COMMISSIONING OF THE ELETTRA FAST ORBIT FEEDBACK SYSTEM

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Abstract

A fast orbit feedback system has been installed at Elettra. It globally corrects the closed orbit at 10 kHz rate using all the BPMs and corrector magnets of the storage ring. Libera Electron has been chosen to upgrade the original detectors in order to provide micrometric accuracy and fast data rate of the beam position measurements. The article reports the experience gained during the commissioning of the system and the first operational results.

INTRODUCTION

The Elettra storage ring is made of twelve achromats each with one long straight section. Eleven of them host Insertion Devices (ID) while one is dedicated to the injection system. Each achromat is equipped with eight rhomboidal button-type Beam Position Monitors (BPM) [1] and seven corrector magnets, except for the one hosting the injection where, due to space constraints, only five correctors are installed. In section 2 and 7 two additional BPMs at both sides of the IDs provide enhanced resolution and accuracy thanks to their low-gap profile and to a BPM position measurement system based on carbon fibre reference columns and capacitive sensors [2]. A total of 100 BPMs and 82 magnets are thus available for orbit correction.

The main sources of orbit distortion are caused by thermal effects. The rhomboidal BPMs are integral part of the vacuum chamber and are fixed to the quadrupole magnets through rigid supports. The expansion of the vacuum chamber due to thermal load produced by synchrotron radiation induces transversal displacements of the BPMs and consequently moves the quadrupoles. Due to the amplification factor, this results in significant orbit distortion especially during a few hours period after a machine refill. To counteract slow orbit drifts, a program running on a control system computer periodically corrects on a local basis the beam trajectory in each achromat keeping constant angle and position at radiation source points [3]. Due to bandwidth limitations only slow drifts can be corrected, while faster disturbances have to be addressed by a fast feedback system. Vibrations of quadrupoles and sextupoles excited by the cooling water flux generate various frequency components around 23 Hz in the orbit noise spectrum. Perturbations created by ID gap changes are compensated by feeedforward systems with dedicated correction coils, however residual orbit distorsions of the order of a few microns can be detected. Finally, spectral lines at 50 Hz and its harmonics are also present in the spectrum.

All of the BPMs have been included in the fast orbit feedback in order to provide detailed closed orbit detection essential for an effective global correction. The BPMs were originally equipped with multiplexed RF electronics that have been recently replaced by digital detectors (Libera Electron, by Instrumentation Technologies) providing position measurements with resolution better than 0.3 μm (2 kHz bandwidth, 100-300 mA current range) and 10 kHz data rate [4].

The corrector magnets employed for slow orbit corrections feature a cutoff frequency of 70 Hz. As an upgrade with faster magnets is not presently feasible and no additional coils can be installed due to severe space limitations, the feedback system makes use of the same magnets and all of them have been integrated into the system.

FAST FEEDBACK SYSTEM

The fast global orbit feedback is a distributed computing system composed of twelve local stations each connected to a number of BPM detectors and corrector power supplies. The same hardware/software platform used in the Elettra control system is employed in the local stations, which consist of VME crates with Motorola PowerPC boards running the Linux operating system and real-time extension [5]. Using such a standard platform facilitated the feedback development and now allows flexibility and eases the maintainability of hardware and software. Moreover, an effective integration of the feedback system into the control system is obtained thanks to the possibility of concurrently running real-time feedback tasks and the Tango control software on the same CPUs.

Beam position data generated by Libera Electron detectors are sent via Gigabit Ethernet links to each CPU board passing through an Ethernet switch. The transmission of Ethernet packets is synchronized between all of the BPM detectors by means of a distributed timing system. The CPU boards share the acquired BPM data through a low-latency reflective memory using fiber optics and calculate the corrections based on errors with respect to a reference orbit. The corrections are eventually converted to analog and sent to the steerer power supplies. The repetition rate of the feedback is 10 kHz while the total latency of the feedback chain is 500 μs.

An additional station, called master station, connected to the reflective memory is dedicated to the storing of synchronized data into a number of circular buffers at different rates. In particular, up to five seconds of orbit and correction data at 10 kHz rate can be recorded and successively downloaded via the Tango control system. From the master station through the same reflective memory it is also possible to synchronously drive the corrector power supplies with arbitrary excitation signals while the recording system concurrently stores BPM data into the buffers.

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FEEDBACK COMMISSIONING

The feedback implementation has been carried out in two phases: upgrade of the existing BPM detectors and installation of the fast feedback infrastructure. The two phases have been accomplished in parallel and gradually during a period of one year with no interruption of the scheduled storage ring operations.

After setting up the fast feedback infrastructure (timing, reflective memory, Gigabit Ethernet links, connection to corrector power supplies, etc.) a number of tests have been executed on the BPMs and steerers to check if their performance were following the expectations. Some effort has been spent to optimize the Libera Electron parameters in order to provide low-noise beam position measurements in close connection with other laboratories using the same detectors [6]. The correctors efficiency has been checked with measurements of the magnets transfer function performed using the fast feedback system itself. The beam can be excited by driving a corrector power supply with sinusoids at different frequencies and by measuring the corresponding orbit oscillations with the BPMs. The results have revealed differences in the response of the magnets. It has been eventually discovered that this fact is due to a loop in the cooling water circuit made of metallic pipes that increases the inductance of the magnets. Given the different configurations of the cooling water system of the magnets, a number of them have cutoff frequency of about 45 Hz instead of the expected 70 Hz. The modification of these magnets to improve their performance is foreseen in the next months. Figure 1 shows the measured frequency response of a corrector magnet with 70 Hz cutoff frequency.

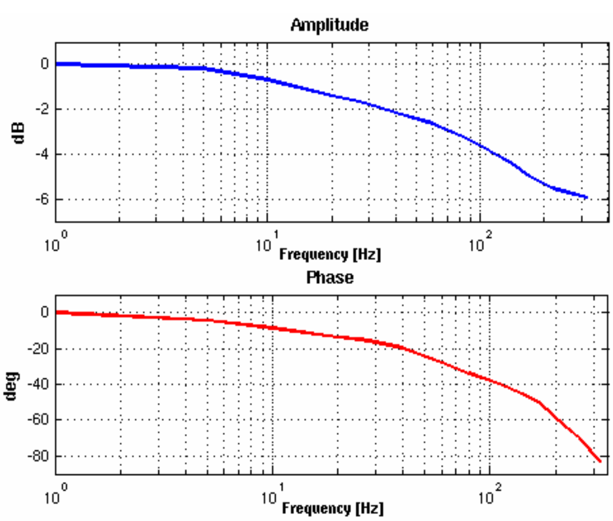

Figure 1: Amplitude and phase response of a corrector magnet measured by exciting it with sinus waves at different frequencies.

After the above tests, the feedback loop has been closed. The adopted global correction algorithm is the Singular Value Decomposition (SVD), while the control algorithm is a Proportional Integral Derivative (PID) regulator. The measured closed loop transfer function, e.g. the efficiency of the feedback in attenuating beam noise components is show in Figure 2. The PID regulator is effective at low frequencies but inevitably excites frequencies above a given threshold (“waterbed” effect).

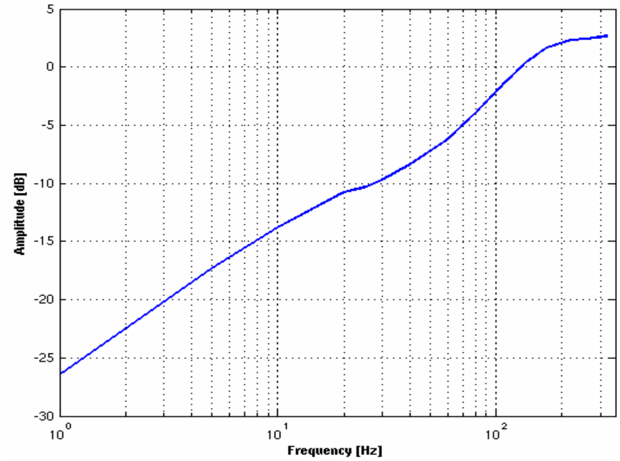

Figure 2: Measured closed loop transfer function (sensitivity function) showing the attenuation of noise components as a function of frequency.

From the analysis of the beam noise spectrum, it can be seen that noise components above 40 Hz are basically harmonics of the 50 Hz, that can be addressed with a number of selective filters in the loop, each dedicated to one of the frequency lines (harmonic suppressors). Figure 3 shows open/closed loop spectra of the beam position using a PID and four harmonic suppressors centered on the main harmonic components. The combination of these two techniques is able to significantly reduce the noise of the beam up to 300 Hz, well beyond the cutoff frequency of the correctors. The incomplete suppression of the 50 Hz harmonics can be explained with the uneven dynamic behavior of the corrector magnets.

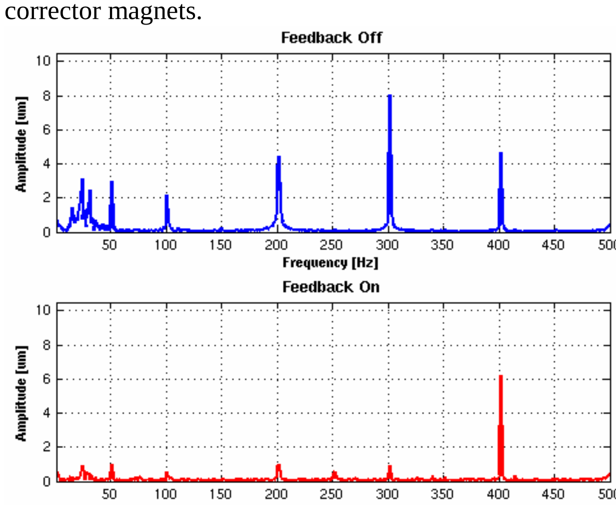

Figure 3: Amplitude spectrum of the horizontal beam position with feedback off and on. The loop is closed with a PID regulator and four harmonic suppressors at 50, 100, 200 and 300 Hz.

The integrated amplitude spectrum of the beam position noise showing the effect of the feedback is depicted in Figure 4.

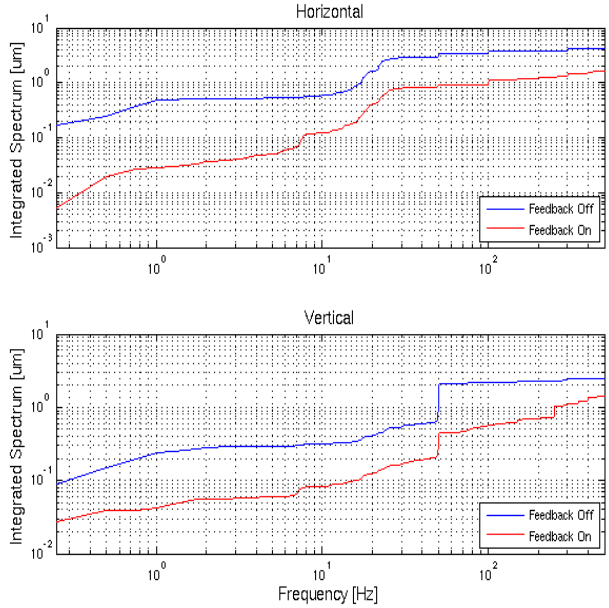

Figure 4: Integrated amplitude spectrum of the beam position noise measured by a BPM with feedback off (blue line) and on (red line).

Preliminary tests have been performed with a photon BPM measuring the vertical position of the photon beam produced by the undulator operating in section 7. During the measurements the beam was perturbed by the electromagnetic elliptical wiggler that was switching the polarity of the horizontal magnetic field with a trapezoidal waveform. The upper/lower plots in Figure 5 are the vertical electron/photon beam positions recorded with feedback off and on.

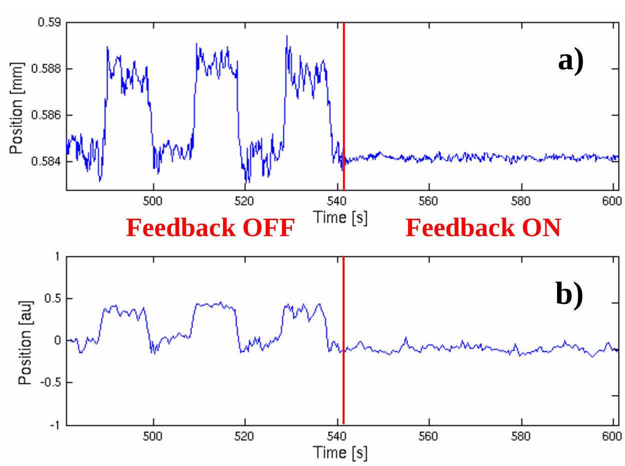

Figure 5: Effect of the feedback in the vertical plane measured by an electron (a) and a photon (b) BPM. The beam orbit is perturbed by the operation of the electromagnetic elliptical wiggler.

Orbit drifts can change the path length of the electrons and thus the beam energy, producing an additional orbit distortion due to dispersion. While it is difficult to counteract this orbit distortion by means of the feedback, a more effective correction can be done by changing the RF frequency. An extended response matrix with an additional "virtual corrector" represented by the RF frequency has been measured and "inverted" with the SVD algorithm. Tests performed with this matrix show that orbit distortions due to energy variations are decoupled from the feedback correction. A slow loop has been implemented to modify the main oscillator frequency according to the required frequency change.

PERSPECTIVES AND CONCLUSIONS

After the achievement of acceptable closed loop performance, some operational aspects have now to be addressed with the aim of putting the feedback in operation during beam line dedicated shifts. Moreover, after the modification of the corrector magnets with low cut-off frequency, further optimization of PID and harmonic suppressors parameters is foreseen in order to minimize the noise *rms* in the frequency range up to 300 Hz.

One of the main remaining concerns is the error in beam position measurements induced by transversal drifts of the BPMs due to thermal effects on the vacuum chamber. Measurements carried out using capacitive sensors confirm that the movement of the BPMs during the few hours following the refill procedure is not negligible. The implementation of a BPM position measurement system to compensate for these errors will be considered only after completion of the new booster injector, which is foreseen by the end of this year [7]. The main objectives of the booster, in fact, are full energy and top-up injection, which should dramatically reduce thermal effects due to variations of beam energy and current.

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