COMMISSIONING OF THE ALBA FAST ORBIT FEEDBACK SYSTEM

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Abstract

The ALBA Fast Orbit FeedBack system (FOFB) started its commissioning phase in September 2013, when all the required hardware was installed and the development of different controls for the feedback started. This report shows our experience tuning the different parameters to setup the system, together with vibration and beam noise measurements at different conditions. Finally, the present results and future steps for this system are described.

FOFB DESCRIPTION

ALBA Synchrotron machine is an already running facility providing beam for users in decay mode (2 injections per day). Even though ALBA has been demonstrated to be a low noise machine, the near use of a Top-up injection mode [1] will demand a better and faster feedback than the current Slow Orbit FeedBack (SOFB). Description of the FOFB layout and the different devices of the system has been already presented on IBIC13 [2]. A description of what have been done during the commissioning and the bottlenecks we have found is reported here.

Correction Calculation and GUI

Most of the effort and time during the last year has been dedicated to the development of the correction code and all required controls associated infrastructure. Correction algorithm runs on the 16 distributed CPUs where the Beam Position Monitors (BPMs) data is transferred to and the new setpoints for the correctors power supplies are computed. Testing of different CPUs has been performed in order to find the ideal hardware to match the FOFB requirements. Performance of one and two cores CPUs has been demonstrated to be not sufficient, since some of the 100 us loops of the FOFB are lost when using these CPUs [3]. Final solution using 4 cores CPUs matches the requirements, especially after the distribution of the different processes to the different cores: one core to do BPMs position data reading, another to perform correction calculation and power supplies interfacing and the other cores to take care of interruptions, handling of operating system, …

Each CPU runs a C correction code that retrieves the position data from the PMC FPGA Board [2]. Correction computation is based on broadly used SVD algorithm and a PI loop controller. 16 TANGO device servers are running on the 16 cPCI crates hosting the CPUs, while a high level device server controls the whole system. A preliminary Graphical User Interface (GUI) has been developed for the commissioning phase of the FOFB, from where we can start/stop the feedback system and set the PI and RF frequency loops parameters (Fig. 1).

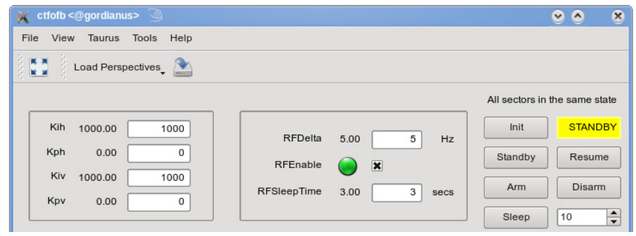
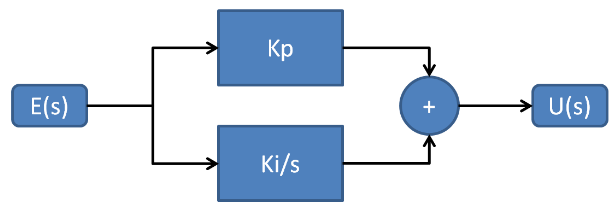


Figure 1: Commissioning FOFB GUI.

PI Controller

Different implementations of the PI loop after the SVD calculation have been tested, being the one showed on Fig. 2 the implementation that gave best results.



$$\boxed{U(n) = U(n-1) + A0 * E(n) + A1 * E(n-1)}$$

$$A0 = (Ki * Ts /2) + Kp$$

$$A1 = (Ki * Ts /2) - Kp$$

Figure 2: PI loop implementation.

Last version of the correction code has separated PI loops for horizontal and vertical plane, since the feedback requirements and beam noise are different depending on the plane.

RF Frequency Control

Our intention is to run just the FOFB during operation, without SOFB. That means that the control of the RF frequency has to be moved from the SOFB, running nowadays as a Matlab MiddleLayer routine, to the FOFB system. Decision has been taken to implement a routine on the high level FOFB device server that monitors the dispersive pattern on the correctors and changes RF frequency in case it is needed. Minimum frequency step and the correction periodicity will be modified from the main FOFB GUI.

System Limitations

Related with the RF frequency control, one of ALBA limitations is that we don't have fast and slow correctors, so the RF frequency cannot be handled in separate power supplies from the FOFB correction.

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Another limitation is that we cannot have a readback of the current from the correctors power supplies, since the time needed to handle the PCI interruptions and acknowledgments occupies too much of the PCI bus time and spoils the performance of the correction loop. The FOFB system is based on the assumption that the correction setpoint sent to the power supply is properly applied.

The electronics layout in the cPCI crate forces the transfer of position data from the PMC FPGA Board to the CPU to go through two PCI bridges. The use of Burst mode data transfer should allow this communication to be done in about 20 us, but that's not the case. For whatever reason not yet understood, burst mode stops after 2 transfer cycles and starts again. Not being capable to use the Burst mode, ALBA FOFB system can only warranty that half of the BPMs data cycles are processed, reducing the handling of position data from 10 kHz to 5 kHz rate.

CORRECTION RESULTS

Two different setups have been used for the time being to analyze the performance of the FOFB system: using a trim coil power supply as a beam perturbation source and closing an Insertion Device.

Trim Coil Excitation

A programmed waveform on a horizontal trim coil power supply has been used as beam excitation. The waveform is built as a combination of sinewaves at frequencies 1.2, 3.6, 12, 36 and 120 Hz. That setup was widely used on the days when we were finding the proper tuning of the PI loop parameters (Kp and Ki).

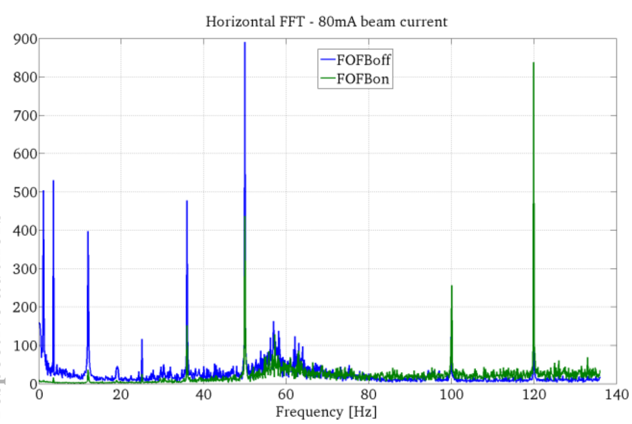

Figure 3: Horizontal FFT of beam position when FOFB was ON and OFF. Trim coil components are identified at 1.2, 3.6, 12, 36 and 120 Hz.

Figures 3 and 4 show the correction capabilities of the FOFB system on an 80 mA beam when using PI loop gains of Kp=0 and Ki=1000. In the FFT spectrum one can identify the components create by the trim coil. The other perturbations at 19 and 25 Hz are from the beam and their sources have not been yet found.

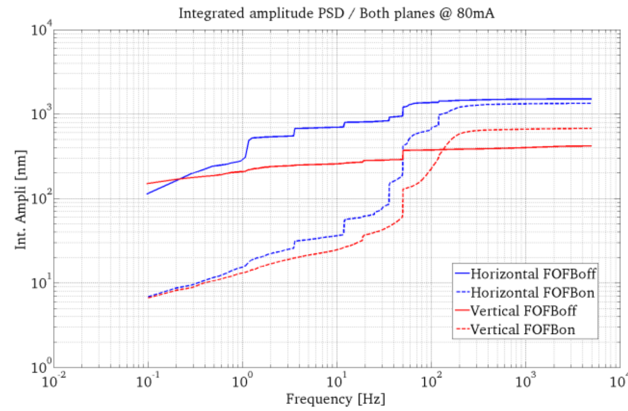

Figure 4: Integrated spectrum of both planes, with FOFB running or not. Beam is excited at different frequencies using a trim coil power supply.

The system properly reduces the contribution of the low frequency components and starts to increase their amplitude for frequencies above ~100 Hz.

Correction of ID Perturbation

ALBA has one super-conducting wiggler, one multipole wiggler, two in-vacuum undulators and two apple-type undulators. For the time being, only the effect of the in-vacuum undulator of XALOC beamline has been analyzed. Figure 5 shows the horizontal and vertical position of the 88 BPMs under different FOFB and ID movement combinations.

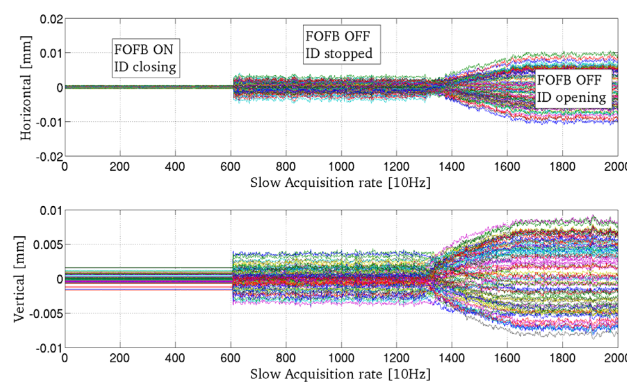

Figure 5: BPMs position when closing/opening the ID.

One can see the overall position correction to the centre of the BPM and also the noise reduction well below the micrometre level, but on a slow rate time scale (10 Hz).

FOFB performance at higher frequencies under same scenario can be seen on Fig. 6 and 7. Integrated noise over the frequency is showed for the BPMs close by the ID and at the source point, typically better since it's usually at the centre of the straight section hosting the ID. FOFB specifications commonly refer to beam stability below 10% of the beam size and beam angle below 10% of beam divergence at the source point. For the particular case of XALOC beamline, the 10% specification refers to position stability below 13.73 um/0.65 um and angle stability below 5.14 urad/0.53 urad for horizontal and vertical planes respectively. Both position and angle stability specs at the source point are accomplished at any given frequency when using ALBA FOFB.

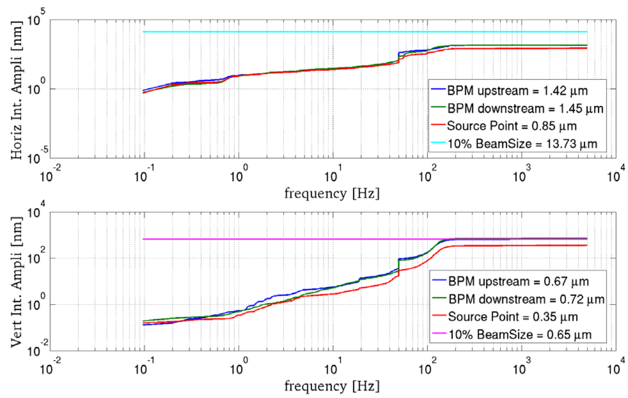

Figure 6: Beam position stability at source point wrt specification of 10% of beam size.

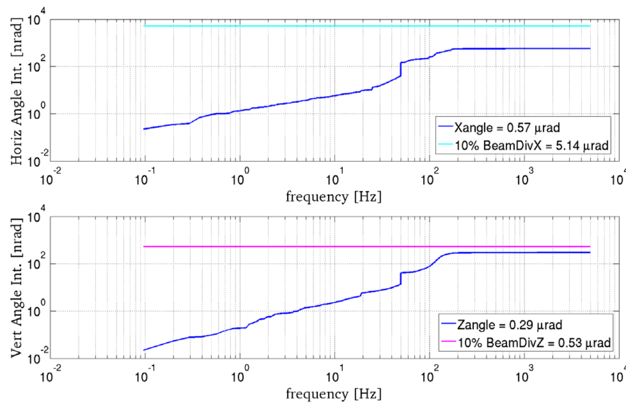

Figure 7: Beam angle stability at source point wrt specification of 10% of beam divergence.

PROBLEMS AND IMPROVEMENTS

Commissioning phase of any system is the time to face problems and to try different solutions and improvements. Here we report about some of them.

Wrong Corrector Setting

After a long shutdown period in April'14, the FOFB behavior was completely spoiled for unknown reasons. Figures 8 and 9 show a performance comparison before and after the shutdown when running the FOFB on a 15 mA beam. No problem was seen when FOFB was OFF. After discussion with Diamond colleagues, they suggested to do a tracking of all the correctors setpoints calculated by the FOFB. That needed some extra programming to be able to store 10 seconds of data on all 176 correctors at a 5 kHz rate and post-process it. The analysis of the data showed that one particular vertical corrector was introducing the perturbation to the beam on the region around 30 Hz (Fig. 10). Deeper investigation on that corrector power supply confirmed that its internal PI regulator was not properly configured.

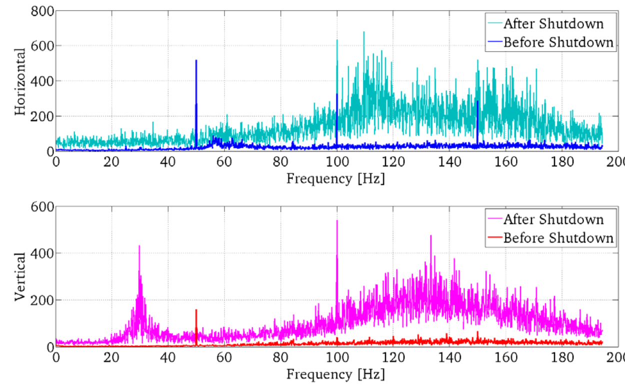

Figure 8: FFT spectrum comparison before and after the shutdown when running the FOFB @ 15 mA beam.

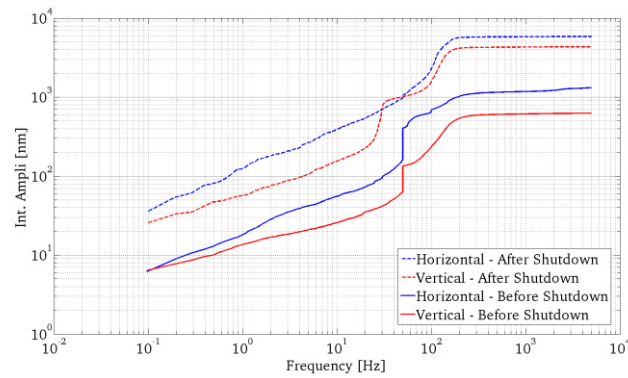

Figure 9: Integrated spectrum comparison before and after the shutdown when running the FOFB @ 15 mA beam.

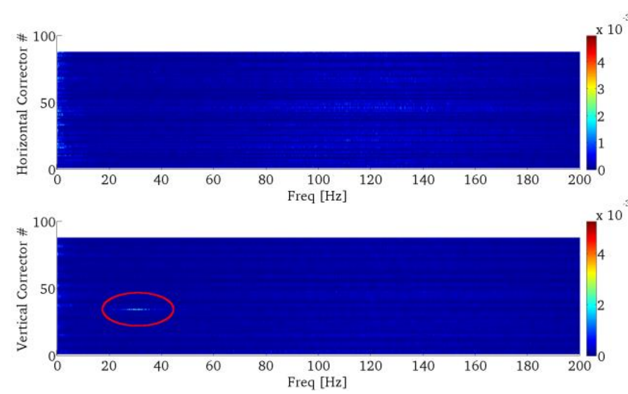

Figure 10: Frequency map of the 88H and 88V correctors setpoints calculated by the FOFB.

Kickers Pulse Suppression

ALBA aims to run in Top-Up mode by the end of 2014, with periodic injections every 10 minutes at a 3 Hz rate. Until now, while running in decay mode, the effect of the injector on the beam orbit has not been an issue since shutters were closed and beamlines not operating during the injection. The study of the effect of the injection kicker magnets on the orbit has revealed a horizontal perturbation near the mm at some BPMs, especially if the injection bump is not properly closed. First tests of Top-up injection together with FOFB showed an orbit

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distortion after the kicker pulse due to the FOFB system, which tries to correct the high frequency kicker pulse perturbation (and obviously it cannot).

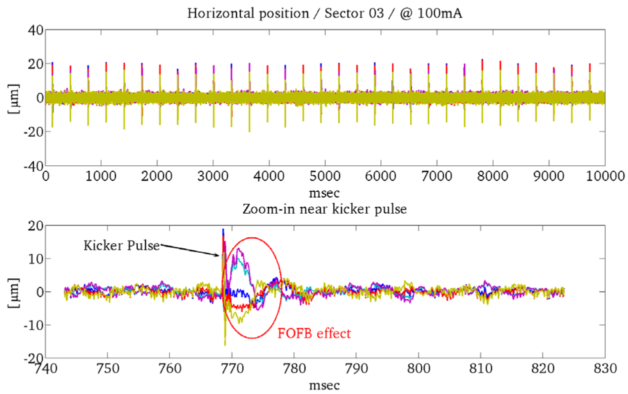

Figure 11: Kicker pulse position distortion and FOFB effect seen on 5 BPMs.

Figure 11 shows the position distortion due to the 3 Hz kicker pulses during a 10 seconds injection. Plot at the bottom is a zoom-in version near one of the kicker pulses. It can be seen both the kicker pulse position perturbation and the effect of the FOFB system trying to correct that perturbation. Figures 12 and 13 show how the noise reduction changes when FOFB and injector are running or not.

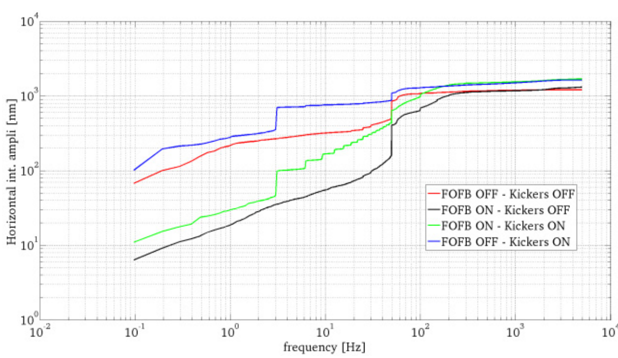

Figure 12: Horizontal comparison for different FOFB and injector status.

The 3 Hz and its harmonics can be clearly seen on the spectrum and are not properly corrected by the FOFB. Even under these conditions, the FOFB is capable to correct the perturbations inside specs up to 200 Hz (10% Vertical Beam size is 0.65 um).

We tried the system to ignore the kicker pulse by defining position limits beyond which the FOFB should not correct, but first attempts ran without success and just degraded the FOFB performance.

Correctors Bandwidth

One of the last improvements we have tried is the modification of the correctors power supplies bandwidth. Intention is to push a bit forward the correction capabilities of the FOFB loop, aiming to have a better high frequency correction.

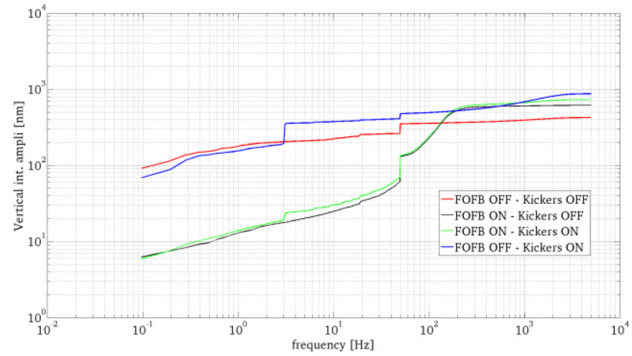

Figure 13: Vertical comparison for different FOFB and injector status.

Figure 14 shows the preliminary results we obtained just before summer shutdown. Improvement is little but confirms that we are on the good way. Note that test has been done on a 15 mA beam, so results will be better (lower noise) on a standard 100-150 mA beam.

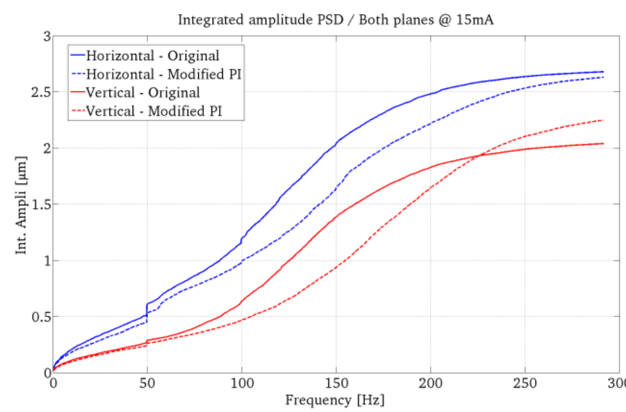

Figure 14: Integrated spectrum improvement when using the modified PI regulator for the correctors power supplies on a 15 mA beam.

NEXT STEPS AND FUTURE PLANS

Filtering of 50 Hz Component

The 50 Hz perturbation is the main contributor to the noise spectrum in our storage ring and its reduction will improve the FOFB overall performance. Even though the system already meets the ALBA FOFB specifications, intention is to implement a Notch-type filter on the computation CPU to go further. The way to do it is nowadays under discussion.

Interlocking of the FOFB

The main pending task regarding the commissioning of the FOFB is to ensure the loop reliability. On such a fast system, the failing of a BPM or a corrector power supply leads to an immediate beam loss due to wrong beam steering. Checks and limitations on position values and correctors setpoints have to be implemented at a 5k Hz rate in order to interlock the FOFB system in a controlled

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way and do not kill the beam. Recovery of FOFB operation after such an interlock is also to be defined.

Upgrade of the FOFB System

The use of already obsolete electronics and the system limitations we found since day one pushed us to think on a future system upgrade. Main purpose of the upgrade is the replacement of the PMC-FPGA board, hosting the BPMs position reading, and the replacement of the CPU, in charge of the correction calculation.

The upgrade will be done in two phases. First phase will change the current Micro-Research EVR-230 FPGA boards [2] by AFC2310-A0 electronics from IOxOS [4]. This first phase upgrade will bring following improvements:

- Better FOFB redundancy and reliability since new electronics have 2 SFP ports to be used as optical links for BPMs position data transfer (current electronics do only have one SFP port).
- More powerful and longer lifetime Xilinx Virtex-6T FPGA (current Virtex-II FPGA is obsolete)
- Increase of position transfer speed to 10 kHz to have a higher FOFB bandwidth (now we run at 5 kHz).
- Two input ports could be used to synchronize the FOFB in all sectors and to disable the correction during the duration of the injection kicker pulses.

The main tasks that have to be done on phase I are the integration of the Diamond Communication Controller [5] on the new boards and the migration of the correction computation from the CPU to the FPGA.

Upgrade phase II is based on the modification of the correctors power supplies interfacing. Intention is to migrate the controllers of the correctors that are embedded on the IP modules to the new FPGA. To accomplish that, a modification on the cPCI crates has been done to use the backplane I/O connector to drive the correctors power supplies. An intermediate board will be needed to change signals from electrical to optical.

Pictures of the IOxOS boards are showed on Fig. 15. A total of 20 boards have been already received (16 needed + 4 spares), together with the SFP-optical transceivers.

Figure 15: New PMC-FPGA board from IOxOS (side and front views).

SUMMARY

The ALBA FOFB has showed its correction capabilities and has demonstrated that matches its specifications. Different problems have been faced during the commissioning phase and some improvements have been already implemented. Deeper testing of the system and programming developments are still to be done, especially on all referring to reliability and time to recover after a failure. The plan for the future upgrade is on the way and main devices for that are already on the site.

ACKNOWLEDGMENT

We would like to thank the organizers and attendants of the first DEELS workshop at ESRF [6] for the fruitful discussions we have with them before, after and during the workshop.

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