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BEAM LOSS MONITORING SYSTEM AT SOLARIS

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Abstract

The SOLARIS storage ring is equipped with a set of twelve Beam Loss Detectors, operated via Libera Beam Loss Monitors. This system significantly enhances the facility's ability to monitor and analyze beam losses, contributing to improved operational efficiency and machine protection. The detectors are strategically positioned around the storage ring and along the transfer line, enabling optimization of injection losses and precise localization of beam loss events.

Real-time monitoring allows for rapid identification and mitigation of abnormal loss patterns, thereby improving overall beam stability and reliability. The data collected by the system support beam lifetime studies and offer valuable insights for future performance diagnostics and machine optimization.

INTRODUCTION

SOLARIS National Synchrotron Radiation Centre located in Kraków, Poland, is a third-generation synchrotron radiation light source, where ensuring high operational reliability is a key priority [1]. In early 2025, the facility commissioned a new beam loss monitoring system based on Libera Beam Loss Monitors (BLM), developed by Instrumentation Technologies [2]. The system is designed to precisely detect and quantify beam loss events, contributing to improved machine protection and performance optimization.

Effective beam loss monitoring is essential for safeguarding accelerator components and maintaining stable operation. The integration of the Libera BLM system into the SOLARIS control environment represents a significant enhancement of the facility's diagnostic infrastructure. It enables real-time detection of loss patterns, supports beam lifetime studies, and provides valuable data for future performance analysis and machine tuning.

HARDWARE

The beam loss monitoring system at SOLARIS consists of twelve Libera Beam Loss Detectors (BLDs) connected to three Libera BLM units. Each BLD incorporates an EJ-200 plastic scintillator coupled to a photomultiplier tube (PMT), which converts the detected radiation into an electrical pulse proportional to its intensity [3]. To minimize background noise from low-energy radiation, each scintillator is enclosed in a 2 mm thick lead housing, ensuring sensitivity to beam loss events while suppressing unwanted signals.

Signals from the PMTs are transmitted to the Libera BLM units, which serve as central data acquisition and processing modules. Each BLM is equipped with a high-speed, four-channel analog-to-digital converter (ADC) operating at 125 MHz, enabling precise digitization of the detector signals. The system is synchronized with the machine's revolution clock, allowing accurate correlation of beam loss events with the longitudinal position in the accelerator and other operational parameters.

Through real-time signal processing, the BLM system provides essential feedback for beam tuning, loss mitigation, and machine protection. It plays a key role in improving operational reliability and supports advanced diagnostics, including beam lifetime studies and performance optimization. Similar systems were implemented in other facilities like ESRF [4] with later upgrade [5], SOLEIL [6] or SPEAR3 [7].

DEPLOYMENT

The Beam Loss Detector units were strategically deployed at locations identified as most sensitive to potential beam instabilities and loss events. Within the storage ring, detectors were installed near critical components such as the RF accelerating cavities, Landau cavities, and selected insertion devices. Additionally, two BLDs were positioned along the transfer line—one near the end of the LINAC and the other immediately after the injection section (Fig. 1).

The majority of detectors were placed on the outer side of the storage ring, specifically at the entrances to the bending sections, where beam losses are expected to be most pronounced due to increased dispersion and reduced dynamic aperture. This configuration ensures comprehensive coverage of both routine operational conditions and non-standard loss scenarios.

Such a distribution enables precise localization of beam loss events and facilitates correlation with beam dynamics simulations and other diagnostic systems. It also supports optimization of injection efficiency and contributes to improved machine protection and operational reliability.

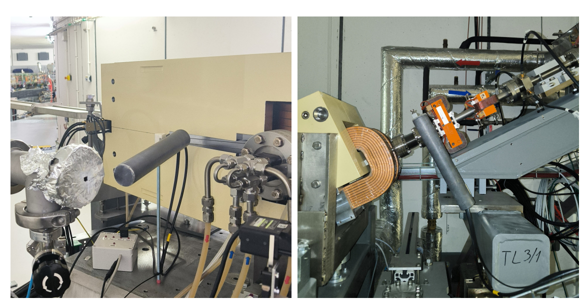

Figure 1: Beam Loss Detector enclosed in lead shielding, installed in the storage ring (left) and along the transfer line (right).

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SYSTEM INTEGRATION

During the initial stages of system deployment, the Libera Beam Loss Monitor (BLM) web graphical user interface (GUI) proved to be a highly effective and user-friendly tool for verifying system functionality and configuration. The interface is accessible via an HTTP connection to the device's IP address, allowing quick validation of detector responses and system status.

Following successful hardware installation, a dedicated device server was implemented within the TANGO control system for all BLM units. This server is now used for continuous data acquisition and archiving. Figure 2 presents a test version of the BLM web GUI developed using the Taranta framework [8], where BLD devices are visualized on a machine layout alongside radiation monitoring stations. This prototype represents the first graphical interface at SOLARIS built in Taranta and lays the foundation for future migration of additional control system interfaces to this platform.

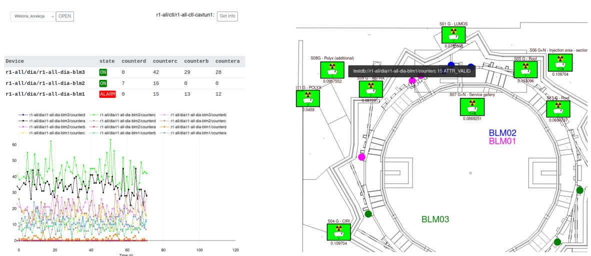

Figure 2: Beam Loss Monitoring GUI displaying radiation monitoring stations (green squares) and Beam Loss Detector locations (purple, blue, and dark green dots) overlaid on the machine layout.

MEASUREMENTS

The primary objective of implementing the Beam Loss Monitoring system at SOLARIS was to enable long-term observation and analysis of beam loss patterns in the storage ring. Particular emphasis was placed on configuring the system in its counter measurement mode, which counts the number of beam loss events occurring between triggers from the synchrotron's master oscillator. The acquisition offset and window settings were adjusted to capture losses across the entire bunch train. Although various windowing configurations were tested, the BLM device server lacked comprehensive parameter reporting, limiting the ability to fully evaluate their impact.

The ADC in the BLM system operates with a maximum sampling period of 8 ns, and isolated loss events are typically identified using three sample points. Given the bucket spacing at SOLARIS is 10 ns, the system does not provide bunch-by-bunch resolution for beam loss detection. Nevertheless, it remains a valuable tool for identifying broader loss trends and anomalies.

Beam Loss During Injection Procedure

Prior to the installation of the BLM system, it was observed that during injection into the storage ring, there were instances where the accumulated charge failed to increase, and the signal on the transfer line disappeared. After deployment of the BLM system, the detector positioned along the transfer line confirmed this anomaly, indicating that the issue likely originates in the LINAC rather than in the accumulation process.

During standard injection, the BLM counter typically registers 6–7 counts (see Fig. 3). However, when the beam loss anomaly occurs, the counter reports zero counts, suggesting that no beam reaches the transfer line during these events. This insight has proven valuable for diagnosing injection inefficiencies and guiding further investigation into LINAC performance.

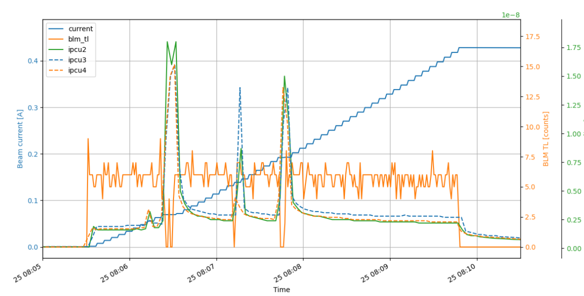

Figure 3: Beam loss during the injection procedure. The accumulated beam current (blue) stops increasing as vacuum pressure rises in the gun section (green), while the BLD counter signal (orange) reflects the presence or absence of beam loss events.

Beam Loss During Insertion Device Movement

Libera BLD devices are installed at critical locations around the storage ring to monitor beam losses under various operating conditions. During user operation, variations in BLM counter readings are particularly noticeable near insertion devices, especially around beamline 06, which is equipped with an undulator source. These changes are illustrated in Fig. 4.

A clear correlation has been observed between the movement of the insertion device gap, associated phase shifts, and a reduction in BLM counts. This relationship is summarized in Table 1, highlighting the sensitivity of the BLM system to dynamic changes in beamline configuration and its usefulness for operational diagnostics.

Table 1: BLD at Bending Magnet (BM06) Counter Events

Undulator Gap	BLD BM06 Counter
200 mm	25 - 30 counts
40 mm	10 - 15 counts
14 mm	0 - 3 counts

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When the phase shift is varied at a gap of 14 mm, a noticeable reduction in beam loss counts is observed across multiple BLD devices installed around the storage ring. This indicates a clear sensitivity of the system to changes in insertion device configuration. In contrast, when the gap is opened beyond 20 mm, no such effect is detected, suggesting that beam losses under these conditions are negligible or below the detection threshold of the system.

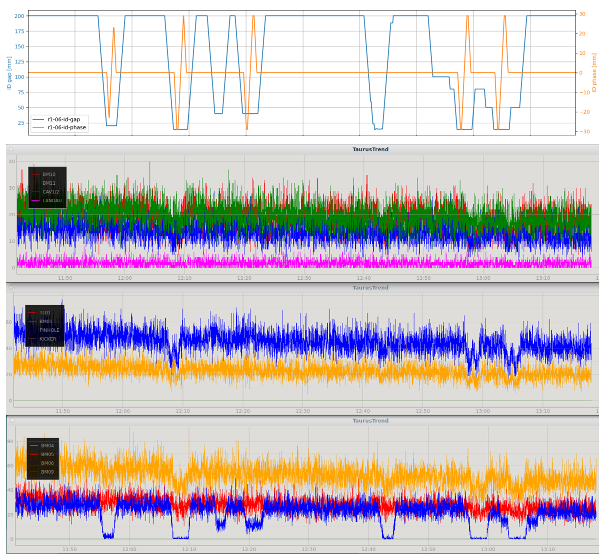

Figure 4: Beam loss during insertion device movement.

Post-Shutdown Injection Performance

Following the scheduled 35-day facility shutdown, operational difficulties were encountered during the recommissioning phase, particularly in the injection process and the subsequent accumulation of beam in the storage ring. Compared with pre-shutdown operation, a significant increase in the beam loss monitor signal was observed along the transfer line connecting the linear accelerator to the storage ring. As shown in Fig. 5, the BLM TL counter previously read 6–7 counts, whereas afterward it ranged from 12 to 20, displaying a periodic pattern with a period of 15 seconds.

The elevated readings indicate that beam transmission efficiency through the transfer line was reduced relative to baseline conditions, leading to higher losses prior to storage ring injection. These losses imposed a limitation on the achievable accumulation rate and overall injection efficiency. The degradation was consistently reproducible across multiple injection attempts. However, during the recommissioning phase the effect was observed to decrease gradually, suggesting that the system had not yet fully stabilized or reached its optimal thermal state following the extended shutdown period.

Bunch Cleaning

During the bunch cleaning process, illustrated in Fig. 6, the beam loss monitors (BLMs) in the synchrotron register increased counting rates as a direct consequence of removing unwanted particles from the circulating beam. This procedure intentionally excites and ejects particles located outside the nominal RF buckets, causing them to collide with the vacuum chamber walls. The bunch cleaning is performed using the Bunch-by-Bunch Feedback System [9]. The BLM system detects these events as sharp spikes in loss counts, which are synchronized with the applied cleaning cycles. The highest beam loss readings are observed in section 12, where the BLD is installed downstream of the stripline used to excite the bunches.

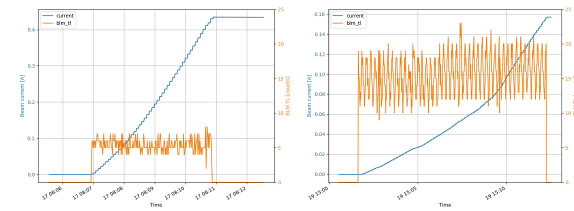

Figure 5: Beam loss at transfer line: accumulated beam current (blue) and transfer line BLD counter (orange). Data recorded before shutdown (left) and after shutdown (right).

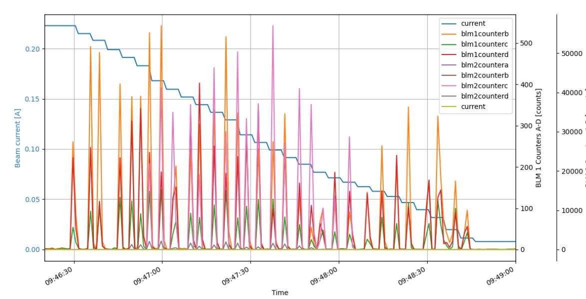

Figure 6: BLM counts during bunch cleaning. Each cleaned bucket is indicated by a drop in beam current and a corresponding spike in BLD readings.

CONCLUSION

The Libera Beam Loss Monitoring (BLM) system is a valuable addition to the SOLARIS diagnostics suite. Its integration with the Tango control system enables reliable acquisition, visualization, and real-time correlation of BLM data with other machine parameters, supporting both routine operations and in-depth studies during recommissioning. Measurements performed using the BLM system have provided valuable insights into beam loss events, including their locations and probable causes. Future developments will focus on expanding the system's coverage and enhancing its graphical user interface–based control.

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