FAST ORBIT FEEDBACK DEVELOPMENTS AT ELETTRA

D. Bulfone, R. De Monte, M. Ferianis, V. Forchi', M. Lonza, Sincrotrone Trieste, Trieste, Italy

Abstract

A number of fast local orbit feedback stations are being sequentially installed at ELETTRA to improve the stability of the electron beam at the Insertion Device (ID) source points. They rely on electron Beam Position Monitors equipped with digital detector electronics that provides high precision and readout rate. The local feedback stations will be integrated in a fast global orbit feedback system, which is the goal of the ongoing developments. The performance and the operational experience gained with the local feedback systems are presented.

BEAM STABILITY

With the installation of the transverse multi-bunch feedback systems [1] and of a super-conducting third-harmonic cavity [2], a beam completely free of multi-bunch instabilities with enhanced lifetime has been obtained at ELETTRA, which has significantly increased the brightness of the photon beam delivered to the beamlines. In order to further improve the quality of the beam, efforts have been focussed on the stabilization of the closed orbit.

Reductions of the coupling and emittance of the machine together with recent progress in experimental techniques and data acquisition rates necessitate orbit stability at Insertion Device (ID) centre in the sub-micron range over frequencies up to several tens of Hz. At frequencies below 0.1 Hz, the main source of disturbance at ELETTRA is the vacuum chamber drift due to the thermal load induced by synchrotron radiation, with its maximum effect after the end of the injection procedure. Frequency components around 23 Hz in the horizontal noise spectrum have been recently investigated and associated to mechanical vibrations of quadrupole magnets, which are produced by the cooling water flow. Despite the feed-forward correction system installed on each of the ID modules, a not negligible orbit distortion can be observed when their gap is changed. The noise spectrum at higher frequencies contains periodic components at the harmonics of 50 Hz that are derived from the mains.

At present, an orbit correction program based on the readings of 96 electron Beam Position Monitors (BPM) corrects the orbit at ID and bending source points with a period of a few minutes.

FAST LOCAL ORBIT FEEDBACK

The local orbit feedback uses two BPMs and four corrector magnets (see Fig. 1) to create a local orbit bump correcting the position and angle of the electron beam at the ID centre on both planes with no distortion to the rest of the orbit. The principle and theory of the local correction are reported in [3].

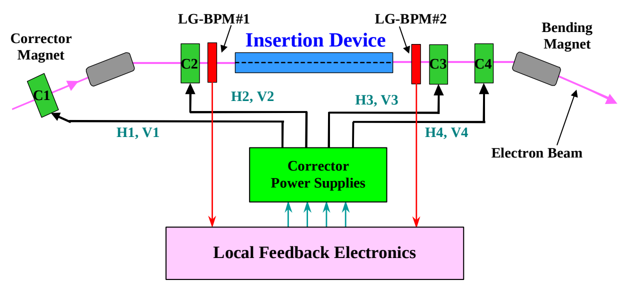

Figure 1: The local orbit feedback layout.

Low-gap BPMs and Digital Receivers

In order to meet the requirements of orbit stability, a new generation of electron BPM [4] has been developed for the fast orbit feedback systems. The four-button BPM is based on a mechanical design that takes advantage of the 14-mm low gap ID chamber. In order to be de-coupled from the rest of the machine, the BPM is equipped with bellows at both sides. The residual mechanical motion is monitored with respect to a reference column made of carbon fibre by a position measurement system featuring 50 nm *rms* accuracy. The measured BPM position is used to compensate the electron beam position readings. These BPMs, named 'low-gap BPMs', have been installed either side of the IDs in section 2 and 7.

The detector electronics consist of an analog front-end plus a four-channel digital receiver VME board that provides the digital values of the signal for each of the BPM buttons. The low-gap BPMs equipped with digital electronics feature sub-micron accuracy beam position measurements at 8 kHz rate.

Processing Electronics

The block diagram of the feedback electronics is shown in Fig. 2. The digital samples generated at 8 kHz rate by the digital receiver modules are passed through the VME-bus to a PowerPC CPU board (Motorola MVME5100) running the GNU/Linux operating system. This board manages the local feedback system and connects it to the ELETTRA control system via Ethernet. In addition, the real-time extension RTAI provides the required deterministic response to execute also the feedback control algorithm on the same CPU [5] with no need of dedicated Digital Signal Processor (DSP) boards. A multi-channel 16-bit Digital-to-Analog Converter (DAC) mezzanine board transforms the calculated digital output samples into analog signals that drive the corrector magnet power supplies. The measured total delay of the feedback system from BPMs to correctors is 330 µs.

In parallel to the feedback processing the PowerPC CPU board is able to store a large amount of beam position data at 8 kHz. The feedback can be remotely controlled from Matlab for data processing and visualization.

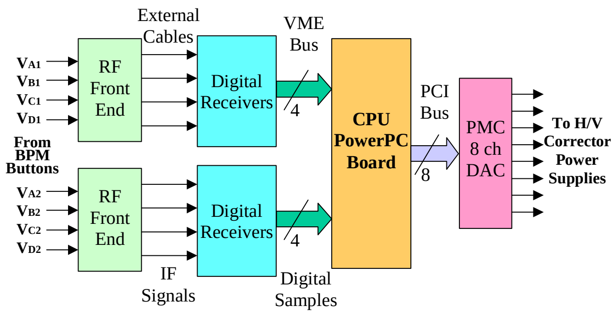

Figure 2: Block diagram of the local feedback electronics.

Correctors

The standard correctors normally used for slow orbit corrections are also employed by the fast feedback system. The magnets present a -3dB cut-off frequency of about 70 Hz, while the eddy currents generated in the stainless steel vacuum chamber by the AC magnetic fields have a negligible effect.

The correction signals generated by the feedback DACs are transmitted to the corrector power supplies by means of shielded differential links to avoid electromagnetic interference and summed to the analog reference signals generated by the DACs of the slow correction system. Table 1 shows the reduced kick range of the feedback with respect to the total range of the magnets, which allows for an excellent resolution of the correction.

Table 1: Corrector ranges of the slow correction and feedback systems.

	Correction Plane	***Current Range***	***Kick Range***
Slow Corr. Component	Horizontal	+/-15 A	+/- 1.8 mrad
	Vertical	+/- 12 A	+/- 2.1 mrad
Feedback Component	Horizontal	+/- 800 mA	+/- 95 µrad
	Vertical	+/- 400 mA	+/- 69 µrad

CONTROL ALGORITHMS

By imposing the condition of orbit bump closure, the two-BPM four-corrector local feedback can be reduced to a two-by-two system with de-coupled channels, where the control algorithms are applied independently on each of them [3].

The basic feedback algorithm is the Proportional Derivative Integral (PID) standard regulator, which is effective on the low frequency components of the noise spectrum. The main limitation of the PID performance is the open-loop phase rotation with frequency due to the corrector magnets. Closed loop simulations using an empirical model of the system have been carried out to optimize the PID parameters in order to reduce the low frequency noise while limiting the enhancement of the spectrum components outside the attenuation band. The performance of the controller measured on the beam agrees with the simulation results, showing a bandwidth of 150 Hz at - 3dB noise rejection.

A different approach, called harmonic suppression, is applied to the harmonics of 50 Hz and exploits the periodic nature of these spectrum components. A digital resonator placed in the loop acts as a notch filter if the open loop phase rotation at the resonance frequency is 360°. Multiple harmonic suppressors working in parallel cancel all of the respective periodic components from the spectrum in a frequency range that can be higher than the open-loop cut-off frequency. Spectra in Fig. 3 have been taken with loop open and closed showing the combined action of the PID controller and four harmonic suppressors.

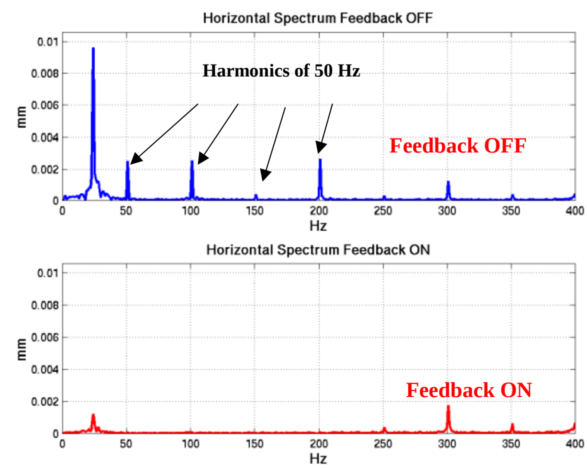

Figure 3: Spectra of the horizontal orbit at one low-gap BPM with loop open/closed using a PID controller and multiple harmonic suppressors centred at 50, 100, 150 and 200 Hz.

RESULTS AND OPERATIONAL EXPERIENCE

Two ID straight sections (2 and 7) have been equipped with local feedback systems. The *rms* of the position (angle) of the source point at the ID centre measured during an 8-hour period in the frequency range from 0 to 10 Hz with the loop closed is 0.15 µm (0.02 µrad) horizontally and 0.06 µm (0.02 µrad) vertically, with the exception of a small number of glitches of 3.1 µm (0.4 µrad) and 3.2 µm (1.5 µrad) peak-to-peak in the horizontal and vertical plane respectively. The *rms* value in the range 10-250 Hz is 0.85 µm (0.13 µrad) horizontally and 0.47 µm (0.14 µrad) vertically.

Experiments have been performed measuring the mirror current on the SuperESCA beam line in section 2. The noise is reduced from 1.2 to 0.3% when the feedback is switched on (Fig. 4). Fig. 5 shows the mirror current measured in a 25-minute period during which a number of IDs have been moved with feedback off/on.

The fast feedback is normally activated at the end of the injection procedure, after a correction at all ID and bending source points by means of an orbit correction program. The corrected horizontal and vertical position values at the low-gap BPMs are then taken as set points by the fast local feedback. In order to avoid interference, the slow orbit correction is disabled in the sections where the fast feedbacks operate.

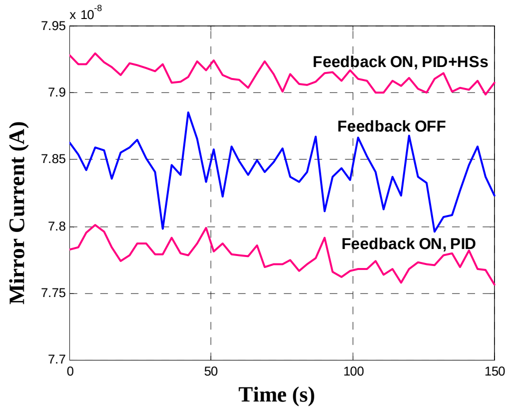

Figure 4: Mirror current measured on the SuperESCA beamline in section 2 with different feedback configurations; with PID and harmonic suppressors activated the noise is reduced from 1.2 to 0.3%.

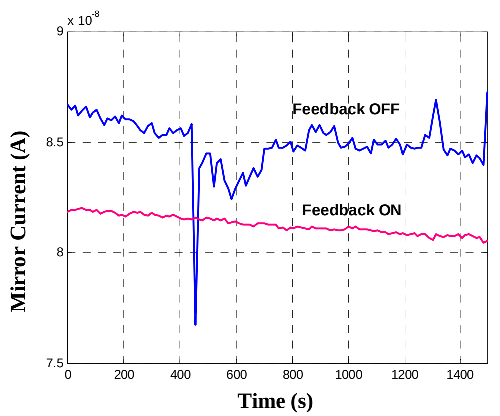

Figure 5: Mirror current measured on the SuperESCA beamline during ID gap changes with feedback off/on.

Given the reduced range of the total corrector current available for the feedback system, large orbit drifts could bring to saturation of the feedback DACs. In order to avoid this event, a slow loop running every minute transfers, through the control system, the mean value of the feedback component to the setting of the slow correction system.

GLOBAL ORBIT FEEDBACK

An orbit correction scheme based on local feedback systems installed on all of the ID straight sections has a number of disadvantages. Local feedbacks correct the orbit at ID but not at bending magnet source points and local corrections cannot guarantee that the orbit does not diverge at locations between local systems. Moreover, cross talk between systems due to leakage of the local bumps, even if irrelevant for two concurrently running systems, could become an issue with many local feedbacks installed.

For the reasons above, the second phase of the fast feedback project consists of the installation of a global orbit feedback system. The local feedback stations have been designed in order to be easily integrated into a global architecture, where a commercial fibre-optic real-time network connects them all. This allows stations to share BPM readings and correction values with a definite low latency and at a high data rate. The existing rhomboidal BPMs equipped with the new digital electronics are included in the global system, which also interfaces to all of the correctors power supplies.

Due to the present space constraints, the installation of additional low-gap BPMs associated with the remaining IDs implies the redesign and subsequent installation of the corresponding straight section vacuum chambers. This process will continue even after the global orbit feedback is completed. When available, low-gap BPMs will be progressively included in the fast global feedback.

CONCLUSION

Two fast local orbit feedback systems, one of which is routinely activated during users shifts, provide sub-micron stability of the corresponding ID source points. The systems are based on BPMs with new mechanical design and digital detector electronics. The combination of the PID regulator with a series of specific harmonic suppressors allows addressing the different components of the beam noise spectrum.

A third local orbit feedback adopting two rhomboidal BPMs equipped with the new digital electronics is also being used in straight section 1 to enhance the stability of the electron beam during the operation of the ELETTRA storage-ring free-electron laser [6].

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