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DESIGN OF A FAST GLOBAL ORBIT FEEDBACK SYSTEM FOR THE ELETTRA STORAGE RING

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ABSTRACT

Following the installation of a number of fast local orbit feedback systems, a global orbit feedback has been designed that will take advantage of all of the Beam Position Monitors (BPM) and corrector magnets of the ELETTRA storage ring. The existing beam position measurement system will be upgraded with digital detector electronics providing position measurements with sub-micron resolution and fast data rate. A distributed processing system based on twelve stations equipped with standard VME CPU boards will share position data by means of a real-time fiber optic network. This article describes the architecture of the system and the results of simulations carried out using a model of the machine.

INTRODUCTION

At ELETTRA, beam position stability requirements have been addressed in the past years by the use of local feedback systems based on dedicated Low Gap BPMs. Two of them, installed in ID (Insertion Device) straight section 2 and 7 are currently operating during users shifts. Remarkable sub-micron/microrad beam stability at the ID center has been achieved in a 0-250 Hz frequency range thanks to the employment of a PID (Proportional Integral Derivative) standard regulator together with dedicated selective filters centered on the periodic components of the noise spectrum [1]. Figure 1 shows the effect of the local feedback when the loop is closed.

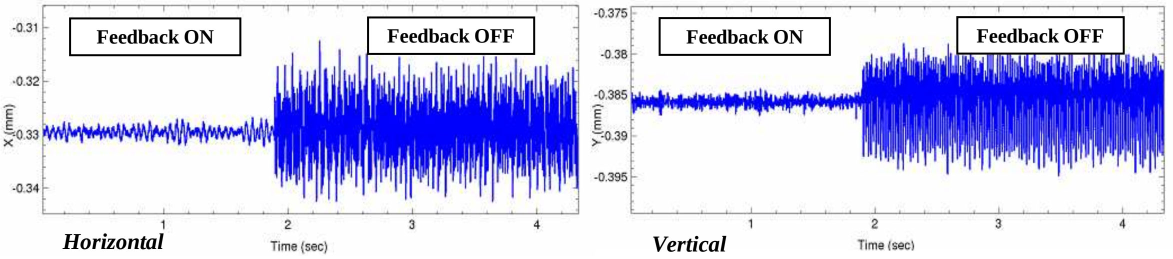

Figure 1: Horizontal and vertical beam position (low-pass filtered at 250 Hz) measured by a Low-Gap BPM in section 2 with feedback ON/OFF. The feedback reduces the *rms* of the beam angle at the ID center below 0.2 μrad in both the horizontal and vertical plane.

All ID and bending magnet source points would need in principle to be stabilized by local feedbacks in order to guarantee transversally stable radiation beams to all of the 21 beamlines. The increased number of local loops and the risk of interference between them led us to consider a global correction scheme, which has the additional advantage of being more effective in correcting orbit distortions with optimized corrector strengths. Moreover, a global feedback system employing an opportunely inverted response matrix offers more flexibility in the implementation of correction algorithms, being able to perform “flat” global correction, weighted correction, local closed bump correction and even more sophisticated schemes if necessary.

A fast feedback system correcting globally the orbit at up to 10 kHz repetition rate has been designed, which makes use of twelve VME based local stations connected together by a real-time fibre-optic network to share BPM data. Each local station manages the BPMs and correctors of one machine section.

BPM SYSTEM UPGRADE

The original closed orbit measurement system, operating at ELETTRA since 1992, consists of 96 button-type rhomboidal BPMs and multiplexed RF electronics based on VME/VXI boards [2]. Their acquisition rate and resolution are not sufficient to achieve the orbit stability goals required to the fast global feedback system. On the other hand, the installation of additional BPMs dedicated to the global feedback is not feasible due to the lack of space along the vacuum chamber. These considerations led us towards a complete upgrade of the existing RF electronics while keeping the rhomboidal BPMs. All of the 96 BPMs will be equipped with state-of-the-art digital detection electronics, providing beam position measurements to both the ELETTRA control system and the fast global orbit feedback. Required features include: slow (10 Hz) and fast (up to 10 kHz) closed orbit acquisition, turn-by-turn and first-turn orbit measurements, synchronized and triggered operations.

Instrumentation Technologies [3] has recently developed a new detector called "*Libera*", a 19-inch standalone box with internal digital signal processing capabilities that samples the RF signals from the BPM buttons and down-converts them to base-band. Beam position data are provided by means of a number of external digital links. The design presented below is based on this option.

Each *Libera* device, which features an internal CPU running the GNU/Linux operating system, will be connected to the ELETTRA control system network by means of a 100 Mbit/s Ethernet link. A dedicated Tango [4] device for each *Libera* will allow BPMs configuration, monitoring and slow (10 Hz) closed orbit acquisition. Turn-by-turn data at the revolution frequency rate will be stored in the internal memory and eventually downloaded through the same interface.

FEEDBACK SYSTEM LAYOUT

A total of 96 BPMs and all of the 82 storage ring corrector magnets (each equipped with horizontal and vertical coils) will be included in the fast global feedback.

The system consists of twelve VME based local stations (Figure 2 shows the layout of one of them), each handling eight BPMs and seven corrector magnets, except for the station located at the injection section which has five magnets. Each VME crate is equipped with a Motorola PowerPC CPU board running Linux and the Tango control system software that interfaces the feedback system to the ELETTRA control system through Ethernet. The twelve local stations share the acquired BPM data by means of reflective memory PMC (PCI Mezzanine Card) modules hosted directly on the CPU boards and connected together in a ring topology by 2.2Gbit/s fibre-optic links.

Optionally, a thirteenth station could be included in the reflective memory ring to perform supervision tasks, global data acquisition and real-time processing at the feedback rate, allowing for additional feedback and machine diagnostics applications.

The *Libera* devices will provide low latency closed orbit data to the feedback system by means of fast serial links. Several options are possible: Gigabit Ethernet, Fiber Channel, FDDI, etc. The following scenario refers to the Gigabit Ethernet option.

Each *Libera* generates small (64 byte) Ethernet packets containing position data at the feedback rate synchronously to the other *Liberas* thanks to a trigger/synchronization system distributed around the ring. A standard gigabit network switch at each location is used to serialize the eight packets and send them to the Motorola CPU board. In order to acquire data at high speed in real-time, the standard Ethernet Linux driver has been opportunely modified to directly manage raw Ethernet packets.

On the Motorola CPU, dedicated tasks running inside the Linux RTAI real-time extension [5] perform feedback processing and data buffering at the feedback repetition rate. The calculated correction values take into account all of the 96 BPM readings available through the reflective memory. The correction samples are eventually converted to analog signals by two 8-channel 16-bit DAC PMC modules, transformed to differential signals and transmitted to the corrector magnets power supplies via shielded cables. The power supplies feature an additional analog input dedicated to the feedback that is summed to the main reference input used by the control system to set the current value. A reduced current range is available for the feedback (±400 mA, corresponding to ±47/69 μrad deflection in the horizontal/vertical plane at 2 GeV) allowing for a fine resolution of the correction.

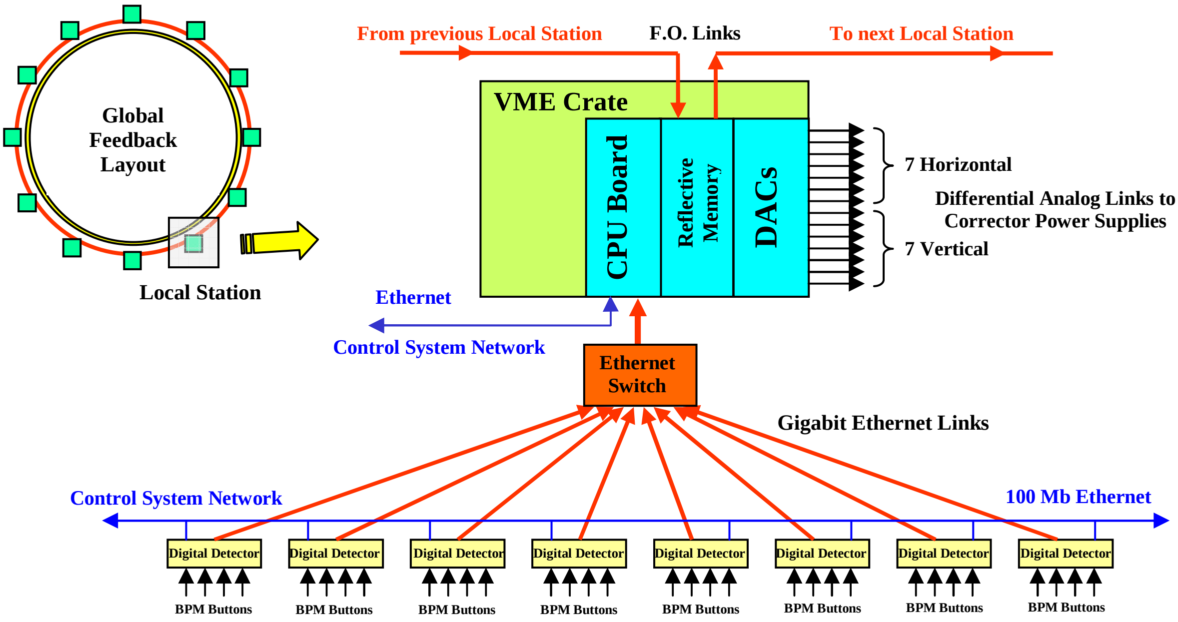

Figure 2: Layout of one of the twelve local stations of the fast global orbit feedback

LATENCY BUDGET OF THE FEEDBACK CHAIN

The total latency of the open loop chain from A/D to D/A conversion is an important parameter of the feedback system, which affects the closed loop bandwidth and stability margin. The data path between *Libera*, CPU, reflective memory, processing task and the DACs has been thoroughly studied and a prototype of the low level communication software has been developed making use of real-time interrupts and DMA data transfers. Tests have been carried out at a 10 kHz data rate using a Motorola MVME6100 CPU board with PowerPC processor running at 1.3 GHz. The estimated delay between the *Libera* digital output and the DAC analog output is about 150 µs. The maximum time available for the processing is 70 µs, which is widely sufficient to perform the required calculations. Thanks to the particular timing sequence implemented, the actual processing time does not affect the total delay.

Estimated preliminary data provided by Instrumentation Technologies set the maximum latency of *Libera* to 300 µs.

ALGORITHMS AND EXPECTED PERFORMANCE

Correction Algorithm

The Singular Value Decomposition (SVD) algorithm will be used to invert the 96x82 response matrix in the global correction scheme. Simulations are under way using a machine simulator (Accelerator Toolbox [6]) to study the correction efficiency with different variants of the basic SVD algorithm, including BPM weighting and singular values reduction. Both the measured and the theoretical matrices have been determined. The plot of the singular values in descending order (Figure 3a)) suggests that a number of them can be neglected at the cost of a slight reduction of the correction efficiency. Figure 3b) reports the simulated correction efficiency as a function of the number of singular values retained in the matrix inversion. The vertical axis is the ratio between the *rms* of the residual and the original orbit distortion.

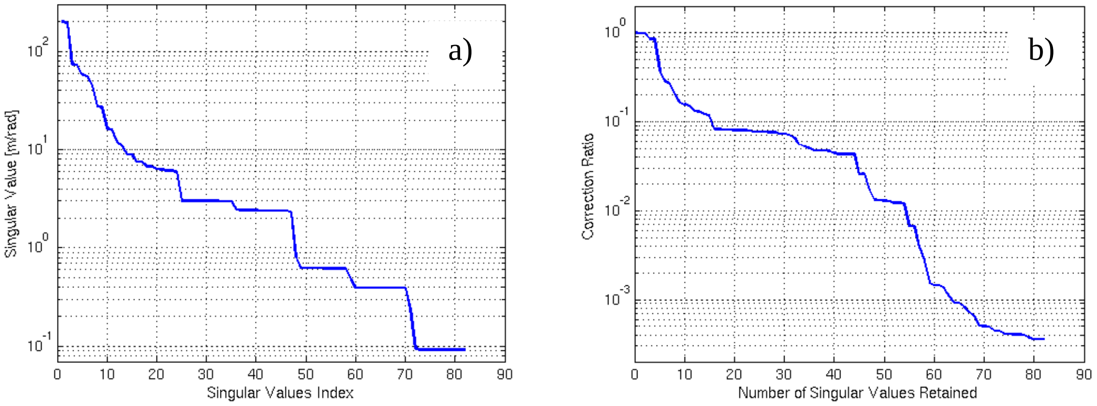

Figure 3: a) singular values of the response matrix in descending order, b) ratio between the *rms* of the residual and the original orbit distortion as a function of the number of singular values retained in the SVD matrix inversion. The analysis has been made using a machine simulator.

Closed Loop Control

The attenuation bandwidth of the feedback loop will be dominated by the dynamics of the corrector magnets (70 Hz cutoff frequency) and by the feedback latency time. Since the latter is also affected by the repetition rate, a relatively high frequency (10 kHz) has been chosen as design value. Simulations carried out using a dynamic model of the system and measurements made on the existing local feedback system, show that a closed-loop bandwidth of about 150 Hz can be achieved employing a standard PID regulator. Only periodic components of the noise can be damped above this frequency. Programmable selective filters included in the loop will be used to suppress the harmonics of the 50 Hz from the noise spectrum. In the local feedback systems, this technique is effective in eliminating components at up to 300 Hz.

Operational Aspects

As all of the machine corrector magnets and BPMs are integrated into the fast global feedback system, no separate DC orbit correction loop running in the control system is foreseen. Before activating the fast feedback, an orbit correction program from a control room workstation will set the required beam position and angle at the ID and bending magnet source points. The obtained orbit will then be taken as reference set-point by the feedback loop.

The reduced corrector kick range available for the feedback system, although assuring a good resolution through the feedback 16-bit D/A converters, could lead to saturation of the feedback outputs in the event of large orbit distortions. The operational experience gained with the local feedback systems confirms that only slow drifts mainly caused by thermal load variations on the vacuum chamber can lead to feedback saturation. Two mechanisms have been implemented to allow a smooth operation of the local feedback systems even in presence of significant orbit distortions. The first is a slow loop that periodically calculates the mean of the feedback correction values and transfers them to the main corrector settings of the control system. In order to prevent system instability, the second suspends the feedback loop in the event of saturation and re-activates it after the disturbance is over or corrected by the first mechanism.

OUTLOOK

One potential concern is the mechanical movement of the BPMs due to the thermal load variation on the vacuum chamber produced by bending magnets synchrotron radiation, which eventually causes errors in the measured beam positions. Test and measurements are foreseen in the next months to decide whether a mechanical position measurement system is necessary to compensate the BPM readings.

Installation of Low-Gap BPMs on the remaining ID straight sections (section 2 and 7 are already equipped) and their integration into the global feedback system have also been foreseen. They can be equipped with carbon fiber reference column and capacitive position measurement system providing excellent absolute precision and better resolution due to the low vertical dimension of the BPM profile (see [7]).

Provision of both ID and bending magnet photon BPMs is also under study. The availability of photon beam position measurements, to be included in the global feedback loop, could noticeably improve the achieved source point stability. While bending magnet photon BPMs can be quite easily deployed in a feedback loop, concerns remain about ID photon BPMs due to contamination from bending magnet radiation and to their dependence on the ID gap values in the position readings.

The project time schedule foresees the accomplishment of the BPM electronics upgrade by the end of 2006. Given the fixed number and the limited duration of shutdown periods available in a user facility like ELETTRA, the gradual installation and commissioning of the new BPM detectors, which have to reliably operate during the subsequent machine run, seem to be one of the major challenges of this project. The commissioning of the fast feedback will follow in the first quarter of 2007.

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