BPM DETECTORS UPGRADE FOR THE ELETTRA FAST ORBIT FEEDBACK

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Abstract

The project of a fast feedback system to stabilize the closed orbit of the Elettra storage ring is in an advanced stage. All of the existing BPMs have been equipped with new digital detectors in order to provide precise and high rate position measurements to the feedback system. A new beam position interlock system has also been installed to protect the vacuum chamber from synchrotron radiation produced by insertion devices. This paper presents features and performance of the new orbit measurement system and reports some preliminary results of the feedback commissioning.

INTRODUCTION

In the past years of operation at Elettra orbit control has been performed by slow loops correcting every few minutes the orbit at Insertion Device (ID) and bending magnet source points. Two fast local feedback systems based on dedicated low-gap BPMs located at both sides of the IDs in sections 2 and 7 have also been installed and operated during users shifts. In 2005 a new project for the development of a fast global orbit feedback including all of the 96 BPMs and 82 corrector magnets of the storage ring has been started [1]. The original BPM electronics providing orbit position measurements at 200 Hz data rate with *rms* resolution of 2.5 μm has been gradually replaced during 2006 with new digital detectors. The chosen product is Libera Electron manufactured by Instrumentation Technologies [2]. Using the existing rhomboidal BPMs, in the 100-320 mA current range, Libera Electron provides position measurements with *rms* resolution of 0.3 μm at 10 kHz rate and 4 μm in turn-by-turn mode. At slower data rate, i.e. 10 Hz, the achievable *rms* resolution can be as low as a few tens of nm.

BPM DETECTORS UPGRADE

The upgrade of the 96 existing BPM detectors (plus four low-gap BPMs) with Libera Electron has been a gradual process lasted several months and performed during dedicated machine shifts. In order not to disrupt the beamline operations, an empirical offset calibration procedure has been adopted with the objective of reproducing the electron beam position during the users shifts immediately following the upgrade of a group of detectors. The procedure consists in measuring the position of a "reference orbit" with the old detectors, connecting the new detectors and calculating appropriate offsets based on the new position measurements. The offsets are eventually applied to the position readings.

Libera Electron detectors have been integrated in the Elettra control system using an embedded Tango server, running in the internal Single Board Computer (SBC) [3], which is connected to the control system network by means of a 100 Mbit/s Ethernet link. During the upgrade period, Elettra has been operated using a heterogeneous BPM system made of old and new detectors. A server program was arranged to acquire data from all the detectors, merge them together and provide homogeneous closed orbit measurements to the control room client programs. Having finished the upgrade, the new BPM acquisition system, which is completely based on Tango, is able to provide a closed orbit measurement in less than 50 ms.

POSITION INTERLOCK SYSTEM

ID synchrotron radiation generated by a badly centered beam can seriously damage the vacuum chamber. After the upgrade, the position interlock system based on the old BPM detectors had to be replaced. The new protection system relies on the BPMs located at the ends of each of the twelve IDs. It adopts a redundant architecture using both the Libera Electron and a newly developed interlock unit equipped with diode detectors.

Libera Electron features an interlock functionality based on absolute position readings. The interlock output is activated as soon as the x/y beam positions exceed given thresholds. Since the interlock uses the 10 kHz data stream, a low pass filter with programmable cut-off frequency can be included to avoid undesired interlock events due to fast spikes.

The interlock units are based on Schottky diode detectors that process the RF signals from the BPM buttons [4]. Diode detectors have the advantage of having high impedance inputs and can be connected to the same BPM buttons used by Libera Electron without significantly interfering with their operation. The resulting base-band signals are then digitized and processed by a micro-controller that calculates the position error with respect to a reference orbit taken when the ID gap is closed. In case the unit detects a potentially dangerous trajectory, the interlock output is activated.

Libera Electron detectors and interlock units are connected to a dedicated Programmable Logic Controller (PLC). The architecture of the system is depicted in Figure 1. When the program running in the PLC detects that at least one of the Libera Electron or interlock units is in alarm, and if the corresponding ID is closed and the stored current is higher than 20 mA, it dumps the beam by interrupting the RF voltage in the accelerating cavities for

4 ms. The PLC is also connected to the control system through an Ethernet TCP/IP interface.

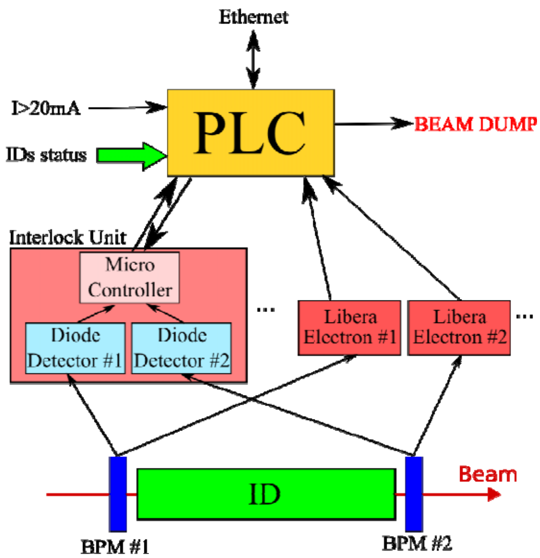

Figure 1: Block diagram of the position interlock system.

BEAM DIAGNOSTIC TOOLS

The global orbit feedback architecture consists of twelve local stations, one for each machine section, and a master station dedicated to global data collection and feedback supervision. The stations are based on VME PowerPC boards running the Linux operating system with real-time extension. The thirteen stations share data by means of reflective memory cards connected by a ring of fibre optics. Each local station collects fast position data at 10 kHz rate from Libera Electron detectors by means of a gigabit Ethernet interface and stores them into the reflective memory. Position errors with respect to a reference orbit are then processed to generate the feedback correction values that are eventually applied to the corrector magnets power supplies via analog links. Each of the twelve stations is in charge of the BPMs and correctors of one machine section. The correction values are also stored in the reflective memory allowing every station to know the whole orbit position and feedback corrections in real-time. A distributed timing system based on VME cards and fibre optics is used to deliver synchronization signals and trigger commands to the local stations.

As a complement to the global orbit feedback a number of diagnostic tools have been developed that take advantage of the fast feedback infrastructure.

Data Recording

A configurable system allows each station to store position and correction data in a number of circular buffers. In the present configuration, each local station stores eight seconds of data at 10 kHz and five days at 1 Hz rate, while the master station stores five seconds of synchronous orbit and correction data at 10 kHz. In the same buffers the status of the feedback components are also recorded to detect and keep track of any anomalous event. By means of the Tango control system, data in the buffers can be downloaded by client programs like graphical panels, machine physics applications and Matlab. Figure 2 is a 3-D plot displaying the amplitude spectrum of each of the 96 BPMs. Spectral components at 23 Hz (quadrupole magnets vibrations) and harmonics of the 50 Hz (from the mains) can be clearly observed.

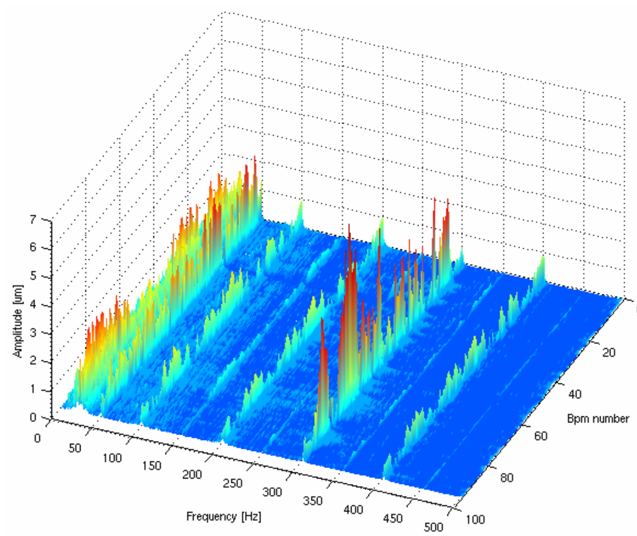

Figure 2: 3-D plot of BPMs amplitude spectra.

Figure 3 shows the control panel of a BPM. Besides the relevant information of the BPM itself, the panel can display horizontal/vertical position data recorded at different rates and plot real-time beam position spectra with 10 Hz refresh rate.

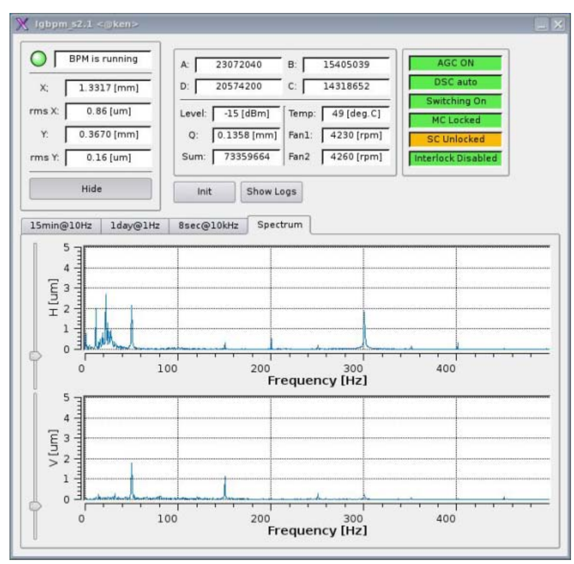

Figure 3: Control room panel of one BPM with real-time position spectra refreshed at 10 Hz rate.

Post Mortem Analysis

The buffering system on the master station implements a mechanism that stops the data acquisition under given conditions, like low BPM sum signal, saturation of the feedback loop, acquisition errors, etc. One use of this feature is the automatic detection of beam losses and acquisition of post-mortem data from the fast and slow buffers. An example is reported in Figure 4. The system automatically detects a beam loss due to an interruption of the RF voltage in the accelerating cavities by monitoring the sum of the button signals on a given number of BPMs and consequently stops the acquisition. The 3-D plot shows the evolution of the horizontal orbit when the RF voltage is switched off.

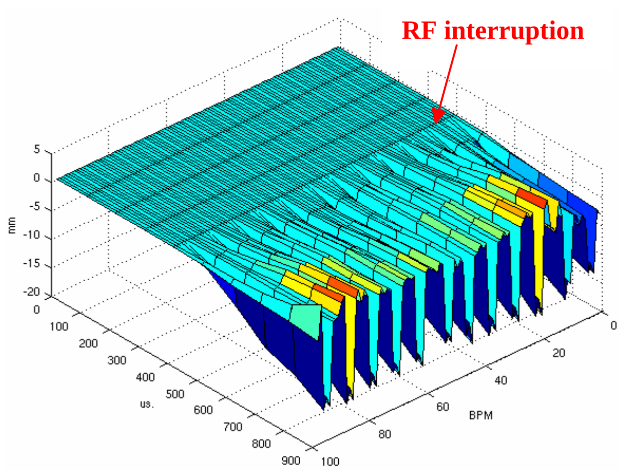

Figure 4: Post mortem data displayed in a 3-D plot: evolution of the horizontal closed orbit after interruption of the RF voltage in the accelerating cavities.

Arbitrary Waveforms Generation

The master station is able to synchronously drive all the corrector magnet power supplies in real-time at 10 kHz using pre-generated waveforms. This feature can be used to characterize the dynamic behaviour of the system by measuring, for example, open/closed loop transfer functions or responses to given excitations. Square and sinusoidal waveforms have been used during the commissioning of the fast feedback to measure the time and frequency domain responses of the corrector magnets.

OPERATIONAL EXPERIENCE

The installation of the new BPM detectors affects many aspects of the day-by-day operations of the storage ring. Slow orbit correction programs benefit from the improved resolution and stability of the beam position measurements and perform more precise orbit corrections. The increased orbit acquisition speed allows performing global orbit corrections in less time, although the maximum repetition rate is still limited by the slow setting of the corrector magnets, which is performed via the power supplies control system interface. The availability of the above mentioned diagnostic tools opens the door to unprecedented opportunities for machine physics studies, investigation of beam noise sources and searching of malfunctioning machine components, with the objective of improving the quality and efficiency of the whole synchrotron light source.

FIRST CLOSED LOOP RESULTS

After the installation of the fast feedback infrastructure, a number of machine shifts have been dedicated to the global feedback commissioning. The feedback loop was successfully closed for the first time using a standard PID regulator and the effects evaluated exploiting the built-in diagnostic features. The PID reduces the noise components up to a frequency of about 100 Hz. The possibility of triggering the post mortem buffers at saturation of the correction values has been a powerful tool for understanding the reasons of unforeseen closed loop instabilities due to software bugs or malfunctioning hardware components. A plot showing the reduction of the horizontal beam position noise at low frequencies (10 Hz data acquisition) when the feedback is activated is shown in Figure 5. The orbit position measurements have been taken from a BPM not included in the feedback loop and specifically used to measure the performance of the feedback.

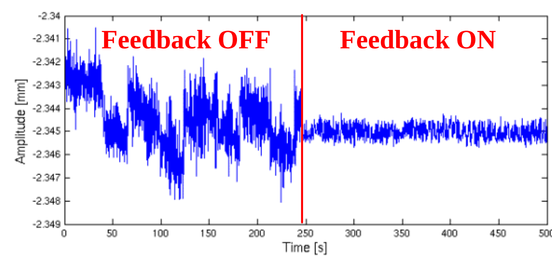

Figure 5: Horizontal beam position measured by a low-gap BPM with feedback off/on.

CURRENT STATUS AND OUTLOOK

The upgrade of the Elettra BPM detectors with digital devices has been completed. The gradual replacement of the existing BPM electronics and the integration of the new devices in the Elettra control system have carried negligible inconvenience to the machine operations and the beam line experiments.

The fast feedback loop has been successfully closed using a PID controller. The commissioning of the feedback will continue with the testing and optimisation of harmonic suppressors, which reduce the periodic components of the noise spectrum as well as with the setting up of the operational procedures for the utilization of the feedback during the users beam time.

REFERENCES

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