TOP-UP OPERATIONAL EXPERIENCE AT ELETTRA

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Abstract

Since May 2010 Elettra, operates in top-up at both 2 and 2.4 GeV user energies. In this paper the experience during more than a year of operation in top-up is discussed and the machine up time statistics are presented and compared with the before top up period.

INTRODUCTION

Elettra, the 2/2.4 GeV third generation Italian light source, has successfully joined the synchrotron facilities that operate fully in top-up mode. Located on the outskirts of Trieste, Elettra has operated for users since 1994, but during the past few years a large upgrade programme has taken place. This has included the construction and start-up operation of a full-energy injector. The new injector chain and the other machine and beam line upgrades, together with the demands for intensity and thermal stability, naturally led to the change to top-up mode, in which frequent beam injections maintain a quasi constant beam current in the storage ring during user operations. This is in contrast with the decay mode, where the stored beam is allowed to decay to some level before refilling occurs.

Elettra was not originally designed for this type of operation (and indeed even operated for many years without a full-energy injector). However, in May 2010, only a year after establishing the stable operations of the new injector, the storage ring began to work successfully with top-up [1,2] at both user energies, 2 GeV and 2.4 GeV. Elettra has thus become another example showing how a third-generation synchrotron that previously operated in decay mode can advance to full top-up operation, in this case at multiple energies.

With top-up operation the photon intensity produced at Elettra is stable and the integrated intensity is 60% higher over a time period equal to the beam lifetime. Thus while keeping the optical components of the beam lines in thermal equilibrium the integrated number of photons is also higher, so providing an additional gain in beam time for the experiments. At the same time the intensity-dependent electronics also remain stable, allowing submicron accuracy in the position of the electron beam and hence a higher stability of the photon beam.

Elettra's upgrade to top-up started in 2009 and included the addition of various diagnostic and radiation-safety instruments, modification of the control and interlock software, fine tuning of the timing of the kicker and septa, as well as a revised operation strategy. A great deal of effort in collaboration with the radiation-protection team resulted in a high-level application with a "top-up controller" handling and controlling all aspects of the procedure. Careful radiation measurements at each beam line under various conditions of the injected beam, together with the high injection efficiencies achieved at both energies, meant that no additional shielding was required for the beam lines. Radiation levels in all beam lines remain below 1 μSv/h for efficiencies higher than 90%.

The storage ring beam current at 2 GeV is set by the users to 310 mA (270 nC) and top-up occurs every 6 minutes by injecting 1 mA in 4 s, thus keeping the current level constant to 3‰. At 2.4 GeV the stored beam current is set to 150 mA and top-up occurs every 20 minutes, injecting 1 mA in 4 s to maintain the current level constant to 7‰. The users have chosen fixed-current interval top-up (1 mA) instead of a fixed time interval. The injection system is perfectly tuned and for the majority of the beam lines does not produce interference with data-acquisition processes. A gating signal is also provided, but up to now only two, very sensitive, beam lines see some interference and therefore are gated.

The change to top-up mode required no transition period and once it began all went exceptionally smoothly, thanks to the very good preparation and the high level of expertise of the personnel involved. Although at the beginning, the operation in top-up was programmed for 20% of users beam time, it became immediately clear that the users strongly preferred this mode and so Elettra has operated in top-up for 100% of the beam time dedicated to uses right from the start.

THE INJECTOR

The project for the full-energy injector started in 2005 and finished by providing beam in March 2008 on time and within budget [3]. The injection chain consists of a 100 MeV linear accelerator and a 2.5 GeV 3 Hz booster. At the very beginning the injection system was plagued with problems concentrated on the booster dipole and quadrupole digital power supplies and the stability of the water and air cooling system. After about one year of interventions and refurbishing of the power supplies by the constructor, the Elettra team finally was able to render the injector highly reliable. The booster operates in the on-fly mode whereby the energy required is obtained by adjusting the extraction time while the booster itself is always performing the full cycle i.e. 100 MeV to 2.5 GeV. The booster can provide any energy from 0.1 to 2.5 GeV but the energies used in the storage ring are 1 and 1.5 GeV for THz, 1.8 GeV for the SR-FEL, 2 and 2.4 GeV for the main users. Although the maximum achieved accumulated current in the booster was about 6 mA/s (above specs) for practical reasons no more that 2 mA/s are needed for refilling the storage ring and during top up this current is reduced to 0.2 mA/s due to radioprotection.

At the same time a big effort was made to fully thermally stabilize the injector as well as provide for

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redundancy of its critical parts. Thus a second thermionic gun and a spare modulator have being constructed, local knowhow on repairing the modules of the digital power supplies was achieved and an effort to reduce klystron discharges is under way. Normally those discharges do not hinder the top-up mode because their recovery time is short compared to the interval between injections however it is desirable that the one discharge per day at present, to be reduced to one per week.

The percentage of time in top-up compared to total beam time delivered for users is a measure of the availability of the injector which for 2011 is 98.7%.

THE STORAGE RING

In order to satisfy the strict safety requirements of top-up operations the control system monitors on a shot-by-shot basis the balance of the net charge extracted from the booster and the charge effectively injected in the storage ring, using a 24-bit resolution fast current monitor.

To control the beam losses an intensity loss budget is set that should not exceed 10 mA/h at 2 GeV and 5 mA/h at 2.4 GeV. If the budget is exceeded the top-up process stops for the rest of the hour. This mechanism sets the lower limit of a tolerable efficiency to 60% and only very few times within a year the top-up process stopped due to this reason. At the same time a radiation budget is also set for each beam line of about 0.4 µSv for a four hour time interval, exceeding this budget the shutters of the beam line remain shut for the rest four hours, a situation that has never happed until now. From the radiation protection point of view the Elettra experimental hall is classified as "free area" (i.e. an area where radiation dose is less than 1 mSv/year) .

The injection, refill and top-up are completely automatic and the operators intervene only in case of faults. The automation is achieved on the higher level with the top-up supervisor, a software process that coordinates and controls all the non-safety related operations of the top-up and estimates some parameters which are very useful for the control room operators. Thus it constantly monitors the storage ring current and when the lower current threshold is reached, starts a new top-up cycle: the booster ramping cycle is started and after the time needed to settle the power supplies and other systems to their running values, all the necessary triggers are enabled and injection starts.

During injection the booster and storage ring currents are continuously monitored and the booster charge is stabilized acting on the linac gun grid voltage with a feedback algorithm.

At the same time the supervisor measures the injection efficiency and estimates the "risk" of exceeding a predetermined limit of current loss both on short term and long term basis. If the limit is reached, the safety PLC inhibits the top-up injection as described before. When the desired storage ring current is reached, the supervisor stops the injection. The application is also used to normally refill the storage ring and/or perform top up like injections in top up off mode. This operation mode is for testing the top-up settings and for vacuum conditioning.

The top-up supervisor is technically implemented as a Tango device server. The operator graphical interface is developed with the QTango toolkit (Fig. 2).

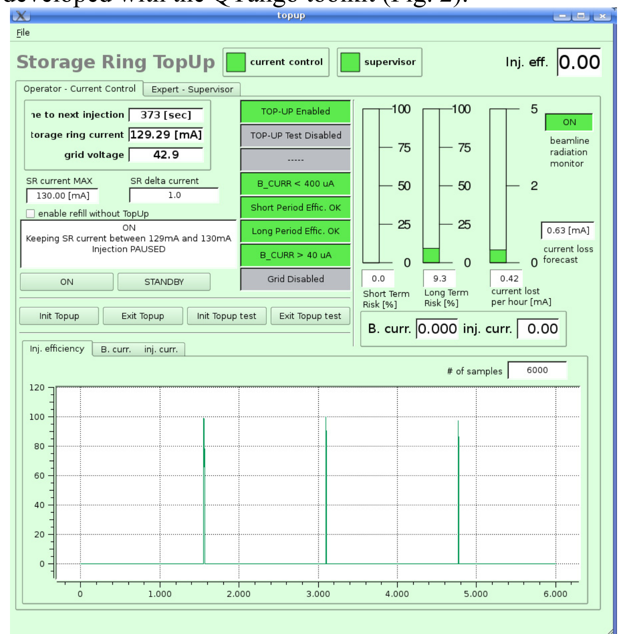

Figure 1: Top-up supervisor panel. The graph in the panel shows the injection events and the % of efficiency.

It was highly expected that top-up would improve the availability of the storage ring. In fact in the next Figure 2 one can see the net availability (blue) during the 3 phases of operations of Elettra while with red is shown the downtime, with yellow the time lost for refilling and with light turquoise the time lost due to electricity surges.

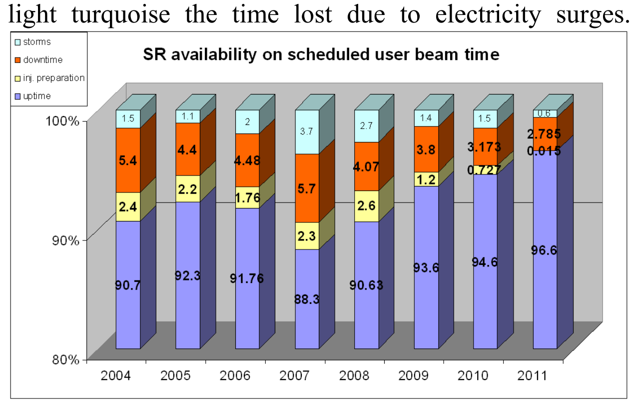

Figure 2: Availability of Elettra since 2004.

In fact before 2008 the storage ring ramped in energy, whereas since 2008 operated with a full energy injector and since 2010 functioned in top-up. It is clear from Figure 2 that a net improvement occurred after 2008.

Another important number for the reliability of a light source is the mean time between failures. Also in this case (see Figure 3) a clear improvement can be observed after 2008. The tendency for 2011 is for higher mean time between failures (MTBF) and in fact for the two first runs of 2011 the machine had 130 hours of MTBF. At the same time the longest top up duration between failures has been 200 hours, a very remarkable result indeed.

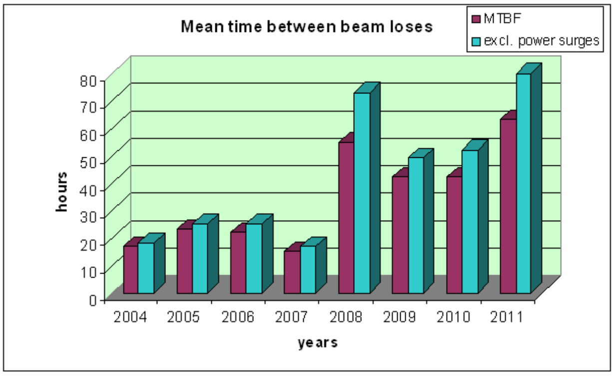

Figure 3: Mean time between beam losses since 2004.

Top-up mainly has been invented for keeping source and experiments thermally stable and the electronics stable. The orbit was monitored over a long period of time i.e. 100 hours with the machine in top up and both the horizontal and vertical position of the bpms were registered.

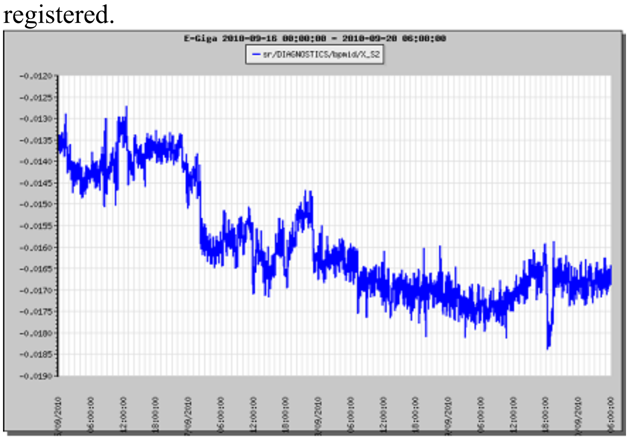

Figure 4: Horizontal orbit stability (y axis in mm) during top up for a period of 100 hours.

Figure 4 shows the horizontal beam position in one bpm and the peak to peak value is 4 um while the corresponding vertical measures 1.5 um.

Since air conditioning is old and under refurbishing occasionally when a big temp gradient between day and night exists the e-orbit follows a day night thermal pattern. The mean orbit feedback changes the radio frequency by about 50Hz that corresponds to 26 um in circumference to keep the mean horizontal orbit at zero.

The orbit reproducibility depends mainly on the thermal equilibrium. The orbit needs some time after refill following a beam dump to arrive to the previous position settings due to the vacuum chamber heating. It was found that 20 C difference (about 10 minutes after the beam dump) affects by 90 um rms the horizontal orbit and only 4 um rms the vertical. When re-injecting from zero to full intensity after a typical mean failure duration (which at present is about 0.8 h) almost 1.5 hours are needed for having the orbit back to its previous "golden orbit" values as seen in the next Figure 5.

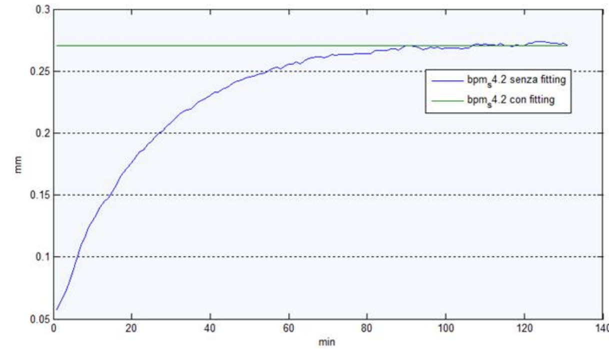

Figure 5: Bpm offset value drift towards "golden orbit" setting versus time after refill.

CONCLUSIONS

The top-up operations mode is the only operational mode for users since May 2010. The top up percentage to the given user beam time is 98.7% a number that reflects also the high availability of the injector. The storage ring availability and the mtbf are very high showing clearly the beneficial effect of the full energy injection and the top up. The injection efficiencies are normally high i.e. more than 90% although the system tolerates also lower efficiencies up to ~60%, it is important however to note that the efficiency is calculated by comparing the booster and storage ring current therefore if the booster does not accumulate well the efficiency appears low even if all available current is injected from the transfer line into the storage ring. The stability and the reproducibility have been also greatly improved. It is important to note that 10 degrees Celsius difference in the temperature of the vacuum chamber translates to about 20-30 μm shift in the reading of a single bpm while the shift due to electronics is about 1μm/10mA.

To keep the synchrotron light source points as stable and reproducible as possible, (after performing a total realignment of the storage ring at the end of 2010 and afterwards a beam based alignment) the orbit is set to zero position and angle at the source points without permitting the users to change them.

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