattice.

The low dipole fields of the lattice cannot be used for the dipole 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 alternatively one can replace the second and fifth quadrupole by a combination of either permanent only or permanent and electro magnets with the central magnet at 1.3 T without gradient and a 3 degree bending angle from a total of 5.6 degrees provided by weaker magnets with gradient. With this variation the bending magnet based beam lines will get their light from the 1.3 T dipoles and need not shift much; the short wiggler solution mentioned above stays still valid.

The proposed optics has an emittance 28 times less than that of Electra giving a brilliance increase of about 15 times at 1keV if assuming the same flux of the insertion devices. Obviously for an order of magnitude more flux the brilliance will increase by more than two orders of magnitude. At the same time the coherence level will also increase thus at 1keV the coherence level will be at 38% to be compared with the 2% of the present machine.

Diffraction limited rings require very strong focusing i.e. magnets with high gradient which require a challenging high precision engineering. At the same time the high fields increase the chromaticity whose cure introduces strong non linear effects that result in the reduction of the dynamic aperture. Since the circumference available is 260 m the magnets have to be longitudinally short and due to lack of space also their intra-magnet distances will be reduced. However those problems are not beyond reach and can be answered with the present technology.

CONCLUSIONS

Elettra operates for 22 years delivering more than 100000 hours of synchrotron radiation in the range of IR to soft X-rays to more than 1000 users per year of the scientific community. At the beginning and for 14 years the injection and operation energies did not match a really difficult task also because after 1999 Elettra was operating at both 2 and 2.4 GeV being probably the only light source operating at two different energies. Top-up operation was established in 2010 rendering Elettra competitive with the more recent and modern synchrotron light sources. Many small projects and studies followed aiming to further improve the facility. The overall benefit on availability, stability, reproducibility, flexibility and versatility is evident.

In the last few years studies are ongoing in order to examine the near and far future of Elettra, described as phase I and II. Phase I includes all improvements on the actual machine such as upgrading the high energy part of operations from 2.4 to 2.5 GeV, coupling control, emittance reduction and unification of the free space for additional insertion devices.

For the phase II a new machine with an emittance of 250 pm-rad is in the conceptual design phase. This next generation light source will replace the actual Elettra in the same tunnel while respecting all photon source point positions.

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