INITIAL DESIGN OF A GLOBAL FAST ORBIT FEEDBACK SYSTEM FOR THE ALBA SYNCHROTRON

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Abstract

This paper presents the initial design of the Global Fast Orbit Feedback (FOFB) system for the ALBA Storage Ring. The FOFB system is designed to reach a submicron stability of the electron beam working at frequencies of at least 100 Hz. It compensates the small perturbations produced by vibrations, electromagnetic noise and changes in the gap or phase of the insertion devices, etc. A description of the model is shown. The different subsystems have been identified and modeled: the BPM processor, the iron lamination and the vacuum chamber. The power converters for the correctors play an important role in the system, and they have been designed (strength, resolution, bandwidth, voltage output) accordingly with the FOFB requirements. We have also studied the latency of the system (communication network, processing times). The orbit correction is computed by a PID controller. The simulations of the closed loop response show a damping of the perturbation between 0 and 100 Hz, although the system also introduces a small amplification of the noise just after this bandwidth. Finally the paper presents the initial design of the hardware architecture of the FOFB system.

INTRODUCTION

ALBA is the first Spanish Light Source which is intended to provide Spain with a powerful source of X-rays. The project is funded by the Spanish and Catalan Governments at equal parts. The first phase includes the construction and commissioning a linear accelerator, a booster accelerator, a storage ring and 7 beamlines, with the start of operation planned for 2010.

ALBA is a 3rd generation 3 GeV light source, with a perimeter of 268 m, With such an energy the brilliance at 20 keV reaches 10^{19} Ph/s/mm2/mrad2/0.1%BW for in-vacuum undulators with 5 mm gap.

The lattice has 16 cells with a 4-fold symmetry in order to increase the number of available straight sections for experiments, providing 16 medium straight sections of 4.2 m, 4 longs ones of 8 m and 12 short ones of 2.2. For more information see reference [1]

ORBIT CORRECTION BASICS

In order to provide a stable beam for the experiments, the electron beam has to be stable to values smaller than 10% of the beam size. In the vertical plane, where the beam size is of the order 5 to 10 µm in the medium straight section, this corresponds to a sub-micrometer stability of the electron beam. The closed orbit correction system is in charge of keeping the beam stable. The system is composed of two conceptual parts: The slow and the fast orbit feedback. The two components share most of the hardware, and could be integrate in a single loop in the future. The main components of the orbit correction system are the Beam Position Monitors (in charge of reading the position of the electron beam around the ring), the Corrector Magnets (that introduce displacement in the beam to bring back the orbit to the desired one) and a system of CPUs that predict the settings of the corrector magnets based in the readings of the BPMs.

The slow orbit feedback takes care of the correction of the orbit created by "large" static perturbation, such as misalignment of magnets, etc. It would compensate errors up to a few mm, with corrector strength up to 1 mrad, and is mostly a static system, taking care also of adjusting the frequency of the RF to have a centred horizontal orbit.

The fast global orbit feedback system is in charge to stabilize the electron beam up to frequencies of at least 100 Hz, compensating the small perturbations produced by vibrations, electromagnetic noise and changes in the gap or phase of the insertion devices. Typically, the maximum corrector strength needed will be of circa 50 µrad at 50 Hz. The elements involved in the FOFB are the BPM detectors and the BPM electronics, the corrector power supplies, the corrector magnets, the vacuum chamber, the frequency of the RF system, and a computer system and network, that collects the information from the BPM electronics, runs correction algorithms and acts on the storage ring corrector magnets and in the frequency of the RF. Those elements are described in the next section.

FAST ORBIT FEEDBACK SUBSYSTEMS

This section describes the influence of the different subsystems involved in the FOFB:

- BPM electronics.
- The Power supply.
- Iron lamination, corrector coil, and vacuum chamber.

Figure 1 shows the model of the correction loop.

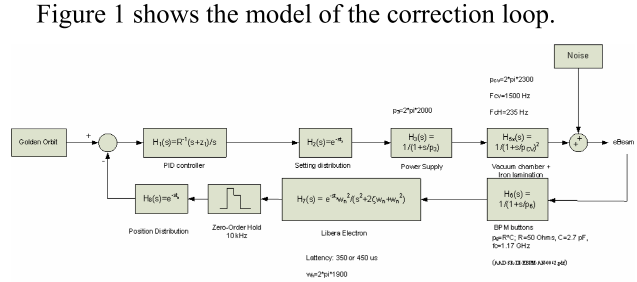

Figure 1: Model of the FOFB correction loop.

BPM Electronics: Libera Electron Processor

Libera Electron [2] is a standalone device composed of a RF analogue front-end, four ADCs, a FPGA, and a Single Board Computer. The electron beam is determined by sampling at 118.2218 MS/s the signals from the four BPM buttons for the storage ring and by processing the samples in a multiple-stage filtering and decimation scheme.

We have measured the step response of the fast acquisition data path, which is shown in Figure 2.

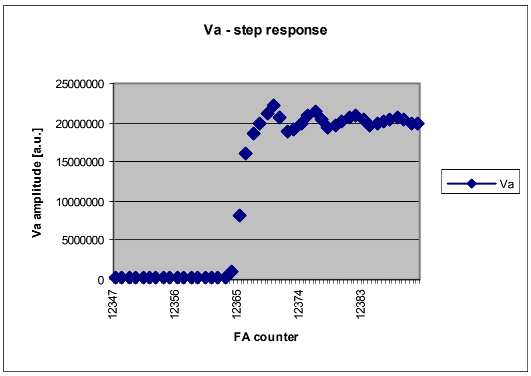

Figure 2: Libera Fast acquisition response, with a sampling rate of 10 kHz.

This is a second order underdamped system, with a damping ratio of 0.47 and an undamped natural frequency of 11918 rad/s. We have to add the latency of the digital system, as we could correlate this value with the turn-by-turn acquisition (1 us resolution). This gives a latency of 350 µs. So, the transfer function, including the group delay of the digital calculation is:

$$H(s) = e^{-st_o} \frac{w_n^2}{s^2 + 2\zeta w_n + w_n^2},$$

where t_o=350 µs, w_n=11918 rad/s, ζ=0.47.

Iron Lamination and Vacuum Chamber

The Storage Ring sextupoles of ALBA will have additional coils to provide horizontal and vertical corrections to the beam. Due to the fact that the vacuum chambers are made with metal, eddy current will appear, therefore, the magnitude of the magnetic field will be reduced for high frequencies. The ALBA vacuum chamber is made of 3 mm thick stainless steel, but there is a reduction of the vacuum chamber thickness (2 mm) at the location of correctors only at the location of the sextupole poles instead over the whole width of the corrector. Also, the thickness of the laminations of the sextupoles is 0.5 mm, in order to reduce the Eddy currents in the core of the sextupoles.

The document [3] has a simulation of the magnetic field attenuation of the Vertical corrector field in the vacuum chamber. Those simulations take into account the effect of the iron losses on the iron core and the vacuum chamber. A step has been used to measure the bandwidth of the vacuum chamber [4]. The rise time (10-90%) for the vertical field is 1.2 ms, so the cutoff frequency is 290 Hz if a first order system is assumed. The rise time for the horizontal field (vertical correction) is 0.155 ms, and the cutoff frequency is 2.4 kHz. It was also simulated the effects of the eddy current currents due to a sinusoidal waveform. The field attenuation is shown in Figure 3.

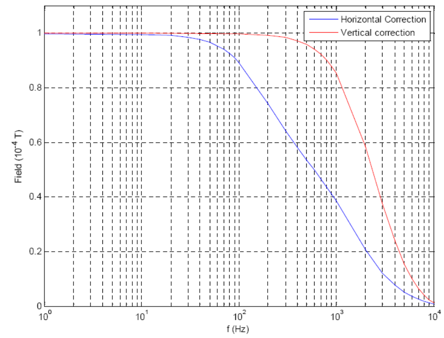

Figure 3: Attenuation of the magnetic field.

The -3 dB attenuation measured in this case is 235 Hz for the horizontal correction and 1551 Hz in the vertical correction. We have adjusted the transfer function for both plots. The vertical correction field has a slope of 40 dB/dec, which corresponds to a second order filter. We have fitted the curve (up to 4 kHz), and it has the following transfer function:

$$H_{CV} = \frac{1}{(s/2\pi f_c + 1)^2}$$, with f_c=2.3 kHz.

The response for the horizontal correction is neither a first order filter. It has a slope of 8.5 dB/dec (the first order filter is 20 dB/dec). We could take a conservative approach, and consider a first order filter with a cut-off frequency of 235 Hz

Corrector Power Supply

This section shows the specification of the power supplies, according to the simulations done in the vacuum chamber and the measurements done by the corrector coil manufacturer.

When the project of the FOFB started, the Libera electron processor, the magnet coils and the vacuum chamber where already decided. The only components that we have designed for the optimization of the FOFB system are the corrector power supplies.

The corrector magnets were designed for higher correction fields in static mode. In order to avoid the need of cooling the coils, the magnets present a small resistance but a large inductance. The vertical correction coils have (according to the measurements made by the magnets manufacturer) an inductance of 211 mH and a resistance of 2.24 Ohms. In the dynamic mode requested by the FOFB system, we have to dimension the power supply accordingly, in order to produce current with the appropriate strength and bandwidth the power supply.

Following the experience in other light sources (SLS, Elettra), the dominant noise sources that the fast orbit feedback should cancel are in a range up to 100 Hz, and the highest component is related with the mains network (50 Hz). The correction signal will be the addition of sinusoidal waveforms, and the highest component is 50 Hz. So we calculate the required voltage for a correction of 80 µrad at 50 Hz in the vertical plane, for our load (L=220 mH and R=2.2 Ohms): $V = L * I_{peak} * \cos(\omega t)$ = 55 V. We have to add to this voltage the DC component, which is 1 mrad (10 A). The resistance of the magnet is 2.2 Ohms, and the resistance of the cable is 0.5 Ohms, so the total DC voltage is 2.7*10=27 V. The total voltage will be 55+27≈ 85 V.

The bottom line is a power supply with ± 12 A and ± 85 V. This power supply allows DC corrections of ±1 mrad (10 A) and in addition an AC correction of ±80 µrad (0.8 Apeak) at 50 Hz (or ±40 µrad at 100 Hz) in the vertical plane. The same power supply will be used for the horizontal correction and it will provide a correction of ±115 µrad (1.16 Apeak) at 50 Hz (or ±58 µrad at 100 Hz) in the horizontal plane.

FAST ORBIT FEEDBACK CORRECTION

The FOFB system is closed loop system. The beam position is measured by the BPM, and compared with the reference orbit (set point). The error signal is applied to a PID controller, which computes the correction and it generates a control signal for the corrector power supplies.

The target of the FOFB is to cancel (or attenuate) perturbations below 100 Hz. In our system, the perturbation is modelled as the input signal, and the output is the attenuation of the perturbation.

We simulate the sensitivity transfer function, which is defined by:

(x_beam_position)/(x_noise)=1/(1+H)

where H = HLibera * Htransport_delay * HPower supply * Hmachine_optics.

This transfer function gives the suppression of possible disturbances over the frequency range. The idea is the get the larger and higher attenuation in the stopband. We consider the bandwidth of the system, as the attenuation lower than 3 dB.

Figure 4 shows the Simulink model with the models of the different subsystems involved the in FOFB. The transport delay models the latency of the system: BPM position distribution, processing times, corrector settings distribution.

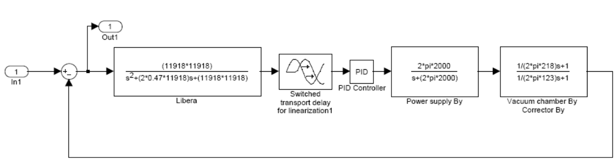

Figure 4: Simulink model of the FOFB.

Using a PI controller $PID = K_p\left(\frac{T_i s + 1}{s}\right)$ with K_p=0.2 and T_i=1/(2*π*50), the frequency response of the sensitivity function is shown in Figure 5. With these moderate values of the PI parameters, the 0 dB point is in the range desired (between 100 and 200 Hz), and the system can compensate realistic values of the noise under 100 Hz.

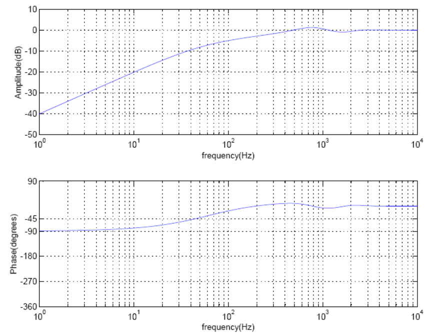

Figure 5: Amplitude and phase response of the sensitivity function.

CONCLUSION

We have studied the different subsystems involved in the FOFB. We have measured their response and simulate their behaviour, in order to produce precise model that will help us study the behaviour of the system. With this complete model, we have adjusted the PID parameters in order to get the desired bandwidth, with the highest attenuation. The idea is to use this model, and together with the real noise measurements in our accelerator, decide the final parameters of the PID. The next steps are to decide in the communication model for the data sharing between the Liberas, the corrector magnet power converters and the CPUs in charge of the PID.

ACKNOWLEDGMENTS

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