

# RECENT DIAGNOSTIC UPGRADES AT THE SOLARIS STORAGE RING

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## Abstract

This work summarizes the most significant diagnostic upgrades that have been implemented, as well as those currently under development, at the SOLARIS synchrotron facility. These include the installation, startup, and initial testing of a Bunch-by-Bunch Feedback (BBFB) system that is currently being implemented at the SOLARIS synchrotron. Once operational, the BBFB system will provide real-time corrections on a per-bunch basis, significantly enhancing beam stability. Efforts are also underway to develop a system for measuring the vertical and horizontal tunes without disturbing the electron beam. Additionally, a beam loss monitoring system is being developed and installed. Complementing these activities, numerous diagnostic scripts have been created, including those that utilize fast acquisition and turn-by-turn data from beam position monitors.

## INTRODUCTION

As part of the ongoing commitment to operational excellence and research advancement, the SOLARIS synchrotron facility continuously refines its diagnostic systems. Accurate, real-time diagnostics are essential for maintaining beam stability, optimizing performance, and ensuring safe operation of the accelerator and beamlines.

This update provides an overview of recent improvements and innovations implemented across SOLARIS diagnostics, covering developments in feedback system as slow and fast orbit feedback for orbit correction (SOFB and FOFB), bunch-by-bunch feedback system (BBFB) and beam loss monitoring (BLM). Additionally diagnostics scripts are developed to support daily operation and increase the performance of implemented systems. By integrating modern technologies and enhancing system responsiveness, SOLARIS aims to support increasingly sophisticated user experiments and maintain alignment with international standards in synchrotron operation.

## ORBIT CORRECTION SYSTEMS

A key area of progress is the orbit correction system, which has undergone significant improvements. The Slow Orbit Feedback (SOFB) system has been completely redesigned and accelerated by over an order of magnitude. In parallel, the successful development and implementation of the Fast Orbit Feedback (FOFB) system have brought further refinement to beam stability [1]. To ensure harmonious operation between both systems, an offloading procedure was introduced, effectively mitigating conflicts between SOFB and FOFB processes. [1]. Collectively, these advancements

have enabled submicron precision in electron beam stability and reproducibility—representing a major milestone in the performance capabilities of the facility clearly visible below in Fig. 1.

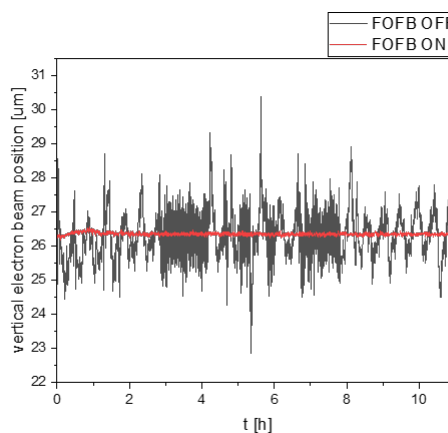


Figure 1: Vertical electron beam orbit comparison: FOFB ON vs. FOFB OFF.

## BUNCH-BY-BUNCH FEEDBACK

In December 2024, a Bunch-by-Bunch Feedback (BBFB) system [2] was installed in the SOLARIS storage ring, based on a Dimtel front-end and HUBERT A1020 amplifiers. For signal acquisition from the beam, we used an existing Beam Position Monitor (BPM), while a stripline with electrodes rotated by 45 degrees with respect to the horizontal and vertical planes was used to apply the correction signals.

The system operates in transverse mode only. Following installation, it required initial configuration, after which it enabled tune measurements and instability detection. An additional feature tested was bunch cleaning, which, based on the currently installed components, is functional for beam energies below 1 GeV. This function was successfully used during beam lifetime measurements, example of modified filling pattern presented in Fig. 2.

Moreover, the application of a positive feedback loop to a single bunch enabled precise tune measurement using the tracking functionality, providing valuable diagnostic data for machine optimization. Figures 3 and 4 show measurement of tune change during beam current decay, performed during system installation.

The system is currently fully operational and is used during routine operation as well as for periodic measurements, such as beam lifetime studies and tune measurement.

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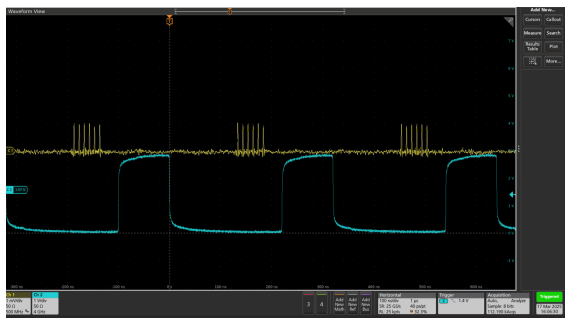


Figure 2: Filling pattern after bunch cleaning procedure. Yellow signal from fast photodiode represent bunches separated by 10 ns, 320 ns revolution period marked on cyan.

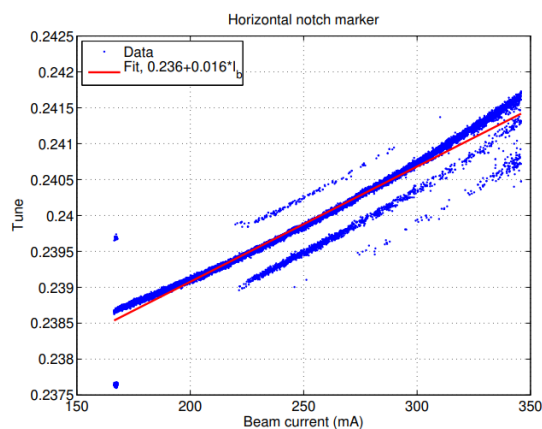


Figure 3: Horizontal tune change during beam current decay.

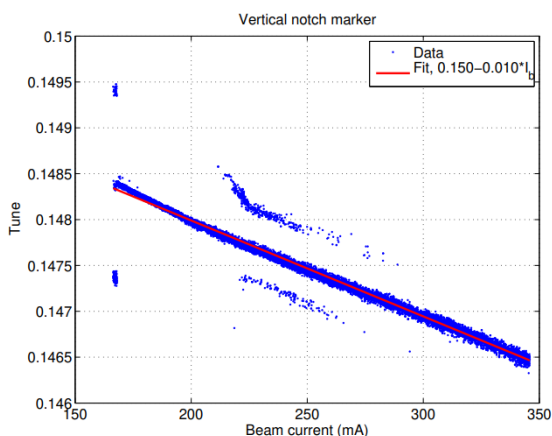


Figure 4: Vertical tune change during beam current decay.

## BEAM LOSS MONITORING

The Libera BLM is a Beam Loss Monitor Readout System that, when combined with a compatible beam loss detector, forms a complete beam loss monitoring system. At the SOLARIS Synchrotron, three of these BLMs have been installed, along with 12 detectors strategically positioned throughout the ring (Fig. 5).

The system is engineered around a 4-channel, 125 MHz digitizer, implementing signal processing specifically cus-

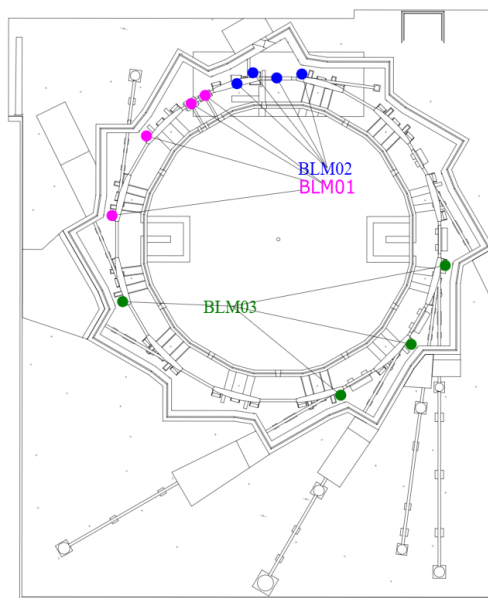


Figure 5: Layout map of detectors and beam loss monitors in the SOLARIS synchrotron storage ring.

tomized for storage rings. It provides power supply and gain control connections for photo-multipliers within beam loss detectors. Its internal electronics feature low power consumption and full Power-over-Ethernet (PoE) compatibility. The instrument's core is a Xilinx Zynq, integrating a dual-core ARM CPU with an FPGA. Its primary function is the acquisition of signals from four channels and the subsequent storage of both raw and processed data into RAM, which can then be retrieved over Ethernet by the control system. We have integrated it into our Tango control system and added its signals to archiving expanding our diagnostics with new data, for instance, as shown in the Fig. 6 illustrating signals measured during the beam dump process.

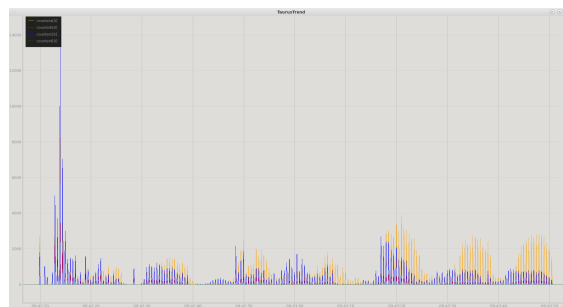


Figure 6: Sample signals from BLM during the beam dump process.

## DIAGNOSTIC SCRIPTS

### *FOFB Watchdog*

New operational and diagnostic scripts are continuously being developed. One example is a script that monitors the performance of fast orbit feedback (FOFB). Its primary

role is to monitor the currents of fast correctors and to react appropriately if the correctors saturate, exceeding 2 A. In such a case, the correctors are gradually relaxed to low values in a slow process so as not to disturb the electron beam like presented in Fig. 7. Subsequently, the FOFB is restarted automatically, without any need for operator intervention.

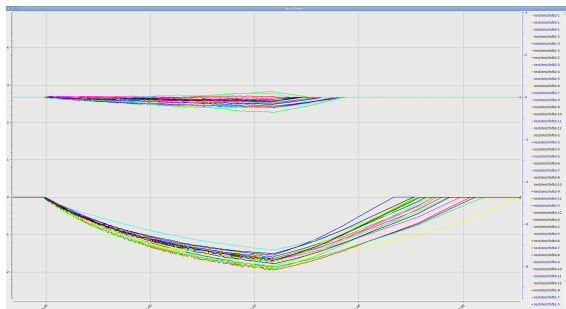


Figure 7: The FOFB watchdog script in action: once the saturation threshold is exceeded, the currents of the fast correctors are gradually brought to zero.

## ML

The Machine Learning (ML) model based on Long Term Short Memory (LSTM) [3] neural network is applied in order to increase the correction capabilities of standard systems (scan based correction tables). LSTM infrastructure was chosen because of the dependence of each input on one another (corrector magnets settings) and the periodicity of the signal. To ensure accurate comparison between the predicted currents and the actual measurements presented in Fig. 8, a dedicated device server was implemented to interface the neural network with the correctors of beamline 05 ID. This setup enabled continuous, long-term monitoring and data acquisition, facilitating reliable validation of the model's performance under real operating conditions.

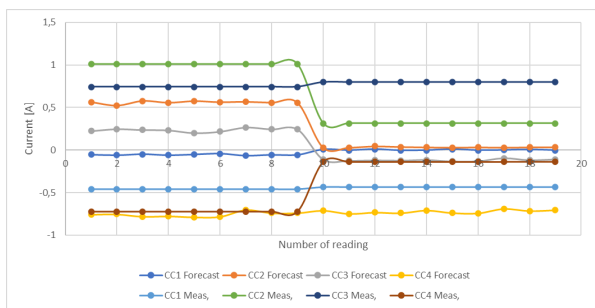


Figure 8: Comparison of forecasted and measured beamline 05 ID correctors currents.

It is possible to change the model during the operation in addition the user can preview the used network type, its architecture and the number of free parameters. Currently the server uses ML model based on TensorFlow [4].

## CONCLUSION

Significant upgrades to beam diagnostics and control systems at the SOLARIS storage ring have enhanced operational stability and precision. The Bunch-by-Bunch Feedback (BBFB) system now enables real-time, per-bunch corrections, improving beam stability and enabling advanced diagnostics. Fast Orbit Feedback (FOFB), optimized with a watchdog script, achieves submicron stability, while Slow Orbit Feedback (SOFB) improvements ensure long-term orbit reproducibility. The new Beam Loss Monitoring (BLM) system offers essential diagnostics for beam dump events and machine protection, fully integrated into the Tango control system. Diagnostic scripts, including machine learning-based corrector predictions, have streamlined operations and reduced manual workload. Ongoing work aims to expand BLM coverage and refine predictive models to further enhance beam stability and support the increasing needs of SOLARIS users.

## ACKNOWLEDGEMENTS

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