A FAST ORBIT FEEDBACK FOR THE ELETTRA STORAGE RING

M. Lonza, D. Bulfone, V. Forchi', G. Gaio, L. Pivetta, Sincrotrone Trieste, Trieste, Italy

Abstract

A fast global orbit feedback using digital Beam Position Monitor (BPM) detectors has been installed and commissioned at Elettra. The system uses 96 BPMs and 82 steerer magnets to correct closed orbit errors at a 10 kHz repetition rate. The feedback processing is performed by twelve VME stations equipped with commercial CPU boards running the Linux operating system with real-time extension and connected to each other by a low-latency fiber optic network. The system is fully controlled by a Tango based control system. The operational experience and the achieved results are presented. Plans for further improvements of the orbit stability are also discussed.

FAST GLOBAL ORBIT FEEDBACK

A project for the development of a fast orbit feedback started in 2005 with the aim of stabilizing the electron beam orbit of the Elettra storage ring to sub-micron levels. The demanding need of stability of the photon beam delivered to the beam lines requires fast digital loops with many BPMs and corrector magnets to counteract the different sources of closed orbit distortion like thermal drifts, vibrations, power supplies ripple, insertion devices gap changes, etc. The choice was to use all of the existing storage ring BPMs and corrector magnets already adopted for slow orbit correction. The BPM detectors have been upgraded with state of the art electronics (*Libera Electron*, by Instrumentation Technologies d.o.o.) to fulfil the requirements of precise beam position measurements and fast acquisition rate [1]. The analog input of the existing corrector power supplies specifically implemented for feedback purposes was available to drive the corrector magnets. The choice of the processing and communication framework was driven by the following requirements:

- 10 kHz repetition rate with minimized latency
- adoption of standard commercial components
- processing performed by software
- implementation of a number of diagnostic tools
- effective integration into the Tango control system.

The implemented architecture is a distributed processing system made of twelve local stations each interfaced to a number of BPM detectors and corrector power supplies [2]. Crate (VME), CPU board (Motorola PowerPC), operating system (Linux+RTAI) and control software (Tango) of the local stations are the same used in the accelerator control system.

Gigabit Ethernet links connecting the *Libera Electron* detectors to the local stations via an Ethernet switch are used to acquire beam position data at 10 kHz. This low cost standard technology normally employed in local area networks is also suitable for real-time data transmission if UDP packets are used over a dedicated network. Another advantage is that standard instrumentation and widely available software tools can be used for debugging and troubleshooting of possible communication problems.

The particular correction algorithm based on a global approach where the correction values are calculated by multiplying the position errors of all the BPMs by the inverted response matrix, requires a fast low-latency communication infrastructure to share position data among the local stations. A widely used commercial product (GE-Fanuc PMC-5565) implementing the reflective memory technology through fibre optics has been chosen for this purpose because of its performance and ease of use. A master station included in the reflective memory network is in charge of feedback supervision and data acquisition. The master station can simultaneously transmit through the reflective memory the following data to the local stations:

- feedback set point (reference orbit)
- inverted response matrix
- feedback configuration parameters (PID, digital filter coefficients, etc.)
- feedback control commands: close/open loop, freeze/unfreeze, etc.
- time stamps
- output values to drive the corrector power supplies with arbitrary waveforms,

and receive from them synchronous BPM and correction data at 10 kHz.

Clock and trigger signals to synchronize the *Libera Electron* detectors are distributed using a commercial timing system made of fibre optics and VME boards (Event System by Micro-Research Finland Oy).

SOFTWARE ARCHITECTURE

Libera Electron is integrated into the Elettra control system by means of an embedded Tango device server, which provides, through a 100 Mbit/s Ethernet interface, all the basic functionalities including slow (10 Hz) and turn-by-turn acquisition as well as detector configuration. A dedicated Gigabit Ethernet interface supplies low latency position data at 10 kHz to the fast feedback system.

The block diagram of the local station software is depicted in Figure 1. The real-time modules are executed in the Real Time Application Interface (RTAI) kernel space. They include the device drivers of reflective memory, Gigabit Ethernet and DAC boards. The real-time thread is triggered by the Gigabit Ethernet driver through a semaphore and executes the correction and control algorithms. It is also in charge of data recording using a number of circular buffers contained in a 200 Mbytes shared memory. Tango device servers for each of the BPMs and correctors provide the software control

interface. They allow any Tango client to access the data buffers and execute FFTs on 80000 samples providing spectra at up to 10 Hz rate.

The software components of the master station consist of a reflective memory device driver, a real-time thread and a Tango device server implementing feedback management and supervision functionalities. The real-time thread records into circular data buffers 5 seconds of synchronous data at 10 kHz from all of the BPMs and correctors. The data recording can be stopped under given detected conditions, like beam loss or saturation of the feedback loop, allowing for post mortem analysis.

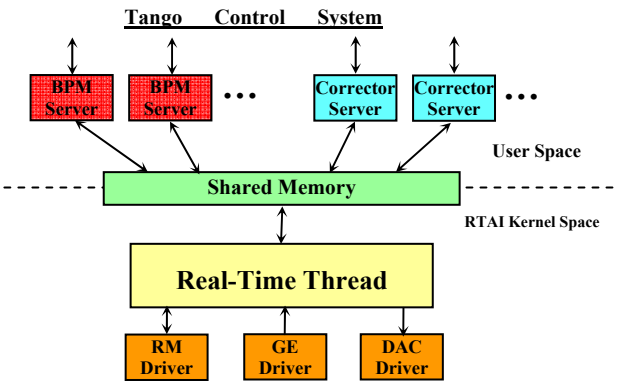

Figure 1: Software architecture of a global feedback local station.

The real-time performance of the system is satisfactory for the feedback purposes. The Gigabit Ethernet links transport data from 10 BPM detectors to the CPU internal memory in less than 10 µs while the reflective memory takes 25 µs to transmit BPM data to all the stations. The feedback processing including matrix multiplication and control algorithm is executed in 21 µs. The total delay of the feedback chain is about 450 µs including a latency of 300 µs due to *Libera Electron*. Given the quite low cut off frequency of the corrector magnets (70 Hz), the latency of the feedback doesn't affect significantly the correction bandwidth.

The choice of running the real-time feedback processing and the Tango control system software in the same CPU has eased the software development and allows an efficient integration of the feedback into the accelerator control system. The load of the local stations CPU due to the real-time tasks is 60-70 %, while the Tango software occupies about 20 % of the CPU in the worst case.

OPERATION, REMOTE CONTROL AND PERFORMANCE

One of the goals of the orbit feedback project was to provide the necessary functionalities and software tools in order to let non-expert people operate the feedback from the control room during beam line dedicated shifts. A number of features have been implemented for this purpose.

The feedback loop can run even with a number of faulty BPMs, which are automatically excluded from the loop by setting to zero the corresponding position error. In the presence of output saturation or severe system malfunctioning, the loop is immediately opened. Moreover, a slow loop running in the master station with a period of ten seconds executes the following automatic actions:

- adjusts the machine radio frequency to correct for horizontal orbit distortions due to changes in the electron path length (dispersion loop)
- in case of beam loss, opens the loop and execute the necessary actions to prepare BPM detectors and feedback system for a new injection
- checks if the feedback DACs are close to saturation and, if so, transfers their values to the corrector control system DACs. If this is not possible, it freezes the DAC values and opens the loop.

A Tango server performs the necessary procedures to switch on/off the feedback. As a result, the control room panel routinely used by the operators is very simple and features only three commands (ON/OFF/STANDBY), a status window and some reading widgets showing relevant data of the feedback performance. If necessary, a number of additional more specific panels can be launched (Figure 2).

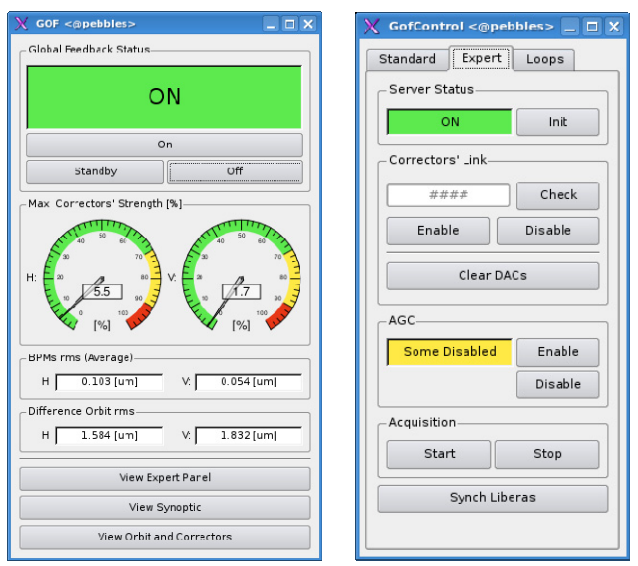

Figure 2: Operator (left) and expert (right) control panels of the fast global orbit feedback.

The fast orbit feedback system is in operation during users shifts since the beginning of September 2007. After a new injection and energy ramping to 2 or 2.4 GeV, an orbit correction program is used to restore to required values the position and angle of the electron beam in the insertion devices and bending magnets. The feedback is eventually activated taking the corrected reference orbit as a set point for the loop.

Commissioning results and closed loop performance are reported in [3]. The adopted global correction algorithm is the Singular Value Decomposition (SVD)

with singular value reduction, while the control algorithm is a Proportional Integral Derivative (PID) regulator with the addition of a number of notch filters applied to the harmonics of the 50 Hz. The combination of these two control techniques allows reducing noise components at frequencies higher than the corrector cut off frequency. Table 1 summarizes the effect of the feedback in reducing the average beam position *rms* in two different frequency ranges.

Table 1: Average beam position *rms* (µm) with feedback off/on in the 0-5 Hz and 0-200 Hz frequency ranges.

I=320mA	0 - 5 Hz	0 - 5 Hz	0 - 200 Hz	0 - 200 Hz
E=2GeV	Horizontal	Vertical	Horizontal	Vertical
FB off	0.4	0.15	3.5	2.1
FB on	0.1	0.06	1.1	0.7

Figure 3 shows the average beam position *rms* during a period of 38 hours in which the beam current at 2 GeV decays from 300 to 120 mA. The slow increase of the noise level visible on the right side of the plots is due to the worsening of the detectors resolution at lower currents.

The trend of the orbit error *rms* with respect to a reference orbit with feedback on is reported in Figure 4. The analysis of the measured orbit drift in the period following the injection and energy ramping leads us to the conclusion that a considerable part of it is not due to real orbit distortions but to the movement of the BPMs driven by thermal drifts. Measurements of the BPM position carried out in the past years confirm this hypothesis. These unreal orbits are only partially corrected by the feedback, especially if singular value reduction is employed in the SVD. Since a quite low number of singular values are normally used in operation to avoid saturation of the feedback outputs, the uncorrected orbit error can be quite large. An improvement to this situation is expected during 2008 after completion of the new booster injector that will allow full energy and top-up injection.

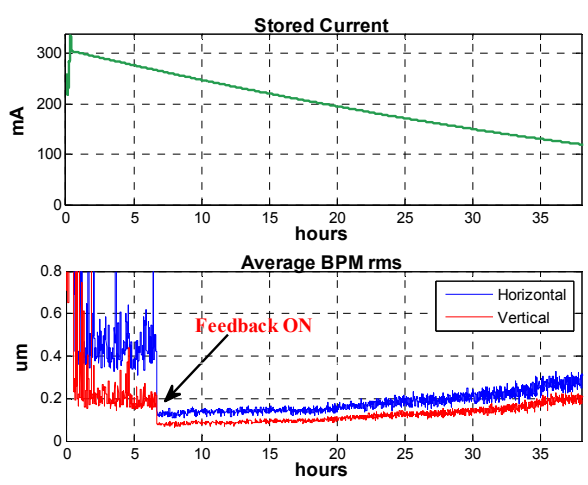

Figure 3: Average beam position *rms* using 10 Hz data of all the BPMs. The feedback is switched on at 270 mA.

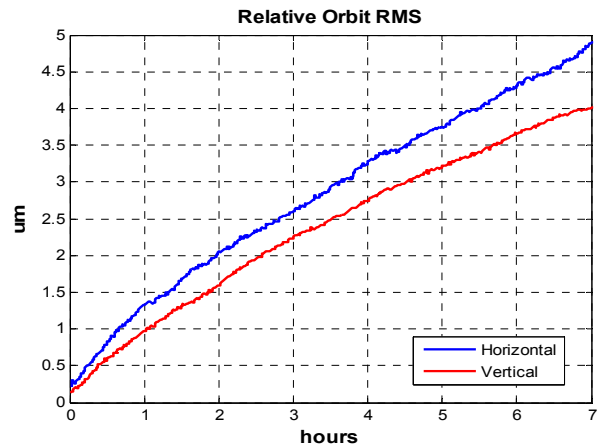

Figure 4: Orbit error *rms* with respect to a reference orbit with feedback on in a time period of 7 hours after injection and energy ramping to 2 GeV.

CONCLUSIONS AND OUTLOOK

Tests carried out with the beam lines users confirm that they benefit from the enhanced photon beam stability. Measurements using beam line diagnostics are going on to further optimize the feedback parameters. In particular, the techniques of singular value reduction and weighting of correctors and BPMs will be better explored.

Although good orbit stability has been achieved with the fast orbit feedback, further improvements are still possible by including in the loop additional high-accuracy BPMs dedicated to stabilizing the beam position at the photon source points. Low-gap electron BPMs installed close to the insertion devices [4] and photon BPMs could notably enhance the quality of the photon beam delivered to the beam lines.

REFERENCES

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