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NEW APPLICATIONS AND STUDIES WITH THE ESRF BEAM LOSS MONITORING AT INJECTION

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Abstract

More than one year after the commissioning of the ESRF's new Extremely Brilliant Source (EBS), the Beam Loss Detectors (BLDs) are continuing to be used for extensive applications and studies, notably at injection. A total of 144 BLDs and 36 associated Libera Beam Loss Monitors (BLMs) are distributed in the EBS ring and the Booster. These BLDs allow to measure slow losses during user-mode operation and fast losses at injection, with a sub-orbit-turn time resolution. In this paper these fast beam loss dynamics are presented at injection for different lattice parameters, collimator-settings and beam conditions. We will also show the excellent correlation with results obtained from the injection efficiency diagnostic and the bunch length acquired with the Streak Camera.

INTRODUCTION

The new Extreme Brilliant Source (EBS) ring at the European Synchrotron Radiation Facility (ESRF) has been installed, commissioned and it is now operational since mid-2020. The 6-GeV and 200-mA electron beam has typically horizontal and vertical emittances of 120-pm and 10-pm, respectively, with a typical beam lifetime of above 20 hours. This allows to generate a coherent and bright x-ray beam for the scientific users [1].

One of the useful accelerator diagnostics present in EBS are the Beam Loss Detectors (BLDs), to measure the distribution of the lost electrons around the accelerator [2]. Since the EBS commissioning phase, 128 BLDs have been installed, calibrated, exploited for Machine Dedicated Time (MDTs) studies and USM-mode operation. Additional 8 BLDs have been installed in the Booster, 4 in the injection zone and 4 in the extraction area. And in the Transfer Line from Booster to the EBS ring another 4 extra BLDs had been installed. In March 2021 and for a couple of months other 4 BLDs have been positioned near the Radio Frequency (RF) cavities of cell 25 to study critical events and dynamics. The total of 144 units of BLDs are controlled by 36 Beam Loss Monitors (BLMs) [3, 4].

The BLDs can be used to measure slow losses during operation and fast losses at injection. In User-mode there are about $5\cdot10^7$ lost electrons per second around the EBS ring, while at each injection it is about $2\cdot10^9$ lost electrons in less than 3 ms. In this paper we concentrate mainly on the injection mode to understand the BLDs fast functionality, behaviour and performance, in order to improve and to optimize the EBS complex, and to correlate and to verify the BLDs signals with other diagnostics.

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BLDS AT INJECTION MODE

The measurement of fast losses can be extremely useful to describe the beam dynamics and the quality of the injection process. At injection, the BLDs termination switches automatically to 50 Ω, which is needed for the required time-resolution, thereby allowing these fast loss measurements.

For a standard 200-mA beam and a uniform filling pattern, the typical distribution of the injection losses is displayed on Fig. 1. In y-axis the BLD position is displayed, considering the standard 128 BLDs installed from cell 1 to cell 32. In x-axis the time is plotted up to 2800 µs, equivalent to 1000 turns. The losses are differently distributed depending on BLD position, aperture limitations, machine and beam parameters. An interesting feature visible in Fig. 1 is a periodic recurrence, measured by some the most critical BLDs, such as:

- BLD n.61, after the Insertion Device (ID) of cell 16, that is often one of the smallest gaps,
- BLD n.96, after the collimator of cell 24.

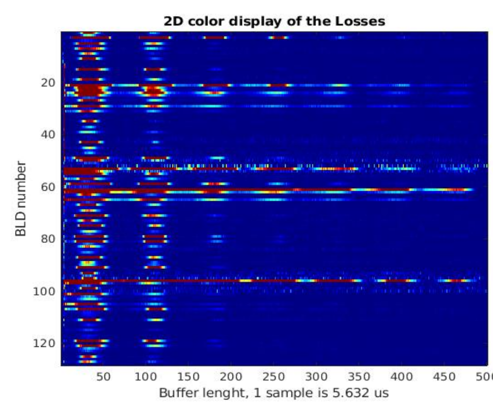

Figure 1: 2D color display of the Losses around EBS, for a 200 mA uniform-filling pattern beam.

The evolution of a single BLD can be analysed to identify the above-mentioned periodicity. In Fig. 2 the so-called Time-Resolved Beam Losses are displayed for the BLD n.96, installed in the middle of the fourth dipole after the collimator of cell 24. A big loss peak is present on the first turns, followed by damped oscillations with a 0.4 ms periodicity. These periodic losses are linked to bunch length oscillations occurring at injection, and presented below.

The evolution in time can also be summed-up so to generate a single value per BLD, the so-called Integrated Injection Losses. The distribution of these losses is reported in Fig. 3. The highest losses are registered on BLDs n.61 and n.96. At each injection, the Integrated

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Injection Losses are automatically recorded and saved in the ESRF database.

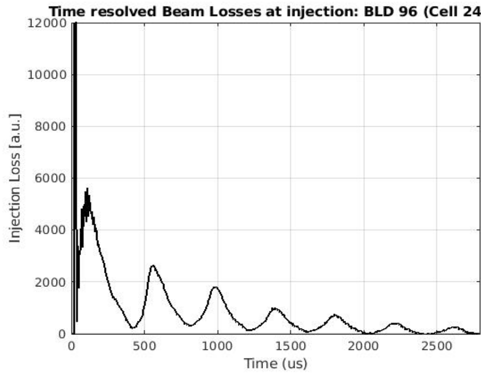

Figure 2: Time-Resolved Beam Losses of BLD n.96, installed down-stream the collimator of cell 24.

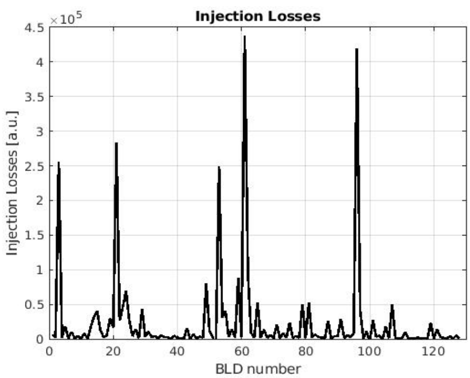

Figure 3: Distribution of the Integrated Injection Losses of the standard 128 BLDs installed in EBS.

As presented above, the 2D-color map, the Time-Resolved Beam Losses, and the Integrated Injection Losses give useful spatial and time informations at injection. In addition, the 2-D color display can be integrated both in time and space, to get a representative value of the losses, called Total Injection Loss, calculated for each injected shot.

MACHINE PARAMETER OPTIMIZATION

One useful application concerns the study of the Time-Resolved Beam Losses as a function of different machine parameters, in order to gain understanding of the BLDs characteristics and to optimize the EBS ring.

The first measurement is about the loss evolution as a function of the aperture of the vertical scraper installed in cell 6, scanned from 4 mm to 10 mm. Fig. 4 shows the fast behaviour of BLD n.24, that sits just after the scraper, as a function of time. The smaller the vertical aperture, the stronger the losses after the scraper, as expected. The losses show a big peak at the first turns, followed by two smaller bumps that appear at around 120 µs and 620 µs, respectively. The losses increase below a 6 mm gap.

The second measurement focuses on the loss evolution as a function of the horizontal collimator apertures (cell 13 and cell 24). The fast losses recorded on BLD n.53 are plotted in Fig. 5. The losses drastically change below a 6 mm gap. Also in this case, the big initial peak corresponds to the losses of the first turns, followed by two additional bumps that appear at the same timestamps as before.

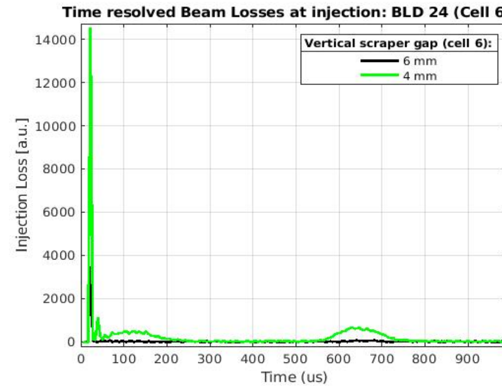

Figure 4: The Time-Resolved Beam Losses of BLD n.24 as a function of the scraper aperture.

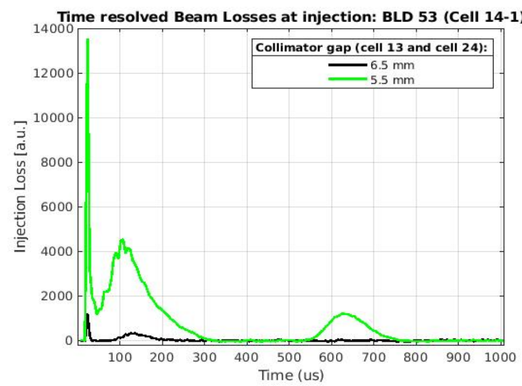

Figure 5: The Time-Resolved Beam Losses of BLD n.53 as a function of the collimator apertures.

The third measurement concerns the sum of all the Time-Resolved Beam Losses as a function of the RF-phase of the Booster with respect to RF-phase of the EBS ring (Fig. 6).

When degrading the optimum phase from -62 to -32 degrees, the losses increase as expected, especially those on the second bump centred at 120 µs. The worst the Booster-to-SR phase matching, the stronger the losses and the weaker the injection efficiency. Therefore, the BLDs fast losses can be an extremely useful measurement to help improving the performance of the injection process.

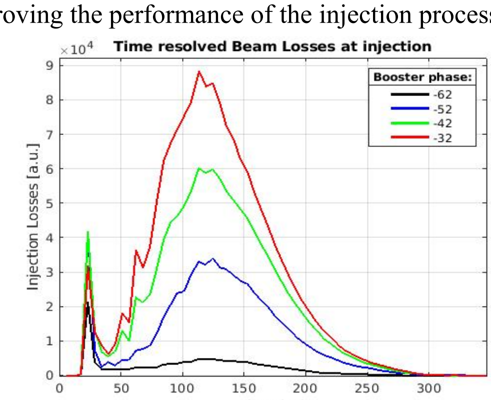

Figure 6: Total sum of the injected Beam Losses as a function of the Booster phase.

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BLDS VS OTHER DIAGNOSTICS

In order to verify the proper reliability of the BLDs, the beam loss readings have been compared with two completely different diagnostics. The first comparison concerns the Time-Resolved Beam Losses and the Injected Bunch Length measured with a Streak Camera (Hamamatsu, series C10910) installed in the ID04 lab [5]. The second is about the Total Injection Losses and the Lost Current calculated from the Transfer Efficiency System.

BLDs vs Streak Camera

The dual time-base Streak Camera (SC) installed in the ID04 lab can be used to measure the bunch length of the stored and injected beam, thanks to its installation in the EBS injection zone (cell 4). A typical image acquired with the SC is displayed in Fig. 7, for an injected beam.

The SC fast sweep operates in the so-called synchro-scan mode at 88 MHz (i.e. exactly a fourth of the EBS RF frequency) thereby allowing to repeat that ultra-fast sweep at this 88 MHz, along the y-axis. In addition to that the dual-time axis module provides a 2nd, much slower sweep, along the x-axis. The combination of the above produces images of two visible streaks in the output. In that the (fast) bunch length image is continuously projected along the y-axis, while being repeated along that slower time (x-axis). In these images the injection occurs on the left side and the (slow) time scale runs from left to right. Calculations on these images then provide bunch-length (y-axis) at different moments after the injection (x-axis).

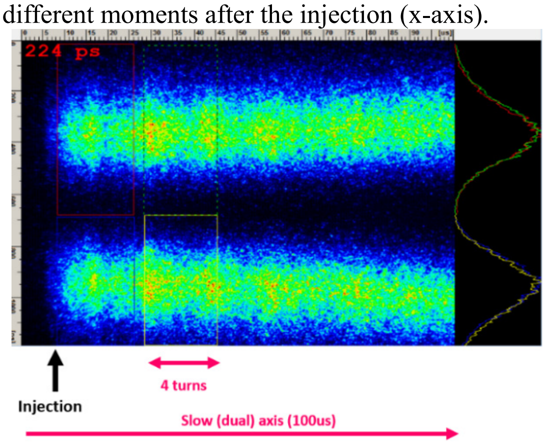

Figure 7: A typical image acquired with the SC, where two streaks of bunches are recorded in parallel for a Booster RF voltage of 7 MV.

An interest study concerned the comparison between the fluctuations of the bunch length (immediately following the injection) of the injected beam on one hand, with the fluctuations of the fast beam losses measured by the BLDs on the other hand. An example of SC measurement is shown in Fig. 8, for a horizontal time scale of 5 ms. The intensity variations in such image correspond to bunch length variations.

This is presented in Fig. 9, for the 1.3 to 2.9 ms after injection. It shows clearly oscillations of the bunch length with a 0.4 ms periodicity. There is also a decrease of bunch length with time as is fully expected.

The periodicity of the bunch length oscillations has a strong resemblance with the Time-Resolved Beam Losses recorded by some BLDs (see Fig. 2). Therefore, we can confirm that the oscillations visible on the injection losses are linked to the bunch length dynamics over the first few milliseconds.

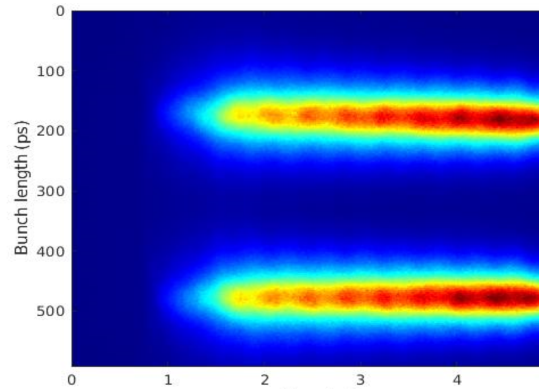

Figure 8: The bunch length fluctuations occurring for a few milliseconds after injection are clearly visible.

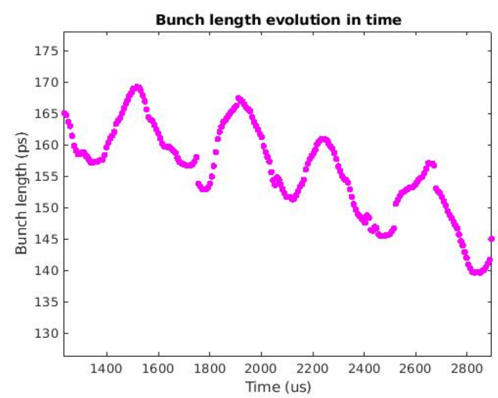

Figure 9: The bunch length evolution is displayed between 1.3 ms and 2.9 ms. The bunch length oscillates and decreases with time.

BLDs vs Injection Efficiency Diagnostic

The injection efficiency between Booster and EBS ring is measured at each injection shot with a fully separate and independent diagnostic called the injection efficiency monitor. It measures both the current (in fact charge, number of electrons) in the Booster (B), and the added current (charge, number of electrons) in the EBS (E). Next to monitoring the injection efficiency (the division of E with B), it can also calculate the Lost Injected Current, which is simply B-E.

The measurement presented below concerns a standard refill during the USM operation, with a filling scheme of 7/8 multibunch and a single bunch. The refill process is composed of three steps, filled respectively with 2 bunches, 4 bunches and one single bunch.

In Fig. 10 the normalised Total Injection Losses (obtained from the BLDs) and this Lost Current (from the injection efficiency monitor) are plotted for more than hundred injection shots. It shows a very good agreement between these two totally independent measurements. The

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BLDs signals are fully proportional to the Lost Current so therefore the BLDs in injection mode generate trustful signals also at injection.

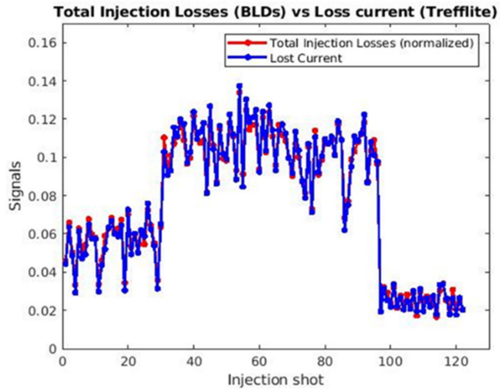

Figure 10: The total Injection Losses from the BLDs and the Lost Current from the injection efficiency monitor.

INJECTION AND EXTRACTION LOSSES IN THE BOOSTER

In the Booster 4 BLDs are positioned in the injection zone and other 4 in the extraction zone, to identify, respectively, the injection and the extraction losses.

The Figure 11 shows the results of the first BLD, positioned at close vicinity to the Transfer Line (Linac to Booster). During a standard refill, two distinct events are visible on this BLD: the injection process and the so-called bunch cleaning that is carried-out about 15 ms after the injection. This cleaning system uses a scraper (in this injection zone) to remove electrons from RF-buckets that are to be fully empty in order to satisfy special requirements of time-resolved experiments with X-rays from EBS.

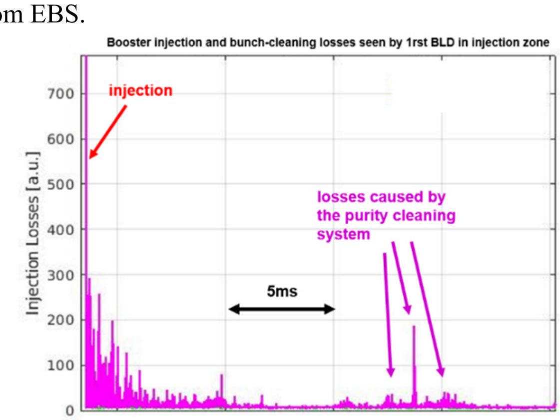

Figure 11: Both injection losses and specific bunch cleaning losses detected in the injection zone of the Booster.

In the extraction zone, interesting losses related to the Booster extraction process are visible on all 4 BLDs (see Fig. 12). The strong rise of these losses starts about 400 us before extraction and shows an oscillatory behaviour that is caused by the complex extraction process itself in which three slow bumpers, one pulse septum magnet and one fast extraction kicker are involved. New tests and studies are planned to further investigate these extraction losses as a function of bumper and kicker parameters.

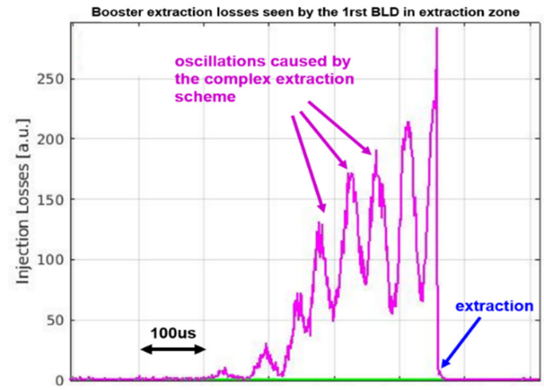

Figure 12: The losses seen in the extraction zone of the Booster. 400 us prior to the extraction moment a strong rise of the losses occurs with an oscillatory behaviour.

CONCLUSION

At ESRF, the BLDs have been intensively and systematically used in EBS, especially now at injection. These time-resolved injection losses have a high potential of helping with the improvement of some of the parameters of both the Injector and the EBS. These fast losses agree very well with other diagnostics, such as the Transfer Efficiency monitor and the Streak Camera. In the Booster, a separate set of BLDs can identify the injection, the bunch cleaning and the extraction processes.

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