

BEAM ORBIT STABILITY AT ELETTRA

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Abstract

The top-up operation established since 2010 at the Elettra third-generation synchrotron light source has solved the problems related to thermal drifts and beam current dependence, and a series of feedback loops acting on the machine optics and radio-frequency systems made easier to setup and operate the ring. Those systems together with the fast orbit feedback in operation since 2007, contributed to very high electron beam orbit stability. A description of the active systems and their performance, future perspectives as well as some still open issues will be presented and discussed.

INTRODUCTION

Elettra, the 2.0/2.4 GeV Italian synchrotron light source operates for users since 1994. In order to keep the facility competitive in terms of the electron beam quality after the advent of more recent light sources, a series of machine upgrades have been made in the last decade.

One of the major upgrades was the replacement of the old injector, a 1 GeV linac that did not allow full energy injection, with a 2.5 GeV booster. Before setting into operation the new injector in 2008, daily refills and energy ramping were a big concern for the complexity of machine preparation and tuning, and also very detrimental for the orbit stability and reproducibility. Drastic changes of thermal load on the vacuum chamber due the electron beam dump and subsequent refill induced large distortions with respect to the orbit measured before the beam dump [1].

Another side effect of operating in decaying mode was the dependence of the Beam Position Monitor (BPM) readings on the current accumulated in the storage ring; an upgrade of the BPM system started in 2006 adopting digital detectors decreased the beam current dependence to $1\mu\text{m}/10\text{mA}$ [1] but still leaving open issues with current decaying from 300mA to 150mA.

The next major upgrade was the successful change of the operation mode to that of the top-up, although Elettra was not designed for it, that also solved as expected the majority of the problems related to orbit stability. The maximum decaying current in top-up regime is fixed to 1mA, which requires an injection every 6 minutes at 2 GeV or 20 minutes at 2.4 GeV. Moreover, the possibility to re-inject at full energy after a beam dump with no need of energy ramping has dramatically decreased the average time required to restore the beam and reduced the time needed by the vacuum chamber to reach the thermal equilibrium. As a consequence, the mid-term orbit stability, estimated as the *rms* of the difference orbit with

respect to the reference, has been improved significantly (see Fig. 1) with respect to the previous situation [2].

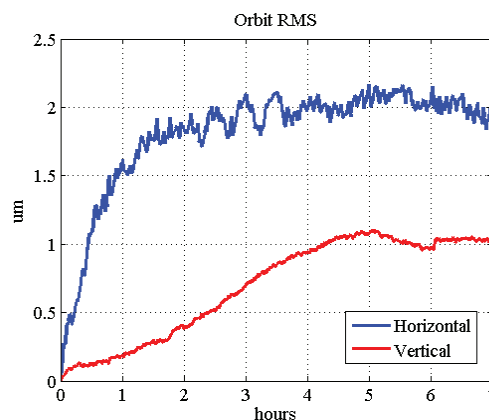


Figure 1: Orbit *rms* after a storage ring refill.

The improvements in the orbit stability by the top-up operation however revealed noise sources not seen or being important before. In particular, some beam-lines started to be sensitive to electron beam energy drifts due to slow horizontal orbit changes from tides and/or soil temperature gradients, eventually compensated by RF frequency adjustments.

Several software applications were developed to guarantee the electron beam stability, requiring the intervention of the operator only for the machine setting-up. After a new refill, a slow orbit correction program restores the electron beam position and angle in the bending magnets and undulators. Then the following applications are turned on:

- **Top-up manager:** keeps the current constant in the storage ring;
- **Energy feedback:** changes the RF frequency in order to keep constant the horizontal average orbit;
- **Tune feedback:** changes the current of two quadrupole magnet families to keep constant the horizontal and vertical tunes;
- **Fast orbit feedback:** corrects the global electron beam orbit at 10 kHz rate.

In addition, a software application monitors the beam orbit stability by acquiring synchronous orbit positions and corrector magnet values at 10 kHz rate from the fast orbit feedback system and detects major sources of noise through spectral analysis.

FEEDBACK SYSTEMS

Top-Up Manager

A high level application manages the top-up operation: at every injection, it selects the storage ring buckets that

have to be refilled, regulates the charge accumulated in the booster by acting on the pre-injector gun voltage and finally fixes the number of shots to be injected by acting on the timing system.

In order to minimize the injection time, single bunch injection is reserved only for particular filling patterns; usually a train of 60 bunches are injected at each shot for a total current of 0.25mA per shot. It is possible to load any filling pattern and, in case of hybrid modes (one single bucket filled in the gap), a feedback loop measuring the storage ring filling pattern through an oscilloscope, keeps the current in the single bunch constant. Charge losses along the injection chain are continuously monitored; a prediction of the losses and the risk for injection inhibition by the personnel safety system is also provided.

Energy Feedback

The energy feedback keeps constant the horizontal average orbit by tuning the frequency of the RF master oscillator. The dispersive orbit is subtracted from the fast orbit feedback correction to avoid cross talks between feedbacks. The peak-to-peak day/night RF frequency excursion is typically less than 100 Hz.

The energy feedback is effective in stabilizing slow drifts of the photon flux not only in the bending magnet beam-lines where the electron beam dispersion is high but also in the undulator beam-lines (see Fig.2).

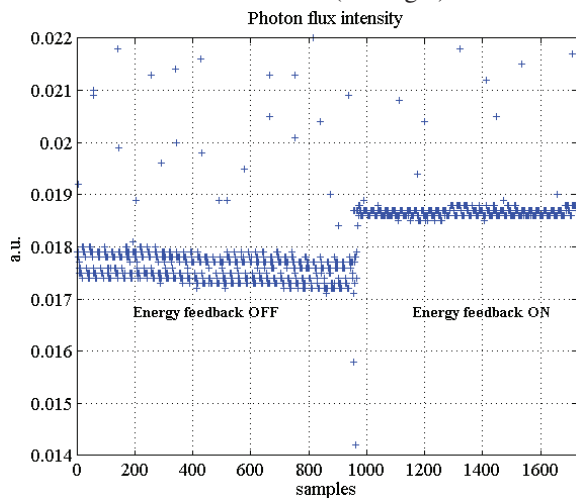


Figure 2: Photon flux intensity measured by the CIPO beam-line with energy feedback turned off and on (data acquired at 1 Hz).

Tune Feedback

An accurate control of the storage ring betatron tunes assures beam optics stability and constant injection efficiency. In fact, fractional tune shifts of the order of 4% can reduce the injection efficiency by about 50%.

Undulator gap changes are the main source of tune shifts. While feed-forward correction systems based on trimming coils together with the fast orbit feedback minimize the effect on the beam orbit, fractional tune

shifts caused by undulator gap changes can be of the order of 10%.

The tune feedback can acquire tune values from the transverse multi-bunch feedback system or from the BPM system. In both cases the measurement is based on excitation and spectral analysis of the transverse electron beam position.

The most accurate method is the one based on BPMs. The detectors are able to acquire up to 16384 turn-by-turn beam position samples. The acquisition is triggered by the same timing signal which acts on the injection kicker magnets allowing parasitic tune measurements during top-up injection. The tune peaks can be clearly identified by calculating the FFT of the acquired data. A simple algorithm avoids confusing the real tune peaks with possible artefacts.

The correction scheme is based on a 2x2 response matrix between the tunes (horizontal/vertical) and two quadrupole families.

Fast Orbit Feedback

A fast orbit feedback has been running at Elettra since 2007 [3]. Twelve VME CPU boards collect position values at 10 kHz from 94 BPMs through Gigabit Ethernet links. The CPUs share the position data by means of a fibre-optic reflective memory, calculate the corrections and apply them to the 82 horizontal and 82 vertical corrector power supplies. The correction scheme is based on the inversion of the response matrix (BPMs vs. correctors) by means of the Singular Value Decomposition (SVD), taking into account the first 23 eigenvalues. As control algorithm a Proportional Integral Derivative (PID) regulator plus six harmonic suppressors centred at 50, 100, 150, 200, 250 and 300 Hz is used.

In order to benchmark the fast orbit feedback performance with an “out-of-the-loop” sensor, a fast CCD acquiring images at 10 kHz rate has been installed in the Synchrotron Radiation Profile Monitor (SRPM) using bending magnet radiation. The results are depicted in Fig. 3.

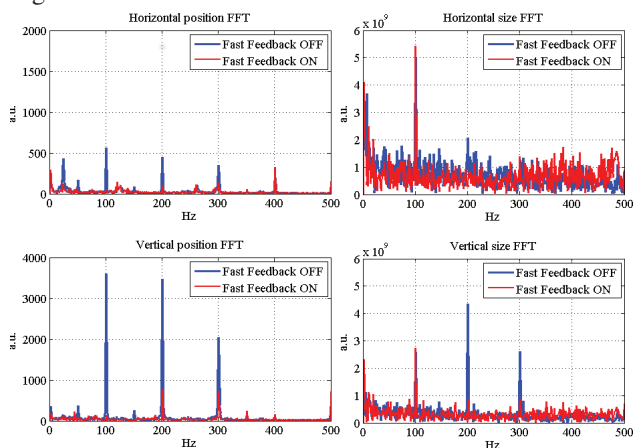


Figure 3: Spectra of the photon beam position and beam size acquired by a fast CCD on the SRPM with fast orbit feedback off and on.

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An offline analysis eventually discriminates photon beam motion from beam shape/intensity fluctuations.

STABILITY MONITORING SYSTEMS

After twenty years of service the Elettra storage ring is facing problems related to aging of its systems. In particular the magnets power supply electronics suffer from electrolytic capacitors drying out, causing an increase of the noise induced on the electron beam at 50 Hz and its harmonics. Even mechanical vibrations induced by anomalous water/air cooling fluxes or sporadic malfunctioning of single BPMs when the fast feedback switched on, sometimes affect the orbit stability.

A software application has been developed to continuously analyze the spectra of orbit positions and corrector currents provided by the fast orbit feedback system (see Fig. 4).

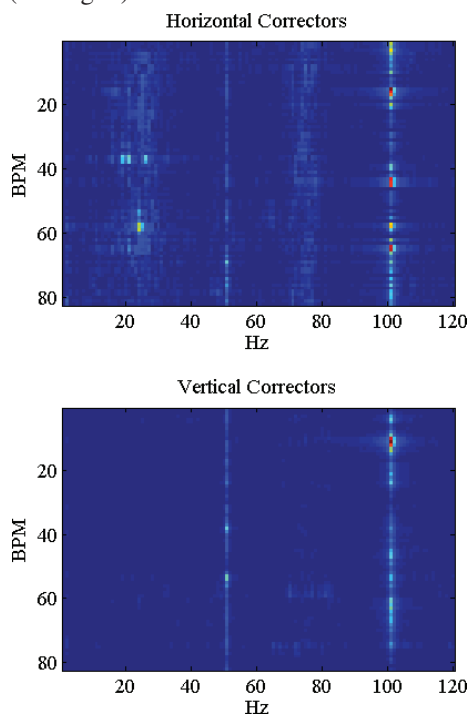


Figure 4: 2D spectra of the horizontal/vertical correctors driven by the fast orbit feedback.

Table 1: Example of spectral analysis of the feedback corrector currents showing noise components above threshold

Corrector	Frequency Hz	Amplitude mA
corr_s2.4 V	100	2.11
corr_s2.3 V	100	1.93
corr_s2.5 V	100	1.69
corr_s3.1 H	100	1.55
corr_s3.2 H	100	1.37

The spectra are continuously analysed and in case of abnormal increase of a noise component with respect to normal values, an alarm is sent to the general alarm system to warn operators in the control room (see Tab. 1).

OPEN ISSUES

The air conditioning control system originally designed to keep the machine and service gallery air temperature stable within $\pm 0.5^\circ\text{C}$, nowadays due to aging, doesn't always guarantee the thermal stability required in order to keep the long term orbit drifts in the sub micron range. In particular, the BPM electronics seems to be one of the most important systems suffering from temperature changes. Day/night temperature excursions, although mitigated by the energy feedback, may change the orbit *rms* by $6\ \mu\text{m}$ during a period of 24h (Fig. 5). The installation of BPM detectors in temperature-controlled cabinets is under discussion while a complete refurbishment of the air-conditioning control system is foreseen in the near future.

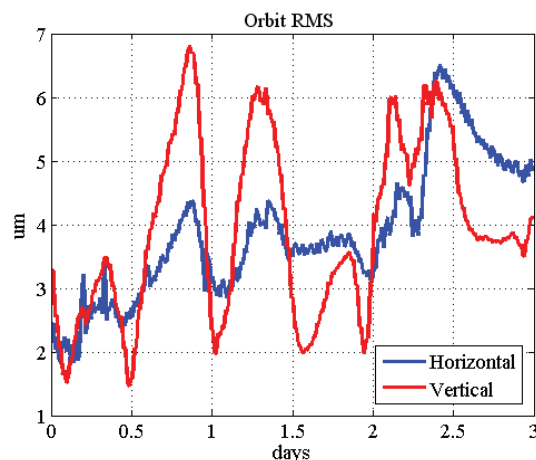


Figure 5: *rms* orbit error during three days.

SUMMARY

Several feedback systems control the main beam parameters and greatly simplify the machine operations. The orbit stability performance achieved is also confirmed by measurements carried out on the beam-lines.

Efforts are going on for better machine monitoring and, when possible, further improvement of the beam orbit stability.

REFERENCES

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- [3] M. Lonza et al., "Commissioning of the ELETTRA Fast Orbit Feedback System", MOPAN024, PAC'07.