OPERATIONAL ADVANCES AT ELETTRA AND ITS NEW FULL ENERGY INJECTOR

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Abstract

A full energy injector consisting of a 100 MeV linac and an up to 2.5 GeV booster is in operation since March 2008 replacing the previous 1 GeV linac injector to be used after refurbishing and upgrade for the new fourth generation light source (FEL) currently under construction at Sincrotrone Trieste. The measurements on the new injector, problems and solutions employed to increase its efficiency, reproducibility and reliability, aiming towards top-up operations in the near future, and its impact on the Elettra storage ring are presented and discussed.

INTRODUCTION

At the end of 2008 the third generation light source Elettra has completed more than fifteen years of operation since the start of commissioning (October 1993). Over this period the facility operated for about 90,000 hours of which more than 67,000 were dedicated to user experiments with good efficiency, ranging in all those years between 92-96%.

The accelerator runs for users at 2.0 GeV for 75% of its user time (being about 5000 from a total of 6500 hours per year) and at 2.4 GeV for the remaining 25%.

Thus for 2009 the user time at 2GeV is 3720 hours and at 2.4 GeV 1248 hours for a total of 5016 hours. Additionally the SR-FEL that operates at 1 GeV absorbs the 20% of the accelerator physics studies time. The accelerator physics studies time is about 25% of the total operation time which for 2009 is set to 6672 hours. The maximum current injected at 2 GeV is 340 mA whereas at the higher energy of 2.4 GeV the current is limited to 140 mA to contain the thermal load on the vacuum chamber at acceptable values. Elettra is able to provide maximum beam energy of 2.5 GeV.

Far from being in a static operations phase, a great deal of investment has being placed for future growth and improvement of the facility including the construction and set in operation of a full energy booster, so that the old injector (a 1 GeV linac) could be upgraded and used for the FERMI@Elettra project, the linac based electron FEL from 1.2 to 1.8 GeV currently under construction at Elettra. Since the full energy injector is naturally bringing the storage ring towards the top-up operational mode there are many plans to benefit from it including the upgrading of the insertion devices so that smaller gaps can be reached, the replacement of some low gap (15 mm) vacuum chambers with a smaller gap (9 mm), the construction of three new beam lines using the light from the superconducting wiggler already since years installed successfully at Elettra, just to name some. Finally an analysis of the thermal load on the vacuum chamber and the machine photon shutters for upgrading the maximum stored current and at the same time repairing the aluminium light exits that after almost ten years of operation have rust problems in the cooling circuit is performed.

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THE INJECTOR

Elettra is operating since March 2008 with the newly constructed full energy injector (table 1) consisting of a 100 MeV linac (per-injector) and a 2.5 GeV booster [1,2]. Although the injector was brought in operation timely so that user operations continued undisturbed as programmed, the booster suffered from its digital power supplies that initially did not meet the specifications. Thus the biggest effort during 2008 continuing also in 2009 is the refurbishing of the booster dipole and quadrupole power supplies [3]. This task was proven very time consuming and is performed by the power supply constructor company. At the same time measurements of the booster tune and orbit greatly helped in improving the machine performance.

The booster operates at any energy up to 2.5 GeV and delivers any filling pattern (multi-bunch, single bunch, or few bunch) with a repetition rate of 2.4 Hz. The maximum specified repetition rate will be achieved at the end of power supply refurbishing program set for June 2009.

Table 1: Main Parameters of the Elettra Booster

Energy (Injection, Extraction)	100 MeV, 2.5 GeV
Circumference	118.8 m
Nominal repetition rate	3.125 Hz
RF Frequency	499.654 MHz
Nominal current	5 mA
Nominal (low) emittance optics	226 (166) nm.rad

The injection efficiency varies and although more than 95% efficiency is achieved, the injector operates usually at 60% if not continuously optimised. The energy stability of the pre-injector, crucial for the injection efficiency occasionally shows drifts up to 2 MeV, comparable to the energy acceptance of the booster at 100 MeV. A measuring program has been set to find the sources of those drifts and in the meantime an energy feed back is under test to be implemented soon.

In order to anticipate for the stability, reproducibility and ripple problems of the booster power supplies a feed forward schema was implemented in the programmable ramp of the quadrupole power converters which by modifying accordingly the ramp values keeps the tunes of the machine as much stable as possible. In figure 1 the left part shows the uncompensated tune shifts from injection to extraction that considerably varies as can be appreciated from the tune diagram shown in figure 2 resulting in reduced extracted current. On the right part of figure 1 a much reduced "compensated" tune shift is shown, achieved using the before mentioned feed forward schema.

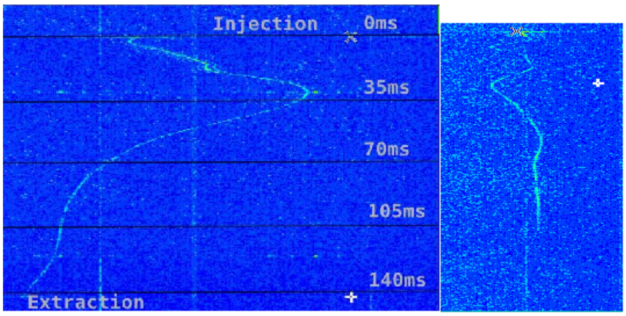

Figure 1: Uncompensated (left) and quite compensated (right) tune shifts during booster cycle. Tunes are shown as continuous curves.

Tunes are measured with the fast sweep method from 250 to 1250 kHz giving 2 measurements /ms

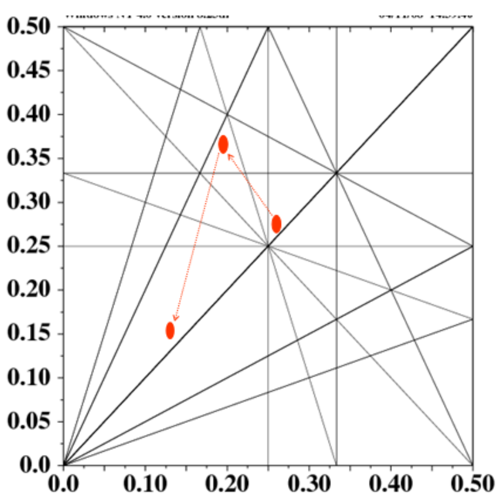

Figure 2: Booster tune diagram and tune shifts during a fully uncompensated cycle.

However the compensation is not yet perfect and due to remaining as yet problems in reproducibility and ripple of the power supplies as well as the energy stability of the per-injector an intensity variation of the order of 15% is still present.

At the moment, while preparing for top up, the refill of Elettra occurs once per day as in the past. To refill, the booster power supplies are ramped up to 2.5 GeV but extraction is done "on-fly" either at 2.0 GeV or 2.4 GeV or at any other energy up to 2.5 GeV by simply adjusting the timing of the extraction system, according to the operating energy of the storage ring. This way the necessary operations are minimised. The refill time with the new injector lasts four times less than that in 2007 when the storage ring had to ramp the energy up from its injection energy of 1 GeV. In figure 3 a graph showing the evolution of refill times also during the 3 quarters of 2008 is shown. The increase of the refill time during the first quarter of 2008 is due to the big problems with the booster main dipole power converters at that time whereas the refill time for 2007 is by using the old 1 GeV linac injector and subsequently ramping the storage ring.

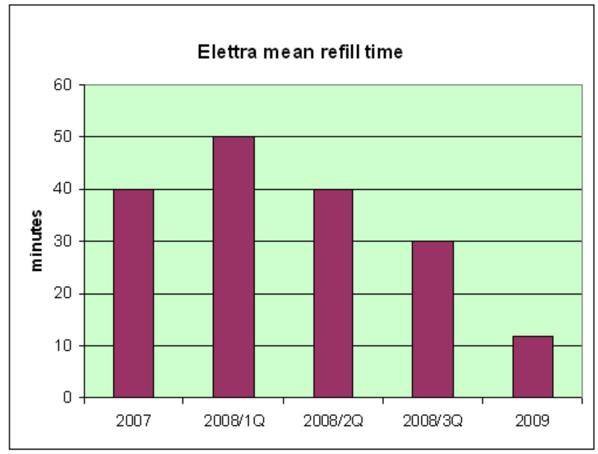

Figure 3: Refill time evolution

TOWARDS TOP UP OPERATIONS

Top-up injection is an operation mode in which the storage ring beam current I is kept at a certain level I_0. The beam current stability tolerance $\varepsilon = (I-I_0)/I_0$ is usually defined in the range of 10^{-3}. In general users prefer the frequent injection top up mode whereby the injection system is not always on but activated only to inject once the beam current is bellow the target I_0. It is intended that this operation should not disturb ideally the beam line measurements or induces any radiation hazards.

The main scope of top-up operation is to improve the photon beam position stability in the experiments by allowing constant thermal load to both storage ring and beam lines and a constant signal to the beam position monitors. Additionally top up renders flexibility in operation, such as higher currents, exotic filling bunch patterns and since lifetime is not an important issue, smaller ID gaps, lower emittance and coupling.

During top-up operations the beam line shutters are open, thus special care should be taken in minimizing the stored beam disturbance and the radiation effects from the injected beam due to various errors that may occur. The important systems for that are the injection and the insertion devices. The injection system is required to operate with high stability; for Elettra a kicker amplitude error of 10^{-4} will create a 20 μm whereas 1 ns timing error will create a 120 μm orbit distortion at the beam source position. In figure 4 the kicker disturbance on the stored beam at 2 GeV is shown for all beam position monitors sampled at 10 kHz, for about 10^4 turns.

The other important issue related with the injected beam is that of the dynamic aperture that enters into Elettra at a minimum initial amplitude of 9.5 mm to damp out after a few turns. The insertion devices introduce non linear fields that can become very strong at these amplitudes and create thus beam losses and hence radiation as well as decrease the injection efficiency.

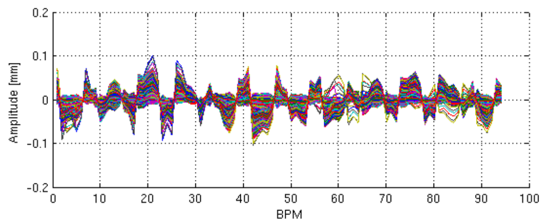

Figure 4: kicker disturbance on the stored beam

In order to experimentally appreciate the dynamic limits of Elettra with and without insertion devices a series of experiments at 2 and 2.4 GeV were performed consisting in using only one kicker and kicking the beam with increasing amplitude registering the lifetime and current until the lifetime reduces to about 10 minutes (figure 5). This is repeated with active insertion devices (one at a time or in groups). The transition from normal lifetime to 10 min was very sharp and occurred at the end of the maximum amplitudes indicated. As an example at 2.4 GeV we see that without active insertion devices the maximum amplitude at the straight section is 27 mm whereas activating all insertions devices the unperturbed amplitude reduces to 18 mm. The situation at 2 GeV with active insertion devices indicates a lower limit (~11 mm) as expected. The measurements confirm that the insertion devices contributing more to the restriction of dynamic aperture, namely the ID1 and ID9 are both of APPLE II type (variable polarisation devices).

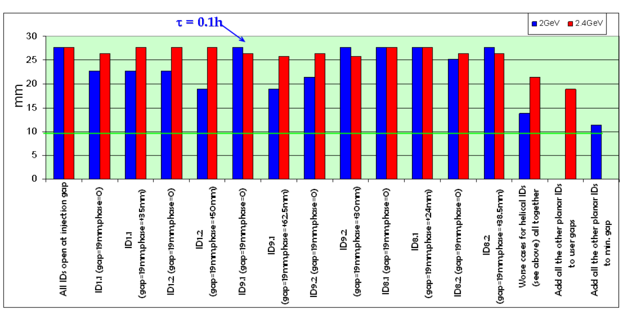

Figure 5: Aperture studies with and without insertion devices at both 2 GeV (blue bars) and 2.4 GeV (red bars)

The measurements indicate that Elettra can perform top up at both 2 and 2.4 GeV without problems although at 2.4 GeV the situation is better. Most probably special treatment of the insertion devices such as shimming does not seem necessary. The above results are also confirmed with real top-up tests. In figure 6 a six hour test is shown with 1mA refill repeated every 10 minutes so that the intensity was kept constant (140 mA) at 2.4 GeV while similar tests with the same good results and for longer times up to 12 hours were performed at 2 GeV too. Needless to say that although the machine was set to the real top-up mode i.e. topping up with the insertion devices active, the beam lines shutters remained shut.

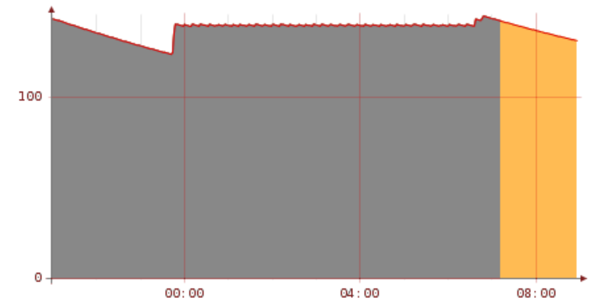

Figure 6: Long top-up test with insertions active for stability and reproducibility observations.

The full implementation of the top up for users is foreseen at the end of 2009 when all instrumentation and interlock systems [4] will be installed and all radiation protection measurements will confirm that the radiation levels in the beam lines are congruent with the radiation norms at any energy. It was found in the past (2003) [5] that when the injection efficiency was higher than 70% the radiation levels were normal in the experimental hutch. Those measurements were performed at the energy of 1 GeV (the then injection energy of Elettra) and appropriately scaled to 2 or 2.4 GeV. At the same time and although not required by the law a simulation work has been started to show the impossibility of the electron beam entering due to a fault in a beam line [6]. It is useful to note that the machine will always be filled the usual way up i.e. insertion devices inactive and shutters closed and only the adding up will be performed with insertions active and shutters open. Finally the reliability, stability and reproducibility of the injector is crucial thus its systems are monitored to detect any source of disturbance.

Depending on the lifetime, the injection might disturb the stored beam orbit often and hence the experiments. It is foreseen to provide also a gating signal to the experimental lines.

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