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PREPARATIONS OF THE ELETTRA BOOSTER FOR ELETTRA 2.0

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Abstract

The commissioning of Elettra 2.0 the low emittance (4th generation) 2.4 GeV light source that will replace Elettra, the 3rd generation light source in use at Trieste Italy, is foreseen for the second half of 2026. Since the injector complex will be reused, improvements are necessary in order to guarantee optimal injection efficiency. Optics modification, hardware upgrade and software development will be undertaken to improve the performance, stability and reliability of the Injector complex.

INTRODUCTION

The Injector should guarantee that the injection efficiency into the new ring will be high i.e. >90%.

The extraction beam energy pulse can be selected in the range from 100 MeV to 2.5 GeV with repetition rate of 2 Hz with max e- beam current of 2 mA (0.4mA in top-up operation mode)

The reduced dynamic aperture of Elettra 2.0 at the injection point requires an upgrade of the Injector in order to reduce as much as possible the emittance of the injected beam. The booster design emittance is 160 nm at 2 GeV and 226 nm at 2.4 GeV. Simulations show that at 2.4 GeV a horizontal emittance of 160 nm is adequate to allow reaching an injection efficiency of 95%. In order to reduce the equilibrium emittance different strategies have been developed and some of them are already in use.

BOOSTER OVERVIEW

The booster has been in operation for Elettra for the last 15 years bringing the electron beam energy from 100 MeV to 2.0 or 2.4 GeV, (max booster energy 2.5 GeV) the energy of the extracted beam selected by changing the extraction time along the energy ramp of the magnets. The used optic is the nominal 226 nm rad at 2.4 GeV. The beam current in top-up mode is 40.4 mA, however the maximum achievable current is about 2-3 mA.

BOOSTER UPGRADE

Optics

In the early 2023, the tune working point of the Booster was changed from $\nu_x = 5.39$ to $\nu_x = 6.8$ and $\nu_y = 3.42$ to $\nu_y = 2.85$ with an emittance reduction at 2.4 GeV from 230 nm to 160 nm [1].

In 2025, new power supply will be installed for the bending and quadrupole magnet of the Booster, the refurbished power supplies will enable different optics solutions to further reduce the equilibrium emittance. The best compromise to ensure sufficient dynamic aperture and low emittance requires changing the tune working point to $\nu_x = 6.8$, $\nu_y = 1.8$. A new quadrupole power supply family will be implemented, splitting the previously used single one of the focusing quadrupoles into two families, each with its own power supply.

The resulting optics (Fig. 1) allows the emittance to be reduced to 136 nmrad without affecting the extraction system and the dynamic aperture. Slightly lower emittance can be achieved with different tune, but at the cost of compromising the dynamic aperture.

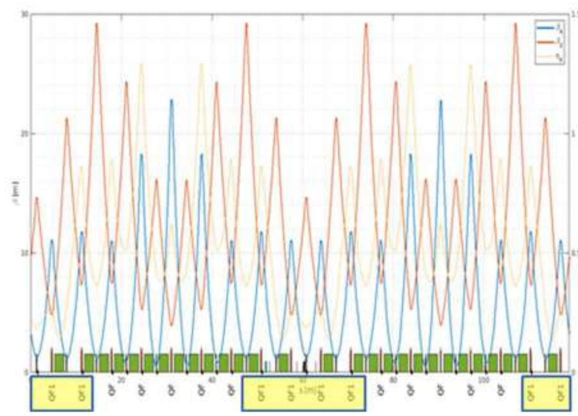

Figure 1: Booster low emittance optics.

RF

An IOT amplifier was installed in the RF Booster system in order to increase the RF voltage from the actual 0.6 MeV to 1 MeV.

The pulse width of the beam extracted from the Booster is in good agreement with the simulation (Fig. 2). The reduced bunch length is expected to improve the longitudinal matching between the injected and stored beam with an estimated 5% increase in injection efficiency.

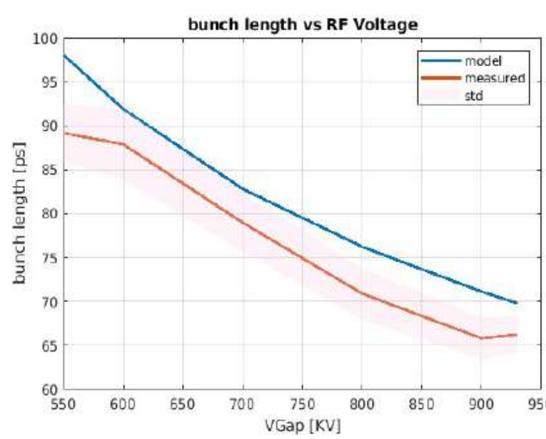

Figure 2: model vs measured bunch length.

Orbit Correction

The orbit correction tool has been adapted to perform both low and high energy corrections. Low and high energy orbits are corrected by changing the DC current

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and ramping parameters of the steerer correctors, using the SVD algorithm in both cases.

The rms orbit improved from 6.3 mm to 1.65 mm in the horizontal plane and from 4.6 mm to 1.7 mm in the vertical plane. As a result, BLMs recorded a consistent reduction in losses and an increase in the current stored in the booster.

The BPMs currently has a std of 0.5 mm and further improvements are expected with the installation of the new BPMs electronics and power supplies.

Off Energy Operation Consideration

The off-energy operation of the Booster [2] has been analysed to further reduce the emittance. With an equivalent booster radius reduction of 3.7 mm, the resulting dispersive orbit allows the emittance to be reduced to 100 nm. The resulting maximum beta beat of 12% is acceptable and the 20 mm circumference reduction can be well compensated by the bellows. The longitudinal emittance increases with off-energy operation, but the bunch length can be reduced by increasing the RF voltage. At an RF voltage of 1 MV, the final bunch length is reduced from 29 mm to 21 mm.

The resulting extracted beam is better suited to the small dynamic aperture of the Elettra 2.0, even without the use of the emittance exchange technique [3]. Without the emittance exchange the expected average injection efficiency is of 92%, much better than the 81% simulated with the low emittance optics without considering the off-energy operation. This delta injection efficiency of 11% disappears when applying the emittance exchange technique, in fact an injection efficiency higher than 97% is obtained in both cases (Table 1).

Table 1: Injection Efficiency with Different Scenario

Tunes (x-y)	6.8 – 1.75
ε_x 2.4 [nmrad]	137
ε_x 2.4 [nmrad] + off-energy	100
InjEff [%]	81
InjEff [%] off-energy	92
InjEff [%] emittance swapped	97
InjEff [%] emittance swapped + off-energy	99

A round injected beam has been simulated to avoid losses at in vacuum undulator positions. The injection efficiency is slightly reduced to 94%, but some losses in the storage ring disappear.

TRANSFER LINES UPGRADE

PTB Energy Feedback

An energy feedback system has been implemented in the Preinjector to Booster (PTB) transfer line, to ensure constant electron energy by monitoring the horizontal position read by a BPM positioned after the bending magnet of the transfer line following the acceleration sections, thereby modulating the modulator's high voltage accordingly. The primary variations in energy are attributed to the acceleration section thermalization system, which will be upgraded in April 2024.

This feedback operates in real-time to maintain the beam energy within specified limits, utilizing a simple feedback matrix response algorithm with PID (Proportional-Integral-Derivative) control. The BPM serves as the sole source of positional feedback. The energy feedback system adjusts the modulator high voltage ensuring a stable beam energy.

By maintaining constant energy, it has become possible to cease modulation of the extracted charge from the gun during top-up injections. This modulation previously compensated for variations in the injection system's energy but significantly increased losses detected by the Beam Loss Monitors (BLM). The implementation of the energy feedback system not only stabilizes the beam energy but also reduces unnecessary modulation, thereby minimizing losses and optimizing the injection process into the new Elettra 2.0 storage ring.

BTS Transfer Lines Trajectory

In the Booster to Storage ring (BTS) transfer line new Libera Spark BPM electronics have been installed that provide resolution <= 10 um. New trajectory correction software is in operation in the BTS that provides full control from position to injection point in the storage ring and on the fluorescent screens dedicated to emittance measurement.

The improved control of the trajectory (Fig. 3), also improved the injection efficiency stability in a long-term period (Fig. 4).

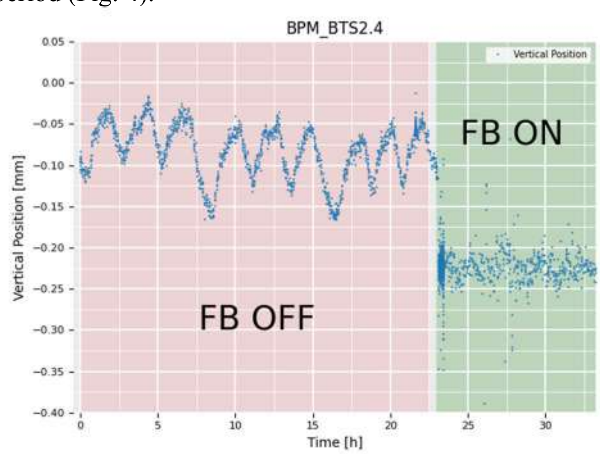

Figure 3: Orbit stability in the vertical plane at the last BPM of the BTS.

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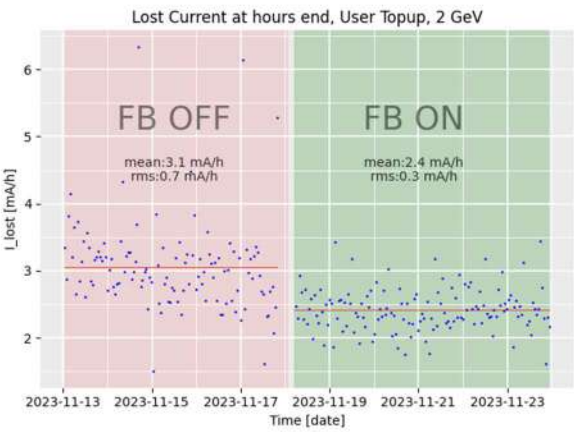

Figure 4: Improved injection efficiency after trajectory correction using the feedback.

BTS Transfer Lines Optics

The emittance measurement is performed at two locations along the transfer line, at the beginning and at the end. The measured emittances are in good agreement with the model (Fig. 5)

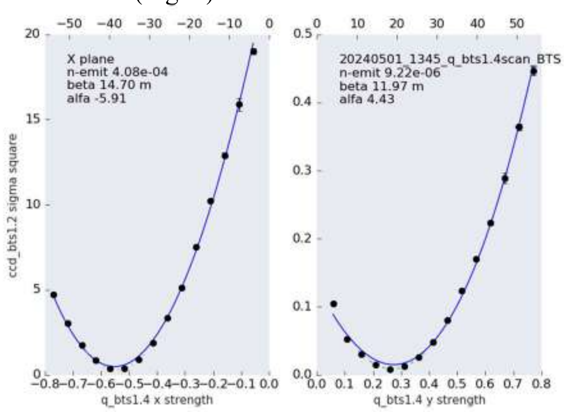

Figure 5: Example of emittance measurement by quad scan method.

The improved knowledge of the optics of the transfer line, allowed us to remove the last quadrupole of the transfer line that were in mechanical conflict with the magnets of Elettra 2.0 and to well adapt to Elettra optics the injected beam parameters. The optics can be adapted to have a zero dispersion at the point of the emittance measure.

BTS Transfer Lines Emittance Control

Two pair of scrapers will be installed along the transfer line in order to have a fine emittance control of the injected beam (Fig. 6). The optics is drawn to guarantee a phase advance of 90° between the two pair of scrapers.

The scrapers can be useful if the emittance exchange doesn't work as expected or can't be applied due to a power supply fault.

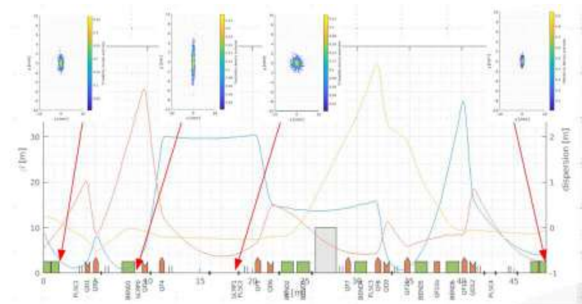

Figure 6: BTS transfer line optics and scrapers positions.

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