THE DESIGN OF THE ELETTRA FAST LOCAL FEEDBACK SYSTEM

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Abstract

The stability of the electron beam position is one of the main issues for third generation synchrotron radiation sources. A fast local feedback system based on digital signal processing techniques has been designed and installed on ELETTRA. After a characterization of the main system components, the design choices are presented. The software environment used for system development and measurements is described.

1 INTRODUCTION

The full exploitation of the high brilliance photon beams produced by third generation synchrotron radiation sources relies on the transverse stability of the electron orbit at the Insertion Device (ID) source points [1]. The main beam perturbations consist of slow drifts and vibrations up to some tens of Hz. In order to achieve the requested performance, active orbit feedback systems are typically used [2].

At ELETTRA, where the development of such systems has been considered since the design phase of the facility [3], a fast local orbit feedback has been developed and preliminarily installed on two out of the five IDs installed. The system presently works in the vertical plane but its operation can be extended to the horizontal one with no hardware modifications. High resolution Photon Beam Position Monitors (phBPM) are adopted. Taking advantage of the recent technology developments, digital signal processing techniques [4] are used for the system controller. They improve system reproducibility and flexibility by allowing to easily change the orbit correction algorithm and/or compensating scheme.

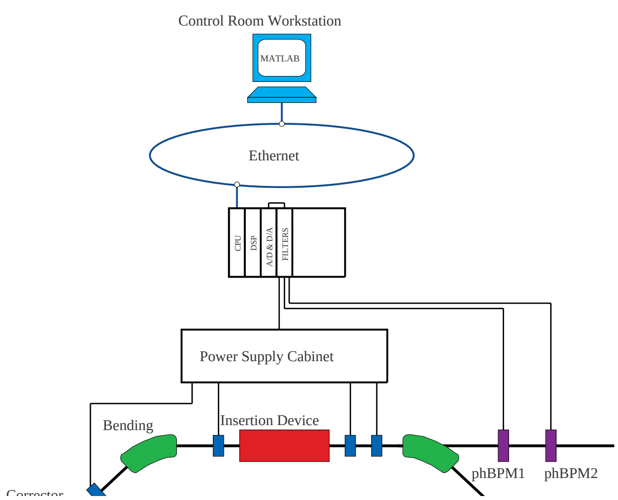

Figure 1: The local feedback layout.

2 SYSTEM LAYOUT

The ELETTRA local feedback system layout is shown in fig. 1: two phBPMs detect the photon beam position in the front-end and four corrector magnets move the electron beam inside the ID straight section. The phBPM signals are sampled by A/D converters and processed by a Digital Signal Processor (DSP) based system which implements the control algorithm. The D/A converters re-transform the resulting output samples in analog signals which drive the power supplies of the corrector magnets. An Ethernet connection allows to communicate with the control system [5] workstations and to remotely control the DSP operation.

2.1 The Photon Beam Position Monitors (phBPM)

The two phBPMs [6] are located in the ELETTRA front-end. They have a separation of 1 m and the first one is located 9 m from the corresponding ID centre. Excellent performance in terms of mechanical stability has been achieved by fixing the monitor supports directly in the rock below the concrete floor of the storage ring. The operation of the monitors is based on the photoemission effect of four blades spaced 90° from each other. Their particular configuration alows to intercept only the fringes of the beam and to sustain the radiation flux and the thermal load. The two monitors are rotated by 45° one respect to each other (fig. 2). In order to avoid non-linearity and cross-talk between planes the photon beam must be placed close to the centre of the photoemitting elements: a motorized x-z translation system has been developed for this purpose.

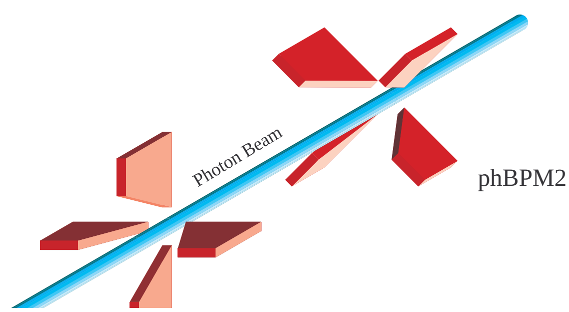

Figure 2: Photon BPM layout.

Each blade signal is proportional to the overall photon flux produced by both the ID and bending magnets. Since only the ID component has to be considered the bending one must be rejected. Its contribution is proportional to the electron beam current and can be evaluated when the ID is still open.

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The signals from the blades are pre-processed by high precision electronics located close to the front-end which provides a submicron sensitivity. They are then conditioned and amplified in order to assure good noise rejection in the transmission to the Controller.

2.2 Corrector Magnets and Power Supplies

The ELETTRA combined horizontal-vertical inverted U-shaped corrector magnets [7] are used also for the feedback system. The corresponding power supplies must therefore provide both DC and AC currents. The maximum allowed frequency of the AC current depends on the DC offset and is limited by the output voltage of the power supplies (65 V peak). AC amplitudes of 400 mA up to 50 Hz and 200 mA at 100 Hz can be obtained for the maximum 12 A of DC current. The feedback input signal is enabled by a solid state switch and is added to the DC setting coming from the control system in the regulation part of the power supply. The phase delay induced by the eddy currents generated in the stainless steel vacuum chamber by the AC magnetic field has been measured. It is about 1 degree at 60 Hz and 2 degrees at 100 Hz.

2.3 The Controller

The Controller is based on the VME bus standard. The eight analog signals coming from the two phBPMs are conditioned and filtered to avoid aliasing effects by a home-developed board with 4th order low-pass filters. The same board provides also filtering and conditioning for the output analog signals going to the power supply cabinet. A single board is in charge of the A/D-D/A conversion: it features a maximum rate of 200 ksamples/s on each independent channel with a resolution of 16 bits. The DSP board mounts a TMS320C40 processor at 40 MHz (50 MHz on the new boards) and its computing power could be enough to run the correction algorithms on both the vertical and horizontal planes at the sampling rate of 8 kHz. An additional CPU board acts as a bridge between the DSP and Ethernet. The A/D-D/A and the DSP boards are connected by a mezzanine bus (Modular Interface eXtension, MIX), while the VMEbus is used for the communication between the DSP and the bridge board.
The programs running in the DSP are written in "C" language. A complete development environment and a special Ethernet communication protocol called SwiftNet [8] allow to compile, download, run and debug the programs in the DSP from UNIX workstations.

3 THE MATLAB-DSP ENVIRONMENT IN ELETTRA (MADE)

The local feedback project has been supported through all its phases by an effective workbench based on Matlab [9] called MADE (MAtlab-Dsp environment in ELETTRA). Matlab is a computing interactive environment suited for data analysis, dynamic system design and simulations. The Matlab standard command set has been expanded in order to communicate with the DSP system directly from any control room workstation. The communication relies on SwiftNet. The newly developed commands take the form of Matlab Mex-files and are associated with specific software running on the DSP. They allow to:

- setup the VME boards (sampling frequency setting, A/D converters calibration, etc...)
- acquire input/output signals
- generate arbitrary output waveforms
- control the local feedback system operation and parameters (filters, controller parameters, open-close loop, etc...)
- acquire data preprocessed by the DSP (spectra, rms values, frequency responses, etc...)
- monitor the control variables.

The ELETTRA control system remote procedure call libraries have also been integrated with Matlab and allow to access the accelerator equipment through simple command line instructions [10]. The control of both the accelerator and local feedback system from the same workspace minimizes the time needed for measurements and tests.

4 SYSTEM MODELLING AND SIMULATION

The feedback setup allowed a quick and effective dynamic characterization of the overall chain made of power supply, magnet, vacuum chamber and phBPM. The frequency response of the system has been measured on the real machine by modulating one vertical corrector with sinusoidal signals at different frequencies generated by the DSP and acquiring the beam oscillations detected by the phBPMs with the DSP itself.
The phBPM does not introduce any appreciable cut-off at the working frequencies (0 - 200 Hz). The dynamic behaviour of the chain is dominated by the corrector magnet and power supply.
A polynomial model in z has been calculated which best fits the frequency response of the system: a third order model is sufficient to characterize it up to 200 Hz. Fig. 3 shows the response of the model compared with the real one.

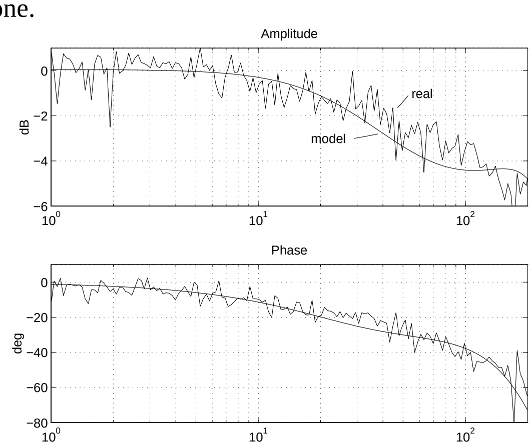

Figure 3: Frequency response of the real system compared with the third order model.

Starting from this model several simulations have been carried out using both Matlab and Simulink [11] to better understand the closed-loop behaviour of the system. The model block diagram is shown in fig. 4. The delay represents the time lag due to the processing and conversion time: it is estimated to be equivalent to two samples, which means 250 μs at the nominal 8 kHz sampling rate. The controller implemented for the first tests is a PID [12] standard regulator with transfer function:

$$R(z) = K_P + \frac{K_I}{1-z^{-1}} + K_D(1-z^{-1})$$

A first-order low-pass filter with cut-off frequency f_C has been added before the PID in order to limit the dynamics of the signal at the higher frequencies and to avoid non-linearity of the power supply.

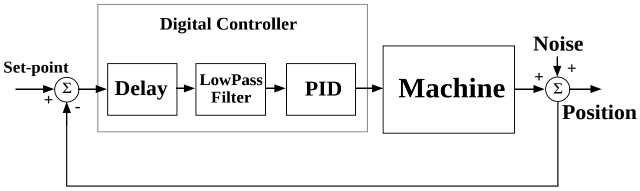

Figure 4: Block diagram of the model used to simulate the closed-loop system behaviour.

As the sampling frequency is much higher than the working frequencies, the model does not take into account neither the anti-aliasing nor the reconstruction analog filters.

Fig. 5 is an example of the simulated frequency response of the closed-loop system and the corresponding open-loop Nyquist diagram.

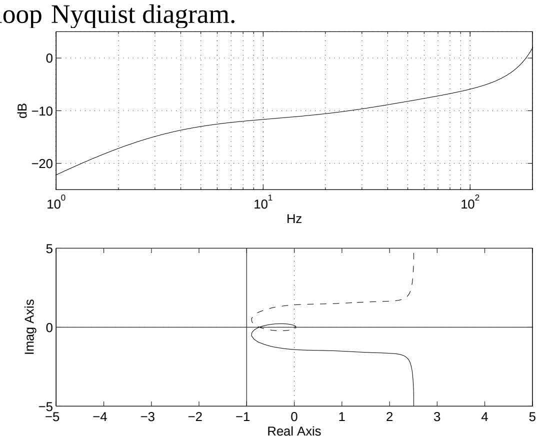

Figure 5: Closed-loop frequency response and open-loop Nyquist diagram of the simulated system (K_P=3, K_I=0.01, K_D=10, f_C=150 Hz).

5 CONCLUSIONS

The ELETTRA fast local feedback system uses phBPMs as position monitors and U-shaped combined corrector magnets as actuators. The magnet power supplies provide both DC and the AC current needed by the feedback system. The Controller is based on commercial DSP VME boards and is completely integrated in the ELETTRA control system.

A powerful software environment suited for digital signal processing applications, called MADE, has been developedand boosted the whole project.

A system model that fits the experimental data has been calculated and is used to predict its closed-loop behaviour. The described fast local orbit feedback system has been installed and the first operational results are presented in [13].

6 ACKNOWLEDGEMENTS

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REFERENCES

[1] H. Winick: 'Synchrotron Radiation Sources, a Primer', World Scientific, 1994.

[2] E. S. Bozoki et al.: 'Orbit Correction and Analysis in Circular Accelerators', AIP Conference Proceedings 315, Upton, NY 1993.

[3] D. Bulfone et al.: 'Design Considerations for the ELETTRA Beam Position Feedback Systems', Proc. 2nd European Particle Accelerator Conference, Nice, France, 1990.

[4] J. G. Proakis and D. G. Manolakis: 'Digital Signal Processing', Prentice Hall, 1996.

[5] D. Bulfone: 'Status and Prospects of the ELETTRA Control System', Nucl. Instr. and Meth. A 352, p. 63, 1994.

[6] A. Galimberti et al.: 'Photon Beam Position Monitors suitable for a Local Feedback System at ELETTRA', Proc. 5th European Particle Accelerator Conference, Sitges, Spain, 1996.

[7] D. Tommasini et al.: 'Design, Construction and Testing of the Corrector Magnets for ELETTRA', Proc. 4th European Particle Accelerator Conference, Sitges, Spain, 1996.

[8] 'SwiftNet Host Software User's Guide', Pentek, Inc. 55 Walnut Street, Norwood, NJ 07648, 1995.

[9] 'Matlab User's Guide', The MathWorks, Inc. 24 Prime Park Way, Natick, Mass. 01760-1500, 1994.

[10] C. Scafuri: 'Integration of Matlab into the ELETTRA Control System', ST/M-TN-97/1, Sincrotrone Trieste, 1997.

[11] 'Simulink User's Guide', The MathWorks, Inc. 24 Prime Park Way, Natick, Mass. 01760-1500, 1995.

[12] G. F. Franklin: 'Feedback Control of Dynamic Systems', Addison-Wesley Pub. Co., 1994.

[13] C. J. Bocchetta et al.: 'First Operational Results with the ELETTRA Fast Local Feedback System', these Proceedings.