STATUS OF THE ELETTRA GLOBAL ORBIT FEEDBACK PROJECT

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Abstract

A fast digital feedback system is under development to stabilize the electron beam closed orbit at the Elettra storage ring. In view of the implementation of the feedback, the existing orbit measurement system is being upgraded to allow for better accuracy in the beam position measurement and higher acquisition rate. A global correction algorithm running on a number of distributed processing units will correct the orbit using all of the storage ring steerer magnets. The status of the project development is given in this article.

INTRODUCTION

The necessity of feedback systems to control the closed orbit in third generation light sources, characterized by low emittance electron beams, is driven by the demanding need of position stability and reproducibility of the high brightness photon beams delivered to the beam lines. Orbit control at the Elettra light source is presently performed by a correction procedure running on a control room computer every five minutes, which keeps the orbit at the eleven IDs (Insertion Devices) and five bending magnet source points within the tolerance of 5μm/5μrad with respect to a previously established reference orbit [1]. This correction scheme can properly counteract slow orbit motions and drifts due to thermal effects. With no correction, orbit position changes of up to 100 μm in the horizontal and 30 μm in the vertical plane have been measured in the ID straight sections in a two hours period after a machine refill. Faster orbit disturbances are mainly generated by ID gap changes, by vibrations of the quadrupole magnets (spectrum component at 23 Hz) and by ripple of the magnet power supplies (50 Hz and harmonics). To address these noise components we started the installation of a number of local orbit feedback systems in the straight sections with the goal to eventually integrate them into one global feedback [2]. Having considered the obsolescence of the BPM detectors, an upgraded global orbit feedback design has recently been developed that uses new BPM electronics.

BPM DETECTORS

As the original multiplexed RF electronics operating since 1992 at Elettra [3] cannot provide the resolution and the data rate required by the feedback system, the rhomboidal button-type BPMs of the storage ring will be equipped with new detector electronics. The commercial product selected for the upgrade is called Libera Electron, manufactured by Instrumentation Technologies [4]. These devices will provide closed orbit measurements both to the control system and to the fast global feedback system.

Libera Electron is a standalone device composed of a RF analog front-end, four A/D converters, a FPGA and a Single Board Computer (SBC). The electron beam position is determined by sampling at 125 Msample/s the signals from the four BPM buttons and by processing the samples in a multiple-stage filtering and decimation scheme. Different data paths provide position data at 10 Hz (slow acquisition), at 10 kHz (fast acquisition) and at the machine revolution frequency (first-turn and turn-by-turn acquisition). The main requested performance parameters with reference to the Elettra users mode of operation are *rms* resolution of 0.5 μm in fast acquisition mode (2 kHz bandwidth) and beam current dependence of 3 μm in a 100 to 320 mA range. The relative masurement error with different filling patterns (e.g. single-bunch, few-bunches and 20 to 100% of consecutive filled buckets) is max 4 μm, while the long term stability over an 8-hour period is 2 μm.

The SBC features a StrongArm microprocessor running the GNU/Linux operating system and a 100 Mbit/s Ethernet port. The Tango control system software [5] has been ported to this platform in order to ease the integration of the Libera Electron devices with the accelerator control system. All of the detector functionalities, including configuration and data acquisition, have been implemented in a Tango Device. This work is the result of a joint collaboration between laboratories belonging to the Tango community.

Fast serial links connecting the internal FPGA to Small Form-Factor Pluggable (SFP) connectors on the front panel can be used to provide low latency closed orbit data at 10 kHz for fast feedback purposes. Several standard protocols can run over these physical links. A development is underway at Elettra to implement the Gigabit Ethernet protocol.

BPM UPGRADE PROGRAM

The original BPM system is based on VXI boards, each serving two BPMs, hosted in twelve crates. Control room applications can get the whole closed orbit from a Local Process Computer (LPC) that collects BPM data from all of the VXI crates using a field-bus connection.

Upgrading of the 96 storage ring BPM detectors will be done gradually during a period of six months including four machine shutdown periods. Particular attention is given to provide a perfectly working BPM system at every machine startup in order to assure a smooth operation of the accelerator in the following periods dedicated to the users.

At each shutdown period a number of new detectors are installed and attached to the control system network, then the calibration procedure is carried out. At the beginning of the following machine run, the upgraded BPMs are tested with the beam and the orbit correction programs are verified. In order to allow for a transparent operation of the control room programs in the presence of a

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heterogeneous BPM system, a server program running on a control system computer collects position data from the old and new detectors and merges them into a single closed orbit array (see Figure 1). Whenever new detectors are added, the server is reconfigured and restarted.

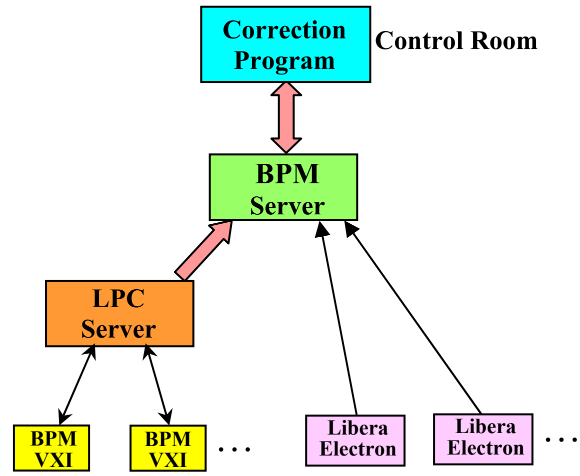

Figure 1: Block diagram of the closed orbit acquisition system that allows for a transparent operation of control room programs in the presence of old and new BPM detectors.

At Elettra, a fast orbit interlock based on the original BPM system protects the vacuum chamber from being hit by synchrotron radiation in the event of a strongly distorted orbit inside the IDs. In order to provide the same protection after the upgrade of the BPM electronics, a new interlock system that operates independently from the Libera Electron detectors has been designed. The new orbit interlock system is made of a number of distributed local units, each dedicated to one ID. The units rely on Schottky diode detectors that provide base-band signals proportional to the amplitude of the RF signal from the BPM buttons. The base-band signals are then converted to digital and processed by a micro-controller to calculate horizontal and vertical beam positions. As no additional BPMs dedicated to the interlock system are available, the interlock units are connected to the same BPM buttons in parallel to the Libera Electron detectors, whose measurements are negligibly affected thanks to the high impedance inputs of the diode detectors. The electron beam positions measured by the BPMs upstream and downstream each ID are used to calculate the angle of the emitted radiation. If this value exceeds the threshold limits, the stored beam is killed. The interlock units will be installed following the schedule of the new BPM detectors.

FAST FEEDBACK SYSTEM

All of the 96 BPMs and 82 corrector magnets of the Elettra storage ring will be included in the fast feedback system, with the addition of two couples of low-gap BPMs [6] already installed in section 2 and 7. The feedback system consists of twelve VME-based stations each handling the BPMs and correctors of one machine section. The stations are equipped with Motorola PowerPC CPU boards (model MVME6100) running the GNU/Linux operating system with the RTAI real-time extension [7] and the Tango control system software. A reflective memory fibre optic network connects together the twelve stations to share BPM position data in real-time. A thirteenth station is included in the network to perform supervision tasks, global data acquisition and real-time processing at the feedback rate, allowing for additional feedback and machine diagnostics applications.

Clock and trigger signals to synchronize all of the Libera Electron detectors will be distributed from a single point using a fibre optic timing system.

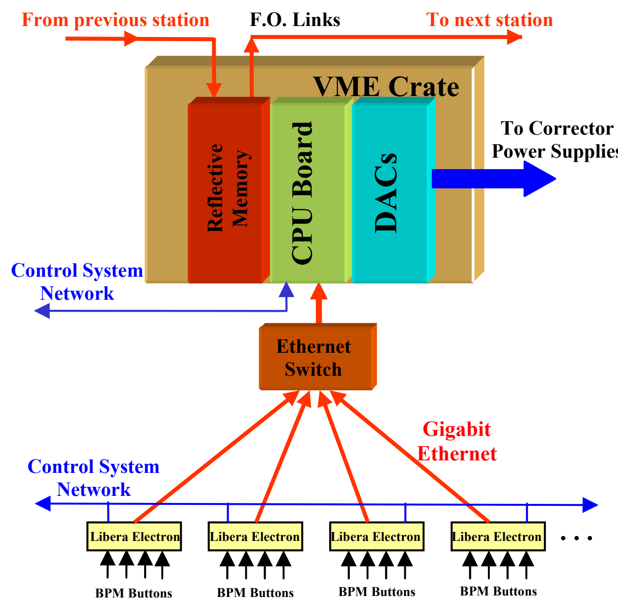

Figure 2: Layout of one of the twelve stations of the fast global orbit feedback.

Each Libera Electron generates small Ethernet packets containing position data at the feedback rate. A commercial Gigabit network switch at each location is used to serialize the packets and send them to the second Ethernet port of the Motorola CPU board. A standard Ethernet Linux driver has been opportunely modified to directly manage raw Ethernet packets in real-time. The position data are then transmitted to the other stations via the real-time fibre optic network. Once the data of all the BPMs have been received by each station, they are processed to calculate the correction values that are eventually converted into analog signals by a number of digital-to-analog converters (DAC). The corrector power supplies feature an analog input dedicated to the feedback that is summed to the main reference input used by the control system to set the current value. The corrector kicks available for the feedback at the energy of 2 GeV are ±95 μrad in the horizontal and ±69 μrad in the vertical plane.

The data path between BPM detectors, CPU, reflective memory, processing task and the DACs has been thoroughly optimized to reduce the total latency time, which can affect the closed loop bandwidth and stability margin. With the chosen feedback repetition frequency of 10 kHz, the maximum estimated latency of the feedback chain is 500 μs. The other factor limiting the feedback performance is the open loop bandwidth that is dominated by the cutoff frequency (about 70 Hz) of the combined horizontal/vertical corrector magnets. The closed loop attenuation bandwidth using a Proportional Integral Derivative (PID) regulator is expected to be about 150 Hz, which is sufficient to attenuate orbit drifts and disturbances due to mechanical vibrations and ID gap changes. Higher-frequency periodic noise components, e.g. the harmonics of the 50 Hz derived from the mains, will be suppressed up to the frequency of 300 Hz by the use of digital selective filters placed in the loop [2].

GLOBAL ORBIT CORRECTION

The fast feedback will correct closed orbit errors with respect to a reference orbit determined by a correction program on the basis of the required beam positions and angles at the ID and bending magnet source points. The orbit correction algorithm chosen for the fast feedback system adopts a global approach based on an opportunely inverted response matrix. One advantage with respect to a multiple local correction approach is that the orbit distortion produced by localized error sources is effectively corrected using nearby steerers and doesn't propagate on the whole orbit, thus minimizing the total correctors strength. On the other hand, if some BPMs or steerers are unusable, the correction can work anyway using the remaining ones even if at the cost of a slightly reduced efficiency.

Studies have been carried out using a machine simulator (Accelerator Toolbox [8]) to evaluate the correction efficiency of different variants of the Singular Value Decomposition (SVD), including singular values reduction and weighting algorithms [9]. Figure 3a is the plot in descending order of the response matrix singular values: the dramatic reduction of the values above the 48th element suggests that many of them can be neglected to optimize the strength of the correction magnets with no considerable reduction of the correction efficiency. This has been verified with simulations by measuring the residual orbit distortion after a global correction with an increasing number of singular values retained in the matrix inversion: the results are reported in Figure 3b.

Further global orbit correction experiments have been performed in the Elettra storage ring to verify the correction efficiency of the SVD algorithm and to measure the strength required to the steerer magnets in the presence of real orbit distortions. Results show that the available correctors range is sufficient to correct most of the orbit distorsions. Only slow drifts, mainly caused by thermal load on the vacuum chamber, can lead to feedback outputs saturation. To overcome this problem a slow loop will be implemented that periodically calculates the mean of the correction values and transfers them to the main corrector settings through the control system.

Horizontal off-energy orbits due to changes in the path-length will be determined and eventually corrected by changing the RF frequency.

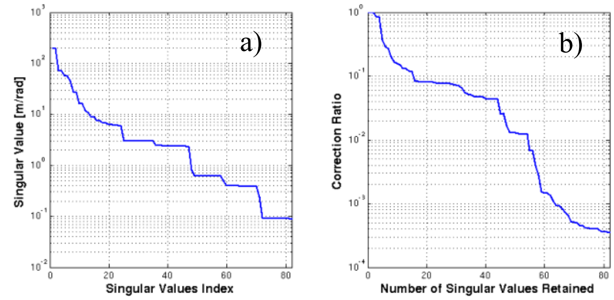

Figure 3: a) Singular values of the response matrix in descending order. b) Ratio between the *rms* of the residual and the original orbit distortion as a function of the number of singular values retained.

CURRENT STATUS AND OUTLOOK

The upgrade of the BPM detectors has begun in the last April shutdown and will continue till the end of the year. During the second half of 2006 the fast feedback infrastructure (VME stations, fibre optics, connection to the corrector power supplies, etc.) will be installed. The commissioning of the feedback system will follow during the first quarter of 2007.

A measurement campaign is underway to survey the transverse movement of the rhomboidal BPMs during standard machine operations. The expansion of the vacuum chamber due to synchrotron radiation heating moves the BPMs horizontally inducing errors in the beam position measurements. Depending on the results of the measurements, the installation of a BPM position measurement system will be considered.

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