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CMOS BASED BEAM LOSS MONITOR AT THE SLS

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Abstract

For several years, the SLS storage ring was not equipped with loss monitors to observe loss patterns around the storage ring; hence, any understanding of the operational losses, accidental losses, or manual beam dumps was missing. Initially, a long quartz fibre (350 m) was installed around the ring to locate losses, and read out with a photomultiplier tube. With the long fibre, we garnered some understanding yet, it was not easy to locate the position of the losses. Hence, we opted for scintillator based fibre loss monitors, installed in choice locations. All the fibres are read out together with a single CMOS based 2.3 MP camera. A device was built with 28 channels. Ten fibres were connected and are located in the injection kicker in the BTRL and three arcs of the storage ring. With these loss monitors, we were able to detect and locate the position of losses due to injection and sudden beam dumps/losses.

In this paper, we will introduce the concept and the components of this monitor, and present the data processing algorithm that identifies the individual fibres in the images, allowing us to locate and track the losses in the SLS storage ring.

INTRODUCTION

At SLS 2.0 [1], loss monitors will be used to monitor beam losses from the Booster-to-Ring transfer line down to the storage ring and around it, to detect low charge on-axis injection and provide loss patterns around the storage ring during filling and top-up operation. For commissioning and daily operation of the storage ring and insertion device protection, loss monitors that can detect "fast" losses (~100 ms) from faults or beam perturbations from injection are needed. The fast losses can be correlated to sudden changes in lifetime. We also need to identify "slow" losses that influence lifetime during standard operation.

At SwissFEL, a beam loss monitor system based on plastic fibre scintillators and photomultiplier tubes as detectors was developed [2]. This system was custom built for the stringent requirements of SwissFEL, where hardware interface to the machine protection system was required for dynamic regulation of beam rate to ensure operability of the facility within the allowed limits.

For the SLS 2.0, we took the SwissFEL BLM approach of distributed scintillating fibres and exchanged the single photomultiplier tube (PMT) per fibre readout with a CMOS camera because the camera would allow observing multiple fibres, simultaneously. A proof of principle experiment was carried out at the end of the injection straight by losing single injected bunches into the SLS storage ring. The CMOS camera was able to detect losses from the scintillating fibres. A prototype BLM system was built in-house that can accommodate 28 fibres. Presented in this paper is the CMOS based BLM, the image processing and first results from the system installed in the SLS storage ring.

LOSS MONITOR SYSTEM

The beam losses cause scintillation light inside the scintillating fibres (Saint Gobain, BCF12 [3]), which is carried out of the tunnel with duplex plastic optical fibres (POF). One end of the POF is connected to an LED [4] for calibration purposes and the other end of the fibre is connected to the camera. The fibres from the tunnel connect to the front panel. The box that contains all the components of the system can be seen in Fig. 1a.

The beam loss system has the following functionalities:

- camera and LED control
- read the CMOS with a computer
- image the light from the fibres
- identify the individual fibres
- calibrate the fibres with LEDs
- display the measurements graphically
- archive the loss data

Hardware

The fibres that connect to the front panel are coupled to a bunch of short fibres inside the box. These fibres are arranged in a dense array by a holder that also serves to shield the fibres from each other and the external light (Fig. 1b). This holder also doubles as a polishing holder for the fibres. All fibre ends have been polished for improved light throughput.

The camera images the fibre holder with two objectives together in a tandem configuration. The focus of both objectives is set to infinity, such that the fibres, located at the flange focal distance of the first objective lens, are imaged onto the CMOS sensor located at the flange focal distance of the second lens. This system allows for a good light collection efficiency with two large-aperture, infinity-corrected objectives. The imaging ratio is the ratio of the focal lengths of the two lenses. We used objectives with f=50 mm and f=16 mm, respectively, resulting in a magnification of M = –1/3.125.

The image sensor is read out by a Jetson Nano [5] through a USB port. Software, written in Python, processes the images and makes the data available to the control system.

A fully functioning setup is installed in the rack at the SLS in a compact housing. All components inside the box and the front panels can be seen in Fig. 1.

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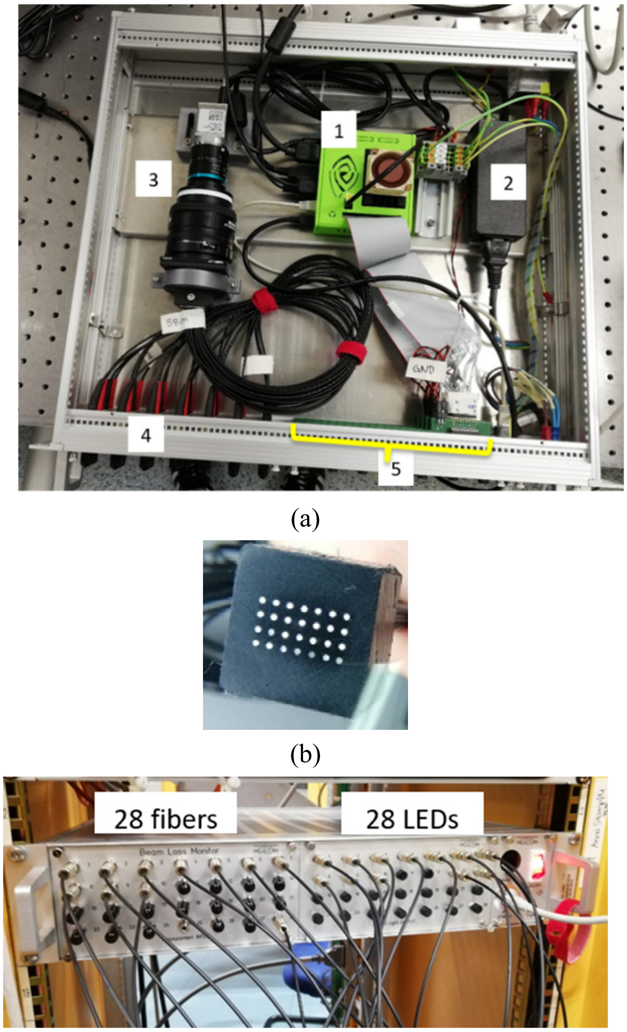

(a)

(b)

(c)

Figure 1: (a) Inside the BLM system, where 1 is the Jetson nano CPU to control system and process data, 2 is the Jetson nano's power supply, 3 is the camera with the objective lenses in tandem, 4 is where the fibres from the tunnel are connected, and 5 are the LEDs. (b) Shows the fibre holder that is imaged by the camera. (c) Front panel of the system mounted in an electronics rack at the SLS.

Image Analysis

The raw camera image is cropped around the fibres as this area is smaller than the entire field-of-view. Since the fibres are arranged in a rectangular pattern of 4x7, a grid can be placed over the image to check the exact alignment of the fibre holder.

All LEDs are switched on to create a bit. The bit mask is then multiplied to every image acquired with the camera mask (see Fig 2). The sum of the area of each fibre yields a value that indicates the light intensity from each fibre, or the loss detected.

All LEDs are imaged one-by-one with a short fibre, and the composite LED image is also used to normalize the variation of intensity between the LEDs (Fig. 3). Once the LED responses have been normalized, this "flat field" is used to normalize the fibre responses that connect from the LEDs, to the scintillators inside the tunnel and back to the front panel for imaging.

Once the fibre responses are "flattened", or normalized to the average intensity of the fibres, the images can be subtracted by the dark image (no beam) and fibre areas are integrated to track beam losses.

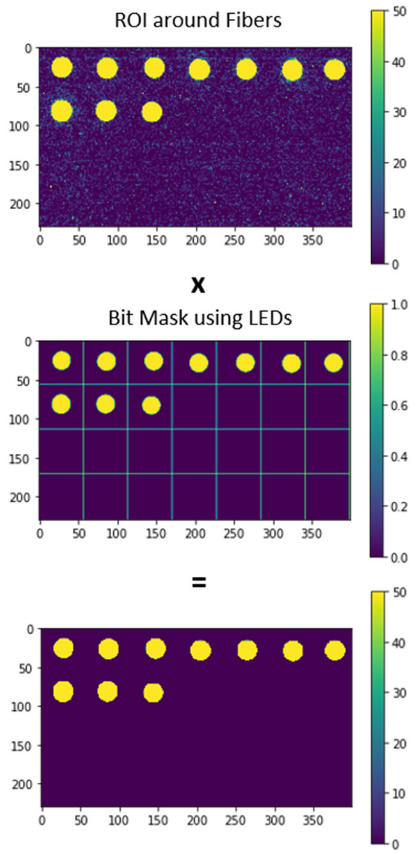

Figure 2: Figure shows how the fibres areas identified. The integrated fibre area gives the loss value.

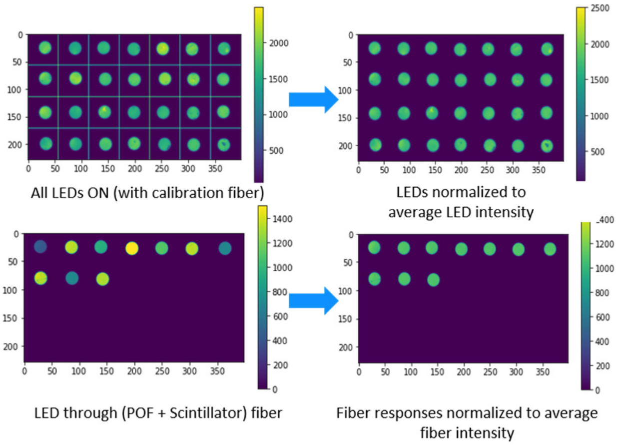

Figure 3: The LEDs are normalized to their average intensity with a short calibration fibre, and then the normalized LED response is used to normalize the response of the POF and scintillator fibres in the tunnel.

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A dark image is calculated by averaging 100 dark images. The dark images are treated same as the raw images and the intensities are subtracted from the fibre intensity values from the raw images.

First Results with Beam

Ten POF duplex fibres, of about 48 m length, were installed at SLS to detect losses from a quarter of the machine. Scintillator coils were made from 2 m scintillator fibres and wrapped around 3D printed holders. An existing map of the radiation hotspots, provided by the radiation safety group, was used to install the scintillator coils in the locations with high probability of seeing losses (Fig. 4).

Data was taken during the filling of the SLS ring after a shutdown. On the day of the measurements, the SLS was experiencing problems with the Booster RF amplifier. Whenever the beam was lost, all the fibres scintillated and when the beam was manually dumped, two fibres scintillated strongly.

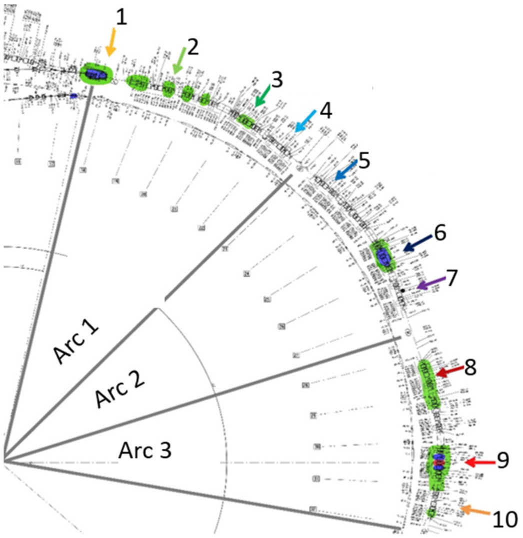

Figure 4: Partial map of SLS showing the locations of the radiation measurements and the ten scintillator fibres.

All disturbances as well as the manual beam dump were measured and can be seen in the plot in Fig. 5 as jumps in fibre intensities. The radiation hotspot corresponds to the last two fibres in the third arc (fibres 9 and 10). This location corresponds to the hotspot measured by the radiation protection group (downstream of second dipole in arc 3), and supports the conjecture that the beam is lost in one location.

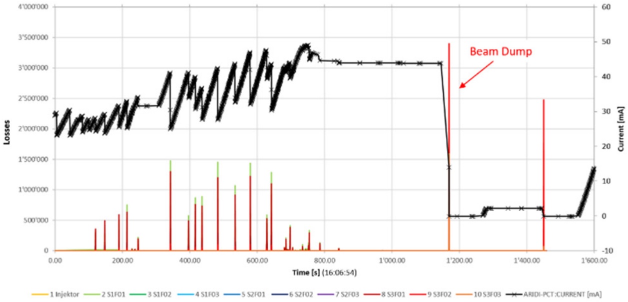

Figure 5: Losses seen over time during machine start up. Booster RF related problems were creating losses in the storage ring that were detected by all fibres. The manual beam dump was detected by two fibres (fibres 9 and 10) that match the hotspot.

CONCLUSION

CMOS based BLM system has proven useful in locating losses around the storage ring, hence, it is good for surveillance. Since a single system hosts 28 fibres, the spatial resolution in locating losses can be easily more than four locations per arc.

Due to the use of a single CMOS camera, this loss monitor system does not allow for turn-by-turn loss detection. However, it does detect injection losses. The CMOS camera makes the system cost effective for the purpose of locating losses.

This system shall be tested at an Undulator exit as a measure of sensitivity for Undulator alignment and protection.

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