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FIRST EXPERIENCES WITH THE NEW PILOT-TONE-BASED eBPM SYSTEM IN ELETTRA STORAGE RING

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Abstract

This paper presents the first experiences acquired with the new eBPM system based on pilot tone compensation, developed for Elettra 2.0. After the successful delivery of seven complete systems, belonging to a pre-series production within the signed partnership with Instrumentation Technologies, we started their integration in the current machine, in order to gain experience and develop all the functionalities required for the future commissioning of the new accelerator, scheduled for 2026. To do so, an entire section of Elettra storage ring has been equipped with the new systems: eight Libera Electron units have been replaced by eight Pilot Tone Front End (PTFE) and four digital platforms (DAQ10SX). Tests were carried out during dedicated machine shifts, focusing on integration with the new global orbit feedback at different data rates (10 kHz, 100 kHz and turn-by-turn), with and without pilot tone compensation. Nevertheless, triggered acquisitions were made in order to test first turn capability of the system. Another unit has been attached to a pair of spare pick-ups (low-gap BPMs), to continue the development of new features and to provide different types of data (raw ADC data, turn-by-turn calculated positions, etc.) for machine physics studies, even during user-dedicated shifts.

INTRODUCTION

In previous papers we presented the global development of the new eBPM (electron beam position monitoring) system for Elettra 2.0, the low-emittance upgrade of the present lightsource based in Trieste, Italy, starting from the proof of concept regarding the pilot tone compensation [1], going through the integration of the first prototype in Elettra's global orbit feedback [2] and finally with the industrialization and series production of the complete system thanks to the partnership signed with Instrumentation Technologies [3, 4]. In this paper we present the first experiences with the new electronics installed in a cell of the current machine, and its operation with the new Global Orbit Feedback system.

SYSTEM INSTALLATION

Thanks to the modular design, we followed a modular design, the analog front end with pilot tone injection (PTFE) is separated from the digital unit (DAQ). The front ends have been installed in Elettra tunnel and connected to eight existing BPM pick-ups of section 6, as shown in Fig. 1. Every DAQ unit is capable to acquire signals from two BPMs. Moreover, for machine physics studies, another pair of front ends have been connected to two low-gap spare BPMs in section 7 (Fig. 2), not involved in orbit calculation and thus available anytime.

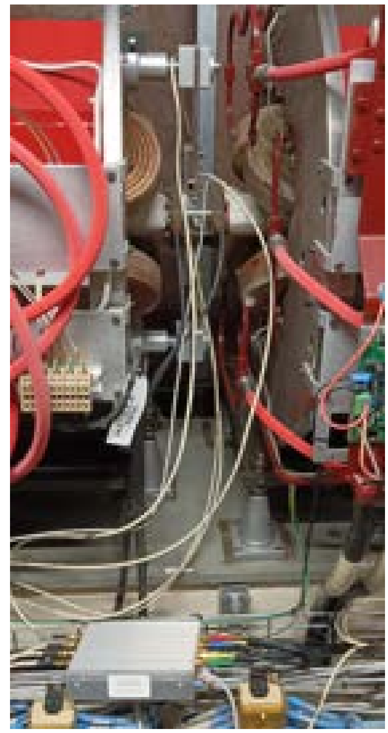

Figure 1: PTFEs in Elettra tunnel connected to BPM pick-ups.

Figure 2: PTFE connected to low-gap BPMs.

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The digital units have been installed in Elettra service area (Fig. 3) side by side with older Libera Electron electronics and connected to two separate networks: the former for housekeeping and configuration, the latter, with 10 Gbit optical Ethernet connections, for feedbacks only. Figure 4 explains the distribution of useful timing and trigger signals to the electronics, like machine revolution clock (MC) for global synchronization and injection event (INJ).

Figure 3: Digital units in Elettra service area.

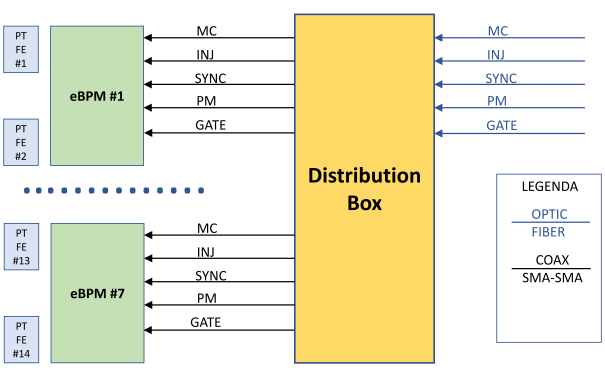

Figure 4: Timing signals.

DPDK AND FAST GLOBAL ORBIT FEEDBACK (GOF)

The Data Plane Development Kit (DPDK) is a critical framework enabling high-performance packet processing by allowing direct interaction with network hardware. DPDK is an industrial-grade solution widely used across various fields, including telecommunications, cloud computing, and research [5]. In particular it is vital for real-time applications at Elettra [6], where both low latency and high throughput are essential.

One of the main objectives of the latest fast orbit feedback upgrade is the integration of eight new BPMs into a test bench designed to closely simulate the operating conditions of Elettra 2.0. Additional goals include evaluating the hardware/software processing and network platforms [7], and addressing the limitations of the legacy fast orbit feedback system's processing power. These limitations had previously prevented the system from effectively eliminating noise from the aging power supplies, which are over 30 years old and produce harmonics up to 1 kHz due to the gradual deterioration of out of maintenance components.

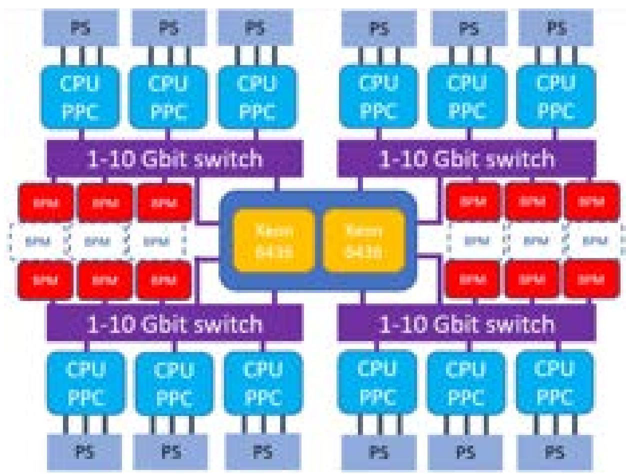

Figure 5: Global orbit feedback architecture.

The new system (see Fig. 5), while is not the Elettra 2.0 configuration (which will be based on Xeon 6-P processors), already offers significant advancements. It is equipped with four 100 Gbit ports for receiving data from the BPMs and four 10 Gbit ports dedicated to setting the power supplies. The Intel drivers used in DPDK have been modified to disable the Interrupt Moderation Rate, which previously introduced a 30 µs random latency in packet reception. The legacy correction system's CPUs now serve only as bridges, receiving settings and applying them to the DAC boards of the power supplies, instead of processing data from the Libera units. In this upgraded system, each network interface is supported by two dedicated cores. Additionally, there is one core dedicated to calculation, one for processing triggered data, and another core specifically for dynamic feedback gain control to prevent instability.

TESTS WITH BEAM

First Turn

We started testing first turn operation mode, that will be the most useful during Elettra 2.0 commissioning. After extracting a single bunch of 0.75 mA coming from the booster, we inserted a fluorescent screen in the storage ring to stop it after one turn. Figure 6 depicts raw signal seen by ADCs, setting the maximum available gain on the front ends and powering off the pilot tone. The residual charge that is not completely stopped by the screen can be seen

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exactly 130 samples after the main signal, corresponding to one turn.

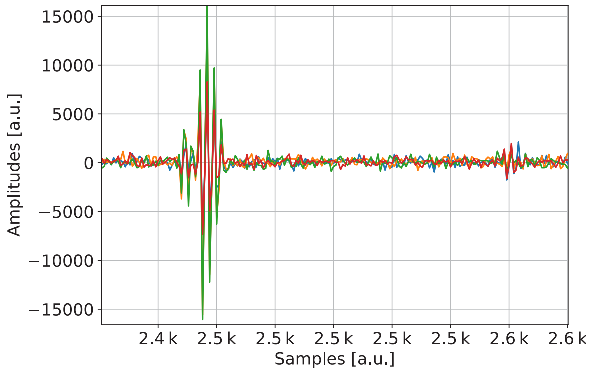

Figure 6: Raw ADC data during single pass injection.

Raw ADC Data Triggered by Injection

Thanks to INJ signal, it is possible to retrieve raw ADC data synchronous to injection process, thus enabling tune calculation. Figure 7 is the fast Fourier transform (FFT) of raw ADC data, centered and zoomed in to 499.654 MHz. Tune sidebands are clearly visible during injection with stored beam at nominal current: horizontal tune is at 0.347 kHz from the carrier, while vertical tune is at 0.231 kHz (respectively 0.4 and 0.2 of the revolution frequency).

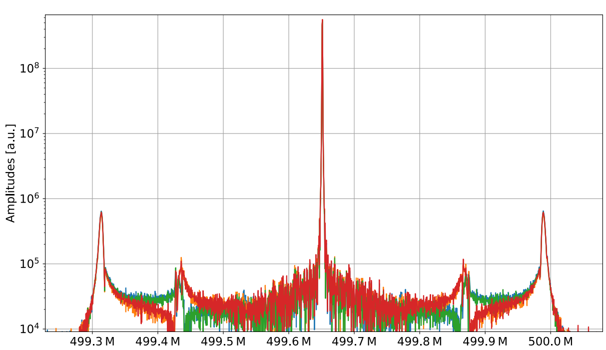

Figure 7: FFT of raw ADC data during injection with stored beam.

Feedback Integration

This enhanced setup has been operational under user conditions for over a month without any issues, seamlessly replacing the previous system without requiring modifications to high-level programs or graphical interfaces. Apart for the enhancement in the orbit stability, the system provides additional diagnostics that were not previously available in old Elettra storage ring, such as the capability of acquiring both data streams at 1.15 MHz and long ADC buffers from the new BPM electronics in parallel to feedback processing.

The control algorithms in the new system include a PID controller for feedback, along with 13 notch filters at frequencies of 50, 100, 150, 200, 250, 300, 350, 400, 500, 600, 700, 800, and 900 Hz, effectively suppressing periodic disturbances (see Figure 8). The total calculation time for these processes is just 10 microseconds. Moreover, the system is highly efficient in matrix computation, requiring only 9 seconds to update both the horizontal and vertical matrices.

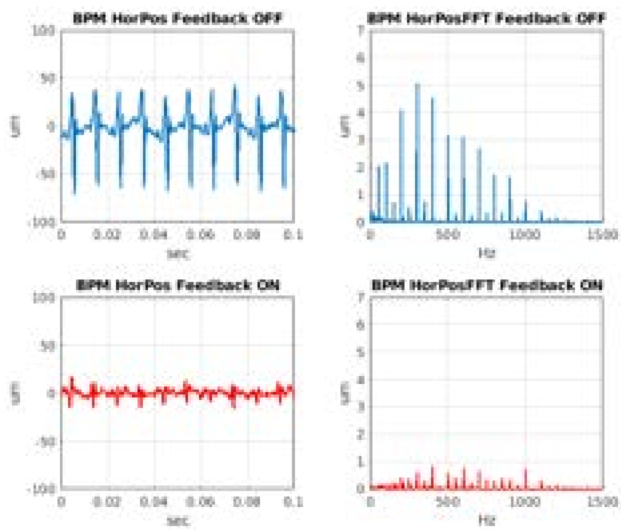

Figure 8: Power supply periodic noise suppression by the upgraded GOF

Figures 9 and 10 show various comparisons in terms of beam positions' cumulative power spectral density (CPS). While the former confirms the noise reduction due to the feedback, in the latter it can be seen the usefulness of pilot tone compensation in reducing 1/f correlated noise at low frequencies, with respect to uncompensated positions.

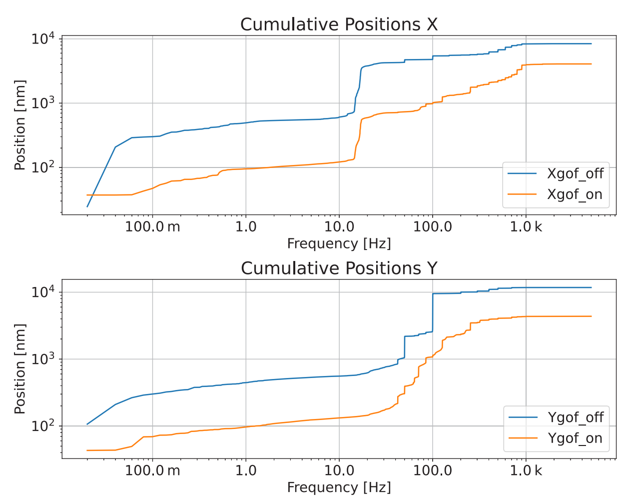

Figure 9: Beam positions CPS with feedback disabled and enabled.

CONCLUSION

We successfully replaced a complete section of Elettra storage ring with new eBPM electronics based on pilot tone compensation, and integrated them in the control infrastructure of the current machine, enabling orbit correction and

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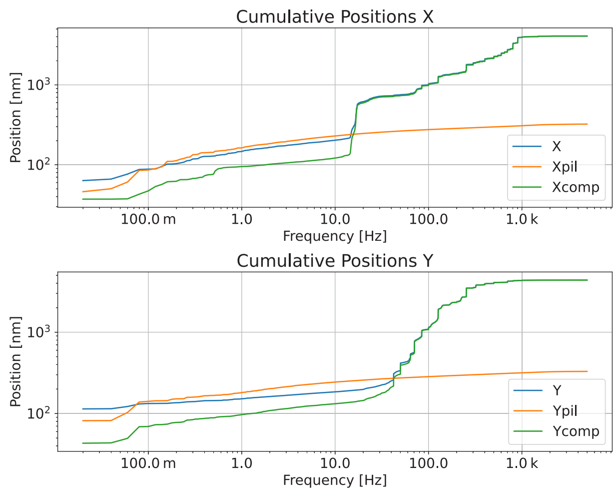

Figure 10: Pilot, compensated and uncompensated beam positions CPS with feedback enabled.

simultaneous operation with the remaining Libera Electron BPMs in the upgraded global orbit feedback.

This transition has allowed us to test the new system's ability to handle the increased demands of Elettra 2.0, demonstrating its readiness for the upcoming full-scale implementation.

The next steps will involve the replacement of a second complete section, as well as the continuous development of firmware and software in order to increase the user-friendliness and reliability of the new system, together with the preparation and testing of the infrastructure prior to the commissioning of Elettra 2.0.

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