The ELETTRA Fast Digital Local Orbit Feedback

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Abstract

An overview is given of the ELETTRA Fast Digital Local Orbit Feedback system. The system has been developed to stabilize the electron orbit in the Insertion Device straight sections. It uses two Photon Beam Position Monitors as detectors and four corrector magnets to act on the electron beam. The controller relies on a Digital Signal Processor (DSP) system based on commercial VME boards and is completely integrated in the ELETTRA Control System. A powerful workbench based on Matlab has been developed and provides complete control of the DSP from any control room workstation. The performance of the closed loop using a Proportional Integral Derivative (PID) controller is in good agreement with the simulations carried out with the system model and shows an attenuation of the noise frequency components up to 150 Hz. A newly developed technique adopts dedicated selective filters to effectively suppress the persistent periodical components of the beam noise. First experiments have also been carried out with two local feedback systems concurrently running on different beamlines.

1 Introduction

A third generation synchrotron light source like ELETTRA is characterized by the extraordinary brightness of the synchrotron radiation generated by the Insertion Devices (ID). However, the full exploitation of the photon beam strongly relies on the stability of the accumulated electron beam. Active feedback systems are usually adopted to counteract undesired beam motions.

The local orbit feedback system developed at ELETTRA corrects the electron beam position at the photon source point by detecting the photon beam motions with two Photon Beam Position Monitors (phBPM) and by acting on the electron beam by four corrector magnets to create a closed orbit bump.

The beam motions at ELETTRA can be classified in two main categories. The first is represented by the low frequency components, up to some Hz; they are mainly due to ground vibrations, thermal effects and closed orbit distortions generated by ID gap changes. The second consists of persistent periodic oscillations at 50 Hz and its harmonics, derived from the mains. Different control techniques have been adopted to counteract each type of beam motion.

2 System overview

The layout of the local feedback system is shown in figure 1. A couple of dedicated phBPMs and four corrector magnets driven by separate power supplies act respectively as sensors and actuators. The phBPM signals are sampled by A/D converters and processed by a DSP based system which implements the control algorithm. The D/A converters retransform 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 room workstations and to remotely control the DSP operation.

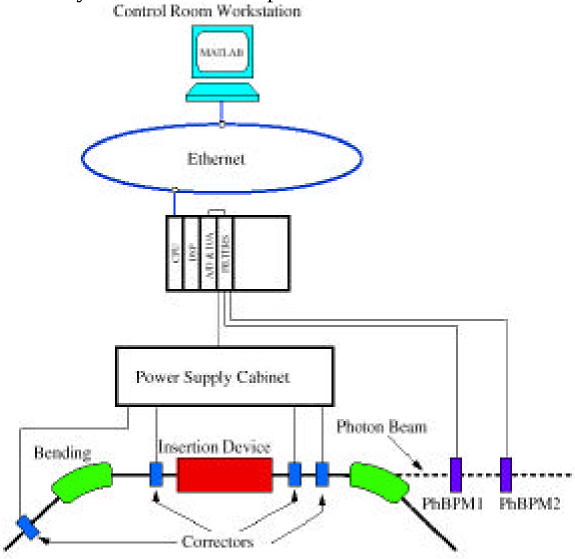

Figure 1: The Local Feedback Layout

2.1 The photon beam position monitors and corrector magnets

The two phBPMs [1] are located in the front-end of each beamline. They are separated by one meter and the first one is located nine meters from the corresponding ID centre. The operation of the monitors is based on the photoemission effect of four blades spaced 90° from each other. The signals from the blades are pre-processed by high precision electronics which provides sub-micron sensitivity. They are then conditioned and amplified in order to assure a good noise rejection in the transmission to the Controller.

The ELETTRA storage ring has 164 corrector magnets (82 horizontal and 82 vertical) and each of them is driven by a dedicated power supply. The local feedback uses two correctors up-stream and two down-stream the ID for each plane. A 4-by-2 empirically evaluated bump matrix provides the corrector strength values which move the photon beam to the desired positions on each phBPM while satisfying the closed bump condition [2].

2.2 The DSP based controller

The Controller is based on the VME bus standard. The eight analog signals coming from the two phBPM blades are conditioned and filtered to avoid aliasing effects by a home-developed board equipped with 4-th order low-pass filters. The same board provides also filtering and conditioning for the eight analog output signals going to the power supply cabinet. A Pentek A/D-D/A board features a maximum rate of 200 ksamples/s on each independent channel with a resolution of 16 bits. We sample at 8 kHz. The DSP board is a Pentek 4284 equipped with one TMS320C40 processor which can run the correction algorithms on both the vertical and horizontal planes. An additional CPU board acts as a bridge between the DSP and the Ethernet. The A/D-D/A and the DSP boards are connected by a mezzanine bus (Modular Interface eXtension, MIX), while the VME bus 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 allow to compile, download, run and debug the programs in the DSP from UNIX workstations. An interactive computer workbench based on Matlab [3] has been developed to support the local feedback project [4].

3 System modelling and simulations

The dynamic behaviour of the local feedback system is dominated by the magnet/power supply transfer function. The eddy current effect in the stainless steel vacuum chamber has been found to be negligible in the frequency range of interest. The overall transfer function has been measured on the machine itself by exciting a corrector with sinusoidal signals at various frequencies and recording the amplitude and phase of the corresponding phBPM signals [5]. A 3-rd order polynomial model fitted to the experimental data gives the best approximation of the frequency response. The transfer functions of the four magnet/power supply channels are considered identical.

The empirical model of the system has been used to simulate the behaviour of the local feedback loop. The simulations are particularly useful because they allow to optimize the control parameters and try new control techniques before their application to the real machine.

4 The standard PID controller

The first control technique adopted is a standard PID (Proportional, Integral, Derivative) controller with the addition of a single-pole low pass filter which limits the input signal dynamics to avoid power supply non-linearities. The simulations allowed to tune the PID parameters in order to optimize the closed-loop response.

The frequency response in the range 0-200 Hz has been optimized, obtaining the following PID parameters: $K_p = 3$, $K_i = 0.01$ and $K_d = 10$. The low pass filter cut-off frequency f_c has been set to 150 Hz. The behaviour of the closed loop on the real machine is in good agreement with the model predictions, showing a 3-dB closed-loop bandwidth of about 150 Hz.

The 50 Hz and its lower order harmonics can be reduced by a PID controller, but other techniques seem to be more effective for this purpose (see below). The PID will be therefore dedicated to the lower frequency noise components. Figure 2 shows the open/closed loop spectra of a real phBPM signal with a PID controller optimized in the 0-40 Hz frequency range.

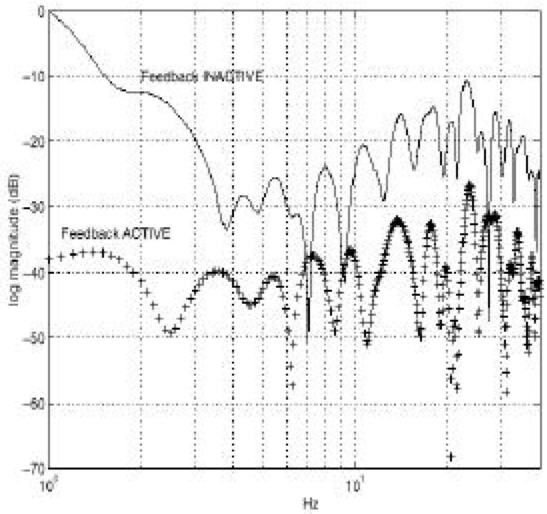

Figure 2: Noise spectra of a real phBPM signal with loop open and closed using a PID optimized for the low frequency noise components

5 Harmonic suppression

Since the beam noise components associated to the mains (50 Hz) and its harmonics are periodic and stable, their reduction is possible even if the frequency is higher than the open-loop cut-off frequency, where the phase rotation is large. A technique called "harmonic suppression" has been developed for this purpose.

The harmonic suppressor scheme consists of a loop with a selective digital filter centered at the frequency to damp (figure 3). The delay is calculated in order to achieve an overall system open-loop rotation of 360° at the chosen frequency. The closed-loop system behaves as a notch filter whose depth is regulated by the programmable gain.

The selective filter is a complex-conjugate two pole digital resonator with two zeros in $z = \pm 1$; its transfer function is:

$$H(z) = G \frac{(1 - z^{-1})(1 + z^{-1})}{1 - (2 r \cos\omega_0) z^{-1} + r^2 z^{-2}}$$

where ω_0 is the resonance frequency and r is the amplitude of the two poles, which must be smaller than one for the stability condition. By properly setting r it is possible to change the width of the notch which must be effective only at the selected frequency.

Simulation results show that, as long as the notches are completely separated from each other, it is possible to implement multiple harmonic suppressors centered at different frequencies working in parallel with a standard PID regulator (figure 3). Figure 4 shows the phBPM signal spectra measured on the machine where the suppressors eliminate the 50 Hz and some selected harmonics while the PID acts on the low frequency non-periodic components.

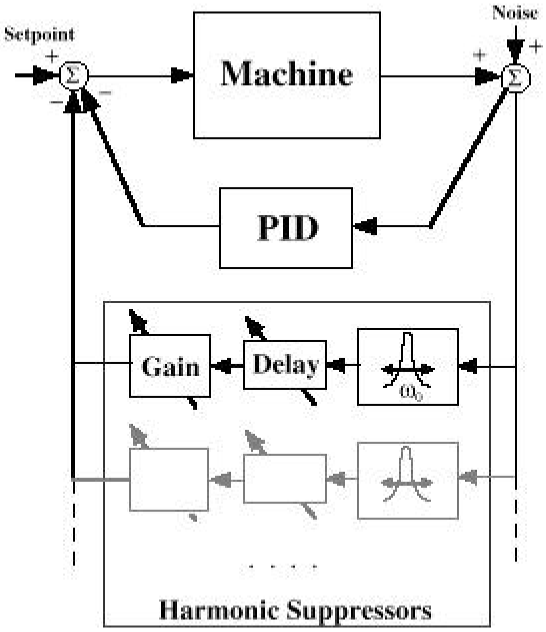

Figure 3: Multiple Harmonic Suppressor scheme

The delay of each harmonic suppressor is calculated from the model, taking into account the closed-loop phase rotation of the system with the PID. Other tests with five harmonic suppressors have reduced the phBPM signal rms by 64%.

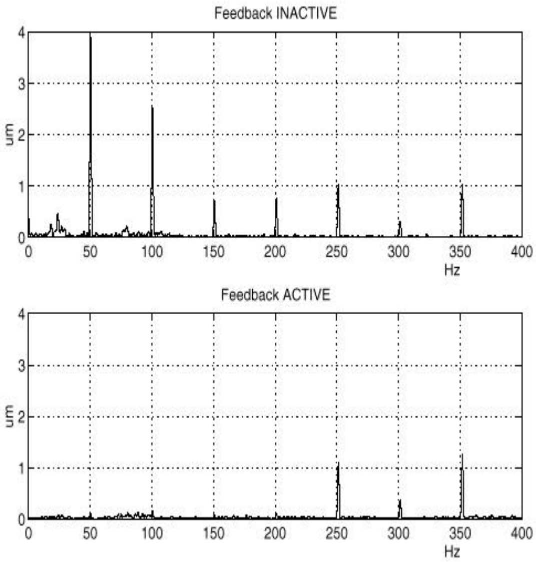

Figure 4: Open/closed loop phBPM signal spectra with a PID regulator together with four harmonic suppressors at 50, 100, 150 and 200 Hz (*r* = 0.99995 and gain (at $_0$) = 100)

6 Interaction between feedback loops

One of the major concerns in a machine with multiple local feedbacks is the interaction between the different systems which can affect the efficiency of the correction or even produce instabilities. An ideal local feedback system does not perturb the orbit outside the bump. In reality, absolute local correction is unachievable because of differences in the dynamics of the four actuators, errors in the bump matrix, etc. A number of measurements have been carried out to quantify the interaction between two feedback systems and study their behaviour when both are running.

The four correctors of the local feedback in section S6.2 have been excited in a closed bump configuration in order to create a sinusoidal position oscillation of the photon beam. The maximum allowed bump amplitude has been used to reproduce the worst case conditions. We define the leakage as the ratio per cent between the amplitudes of the oscillations measured with the phBPMs in section S2.2 and S6.2. The experiment has been repeated for different frequencies, up to 420 Hz. The plot in figure 5 shows the leakage as a function of frequency.

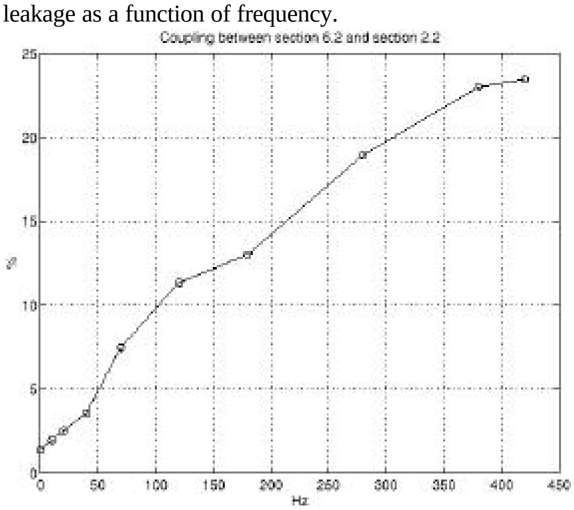

Figure 5: Leakage between section S6.2 and S2.2 as a function of frequency

When two feedback systems are concurrently running, mutual interactions create a coupling phenomenon which under certain conditions of amplitude and phase can give rise to instabilities.

A dedicated measurement has been carried out to investigate the coupling between two active feedback loops at the different frequencies. The measurement scheme is shown in figure 6. The loop is closed in section S2.2 and a large phBPM sinusoidal position oscillation is artificially created in order to make the feedback correct it. The spectra of the perturbed photon beam position signal in section S2.2 are eventually measured in two conditions: loop open and loop closed in section S6.2.

The experiment has been repeated for several artificially induced noise frequencies, from 20 to 320 Hz. The comparison of the spectra reveals no perceptible amplification showing that we are far from the instability condition.

7 Conclusions

A DSP system has been developed to implement a local orbit feedback at ELETTRA. It provides effective tools for a quick characterization of the system and testing of the closed-loop behaviour.

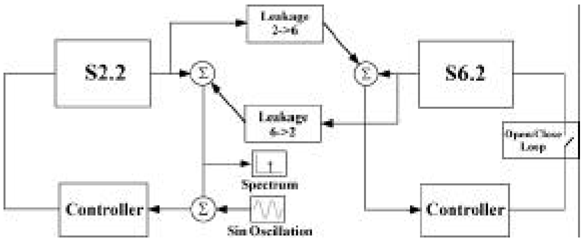

Figure 6: Coupling scheme and measurement set-up

Different control algorithms are applied to counteract the beam motions. Besides the standard PID controller dedicated to the low-frequency noise components, a new technique called "harmonic suppression" is adopted to eliminate the periodic oscillations at 50 Hz ad its harmonics.

Coupling between two local feedback systems installed in different sections has been evaluated: the amount of leakage is not such to affect the feedback performance or create instabilities.

References

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