

## ELETTRA TOP UP REQUIREMENTS AND DESIGN STATUS

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### Abstract

Elettra is a 2.5 GeV third generation light source in operation since 1993. To provide more stable beams to the users, we plan to operate in the so called top up injection mode. The present paper will report on the requirements for the top up operation in terms of radiation safety, diagnostics H/S, timing, modality and the design status.

### INTRODUCTION

At Elettra, the storage ring (will be referred as SR) is operated at 2 and 2.4 GeV for 75 and 25% of the whole users' time, respectively. The nominal electron beam energy of the present injector is 1.2 GeV. The necessary energy ramping of the electron beam in the SR increases the time of the refill, stresses the SR components, example the magnet power supplies, the third harmonic cavity, the RF accelerating cavities, and impacts the thermal and electron beam stability. To avoid the ramping, the present injector will be replaced by a 0.1 GeV linac and a 3 Hz synchrotron booster of 2.5 GeV. The new injector system is under construction and the extraction of the beam from the booster is foreseen for summer 2007[1]. The electron beam lifetime in the SR is 25 and 38 hours for 330 mA at 2 GeV with the 3<sup>rd</sup> harmonic cavity tuned and 150 mA at 2.4 GeV with the 3<sup>rd</sup> harmonic cavity partially parked, respectively. Currently, the refill is performed each 48 hours at 2 GeV and each 24 hours at 2.4 GeV. The lifetime will be significantly reduced with smaller transverse emittance coupling and smaller insertion devices gaps, leading to a further worsening of the thermal stability of both the SR and beam lines. Furthermore, an almost constant beam current reduces the problems linked to the thermal stability: the coupled multi bunch feedbacks and the fast global orbit feedback systems work better, the 3<sup>rd</sup> harmonic cavity effects are maintained constant, etc.

Top up injection means injection on top of the accumulated electron beam with the insertion devices closed and the beam lines front end stoppers open. This has impacts on: a) the safety of the users, b) the safety of the insertion devices, c) the users' measurements, d) the booster performance and reliability, e) the booster to SR transfer line ( will be referred as BTS TL) reliability, f) the SR reliability, g) the filling uniformity.

### RADIATION HAZARDS

At present, Elettra works in "decay mode" and the injection is performed keeping the beam stoppers of the beam lines front-ends always closed. The main radiation safety issue in top up operation is to prevent the extraction of the injected electrons through the beam lines

holes of the ring shielding walls, e.g. due to a dipole power supply failure. In addition, it is important to continuously monitor and keep under safety thresholds the secondary radiation produced by the bremsstrahlung during the injection beam losses, passing through the beam line holes and hitting the beam line components.

To minimize such radiation hazards and assure safety conditions for the experimental hall users, different interlocks will be implemented at Elettra. In particular, the personnel safety system will enable the top up injection only if the following conditions are all fulfilled:

- a safety top up key, kept by the machine operator, must be turned in the position "Top-Up Abi"
- the stored current must be greater than a pre-fixed threshold, this will assure that the lattice settings of the SR are correct
- the energy settings of the BTS TL dipoles must match those of the storage-ring dipoles, this will assure that the energy of the electron beam coming from the booster is the same as the energy of the electron beam stored inside the ring
- the integral of the electron charge losses during top-up injection, measured on a relatively long interval time (one hour), must not exceed a pre-fixed threshold. This value is obtained computing the so-called *top-up-lost-charge* which is the difference between *the injected charge*, measured through a toroid installed at the end of the BTS TL and the *relative current increment*, measured through the ring DCCT. If the integral of the *top-up-lost-charge* per hour exceeds the pre-fixed threshold, the top up process is inhibited for the following hour.

Furthermore, the safety system will interrupt the top up injection if at least one of the previous conditions is not verified or:

- if the charge measured through the toroid installed at the end of the BTS TL is not within a pre-fixed threshold
- Or if the integral of the electron charge losses during top up injection, measured on a relatively brief interval time (about 3-5 s) is not within a pre-fixed threshold. This interlock will permit the safety system to interrupt quickly the operations (through the inhibition of the linac gun) if large beam losses occur along the ring

The two thresholds (point "d" and "f") on the maximum acceptable electron charge losses will be fixed once dedicated radiation measurements will be carried out during the booster commissioning.

Another safety interlock will be based on the beam lines gamma monitors. If one of them exceeds a pre-fixed alarm threshold, the safety system will not interrupt the

top up injection but will close that beam line beam stopper.

During the normal refill the beam stoppers of the beam lines front-ends will be kept closed and the access inside the front-end hutches will be interdicted.

The booster safety system will be based on a Plc belonging to the series Siemens SIMATIC S7-300F, designed for safety applications. Some preliminary tests have been successfully performed on a prototype. The final tests will be performed as soon as the toroid at the end of the BTS TL will be installed.

Furthermore, to promptly detect a degradation of the top up, we foresee a software control. The charge and the position of the electron beam along the BTS TL, the injection efficiency into the SR, and the SR accumulated beam intensity and lifetime are continuously monitored. As soon as one of these parameters goes out threshold, a warning is issued and the top up injection is manually stopped. The thresholds in this case are more conservative with respect to the ones used for the interlock system. According to the found problem and the solution to get a proper setting which restores the nominal conditions of the top up injection, the operator will decide if to go on with top up injection or not. Furthermore, a continuous correction of the electron beam trajectory along the BTS TL is foreseen. A weight is given to the last two BPMs purposely located in a drift of about 1 m. If the position on one of these two BPMs is over a threshold or if the trajectory feedback does not converge, a warning is also issued.

## OPERATION MODES

The SR operation process will be on 4 steps.

1. In the *refill* mode, the beam lines stoppers are closed, the insertion devices are open, the linac is in multi bunch mode, the initial SR accumulated beam is zero or higher. Once the SR and the whole injector settings are ready, fill the SR. Then close the beam stoppers of the BTS TL. Optimize the SR settings in order to close the insertion devices safely.
2. Close the insertion devices and go on with the optimization of the optics, orbit, multi bunch stability, global orbit stability. Meanwhile, switch the linac to single bunch mode and control that the charge is at most 0.1nC.
3. Open the beam stoppers of the BTS TL, except the last one and control the trajectory. Then open the last beam stopper of the BTS TL, and start the trajectory feedback. Control the filling, i.e., control that the beam goes to the right buckets, the injection efficiency, and so on.
4. All controls ok? Turn the safety top up key to enable the top up. Open the beam lines stoppers if the safety system gives the authorization. Start the top up in the OneButtonMachine high level software application program. Top up mode is on.

Note that once we acquire enough confidence and experience, we might close the insertion devices during the refill operation.

### *Filling Uniformity*

To maintain the filling uniformity during the top up injection, it is intended to measure the charge of each bunch and refill the ones with less charge. To be able to fill also the losses due to possible instabilities, where usually a single bucket undergoes losses, the pre injector linac is foreseen to be operating in single bunch during top up. For the normal refill, it's instead in multi bunch, as the maximum charge in single bunch requires about 18 minutes accumulating 330mA. For 2.4GeV, the linac might be in single bunch also in refill mode as only 9 minutes are required to accumulate 150mA.

### *Frequency of the Top Up*

To maintain the current to  $330 \pm 1\text{mA}$  at 2GeV, one has to top up each 9 minutes. At 2.4GeV, the current kept to  $150 \pm 0.5\text{mA}$  requires a top up each 15 minutes. Topping up with a fixed time interval is a good solution for the natural decay of the beam. When losses occur due to spurious instabilities, it's better to top up with a fixed beam current decrease. The time interval and beam current decrease values depend upon the users' requests. The larger (shorter) is the time interval, the larger (shorter) is the time required to complete the top up.

### *Injection Optimization*

With the insertion devices closed, the optimization of the injection into the SR is highly demanding for Elettra: the beam energy can be relatively low (1GeV) and there are many exotic insertion devices installed. There are six APPLE-II permanent elliptical magnets, one Figure-8 permanent magnet, one electromagnetic elliptical wiggler, one planar hybrid wiggler, one superconducting wiggler. A total of 14 insertion devices are installed along the dispersion free sections and one is installed in a dispersive section. Some more are foreseen. In particular, they might be in vacuum. Both theoretical and experimental studies have been performed to investigate the feasibility of the top up. The injection process studies have been implemented in Racetrack in 1992[2] and the theoretical studies have been done in 1992[3] for the planned planar undulators and wiggler and repeated in 2001[4], this time including the exotic insertion devices. Injection into the SR with all the installed insertion devices closed ( Figure 8 and superconducting wiggler not included) and the beam lines stoppers closed has been performed. The result is that once the transverse tunes are restored, there is no difference in the injection efficiency with the insertion devices open or closed. The experiment has to be repeated when also the Figure 8 and the superconducting wiggler are closed, as the theory shows a non negligible reduction of the dynamic aperture.

On the other hand, machine and FEL lasing experiments have been performed with the APPLE-II

elliptical undulators of section 1 closed and the beam line stopper open [5]. The electron beam energy was 0.9GeV, the linac was in single bunch, the SR filling mode was 4 equidistant single bunches. The results have shown that if the injection efficiency is above 70%, the radiation levels outside the beam line hutch are within the limits set for the unclassified areas. Furthermore, the top up regime confirmed that injecting when the laser oscillation is established increases the electron beam current threshold in terms of single bunch instabilities.

On top of a “golden” closed orbit and an optimized injection bump in the SR, a “golden” trajectory along the BTS TL and the first turn along the SR will be always provided before switching to the top up injection mode. This trajectory is maintained by a trajectory feedback. If still needed, users can get a signal to gate their measurements during the top up injection process.

Furthermore, to ease the injection into the storage ring, the booster is foreseen to work in the low emittance mode, that is 166nm instead of the nominal 226nm [6].

## DIAGNOSTICS FOR TOP UP INJECTION

### *TL Beam Position Monitors*

A new TL BPM system [7] based on Bergoz Log Ratio detectors has been developed and commissioned in the past two years. The system acquires, shot by shot, the beam position with a resolution limited to  $40\mu\text{m}_{\text{RMS}}$  due to the electronic noise. The system has been installed at the ELETTRA Linac and TL; it has been used to automatically acquire the response matrix of the TL correctors and subsequently optimize the TL trajectory of the beam.

### *Trajectory Feedback*

A shot by shot feedback system using the BPMs and correctors of the BTS TL is foreseen to keep the trajectory optimised during top up operations. The feedback acts on a given bunch by measuring the positions of the previous ones. For this reason the attenuation bandwidth of the trajectory perturbations is limited to a few tenths of Hz, thus only drifts and slow motions of the trajectory will be corrected.

### *SR Beam Position Monitors*

The first-turn orbit of the electrons injected into the storage ring must also be optimized. New BPM detectors are being installed on the Elettra storage ring during 2006 in view of the implementation of a global orbit feedback system [8]. Besides the required closed orbit measurements, they will also provide turn-by-turn and first-turn measurements. A distributed timing system will allow synchronization of the BPM detectors with the injection trigger in order to acquire the first-turn orbit at every injection shot.

### *Bunch Charge Measurements*

A toroid installed at the end of the BTS TL, equipped with an electronic front end, will measure the effective

injected bunch charge with an electronic resolution of 30nA. The output of the system will be used both for the interlock and high level software application purposes.

An upgrade of the SR diagnostic is foreseen to implement the bunch by bunch charge measurement. This measurement is fundamental to maintain the required filling uniformity. Some preliminary measurements have been performed using a wide band photodiode to acquire the synchrotron radiation pulse from a bending magnet of the SR. For comparison, the signal obtained by summing the 4 button electrodes of a BPM has been acquired as well. A bunch charge variation has been reliably (averaging out fluctuations) observed though on a longer (>30min) time scale with respect to the one (10min) needed by the top up process. To reach the required resolution, the set up has to be optimized and its sensitivities to transverse and longitudinal bunch motions quantified.

### *Timing*

In order to synchronize the cycles of the SR and the booster a new timing system has been designed. The new system will provide the triggers to synchronize the bunch by bunch charge measurement described above and to drive the injection on the required SR bucket with the temporal resolution of 2ns (jitter<sub>RMS</sub> < 10ps).

## CONCLUSIONS

The top up tools are rapidly developing. Some promising top up experiments have been performed and some more are foreseen. The high level software part is also under development [9].

## REFERENCES

- [1] M. Svandrlik et al., “Elettra New Full Energy Injector Status Report”, this conference
- [2] F. Iazzourene et al., “Racetrack User’s Guide”, Version 4.01”, ST/M-92/7, Trieste, July 1992.
- [3] F. Iazzourene, “Injection Simulations with Insertion Devices and Magnets Imperfections”, ST/M-TN-89/38, Trieste, July 1992.
- [4] L. tosi and C.J. Bocchetta, “Top up: Injecting into the Storage Ring with Closed Insertion Devices”, ST/M-01/05, Trieste, October 2001.
- [5] K. Casarin et al., “Injection and FEL Lasing with Front End Open at ELETTRA”, PAC 2003, p. 2309
- [6] F. Iazzourene, “Update on the Linear and Nonlinear Optics of the ELETTRA Full Energy Booster Synchrotron”, EPAC’02, Paris, June 2002, p. 581.
- [7] S. Bassanese, M. Ferianis, F. Iazzourene, V. Verzilov, “Linac and Transfer line beam position monitor at ELETTRA”, DIPAC 2005, Lyon, June 2005, p.252.
- [8] M. Lonza et al., “Status of the Elettra Global Orbit Feedback Project”, these proceedings.
- [9] C. Scafuri and F. Iazzourene, “Elettra New Full Energy Injector High Level Software”, this conference.