FIRST OPERATION OF A FIBER BEAM LOSS MONITOR AT THE SACLA FEL

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Abstract

A fiber-based Cerenkov beam loss monitor (CBLM) has been developed as a quick and long-range detection tool at the SPring-8 angstrom compact free electron laser (SACLA) to control electron beam losses. Based on tests carried out at the 250 MeV SPring-8 Compact SASE Source facility, large core (400 µm), long (>150m) multimode fibers were selected and installed at the SACLA. We report on the first few months of operation of the CBLM. During the commissioning of the X-FEL, the CBLM has performed efficiently, with a detection limit below 1 pC per pulse across the 110 meters of the in-vacuum undulators, and with a position accuracy of less than 1 m.

INTRODUCTION

The SPring-8 angstrom compact free electron laser (maximum electron energy and repetition rate 8.5 GeV and 60 Hz respectively) consists of a 400 m long linac and 110 m long undulators, for a total length of 700 m. As in many advanced light sources, beam losses are a critical issue, both to limit doses outside the machine shielding and to prevent damage to key components: In other words, beam losses should be strictly controlled, and therefore accurately monitored. At the SACLA, radiation safety sets a 0.1% beam loss limit in the undulator hall. To detect such beam losses over more than one hundred meter, in real time, with good position accuracy and sensitivity at a reasonable cost, we chose to develop a fiber-based Cerenkov beam loss monitor [2]: Long, large core optical fibers are set along the vacuum chambers and photo-detectors are used to detect the Cerenkov light emitted by the secondary charger particles as they hit the fibers. While the principle is straightforward and as been used in countless particle detectors, insuring that the minimum detection level is achieved over the whole length of the fiber is a matter of the utmost importance. It is also far from trivial since several factors will limit the usable length of the fiber: The attenuation of the Cerenkov signal due to the fiber attenuation, the dependence of the signal strength on the loss scenario (angle of impact of the primary particle; geometry: in-vacuum type undulator or vacuum beam pipe; etc) and the position (angular and radial) of the fiber with respect to the loss point. A two step approach was followed at SACLA to insure that the required detection sensitivity could be achieved over more than one hundred meters in realistic conditions: First characterization of the fibers (signal strength and attenuation measurements) followed by numerical studies. From these, we concluded that a minimum diameter of 400 µm was necessary and that the Fujikura SC400 would the best compromise [2].

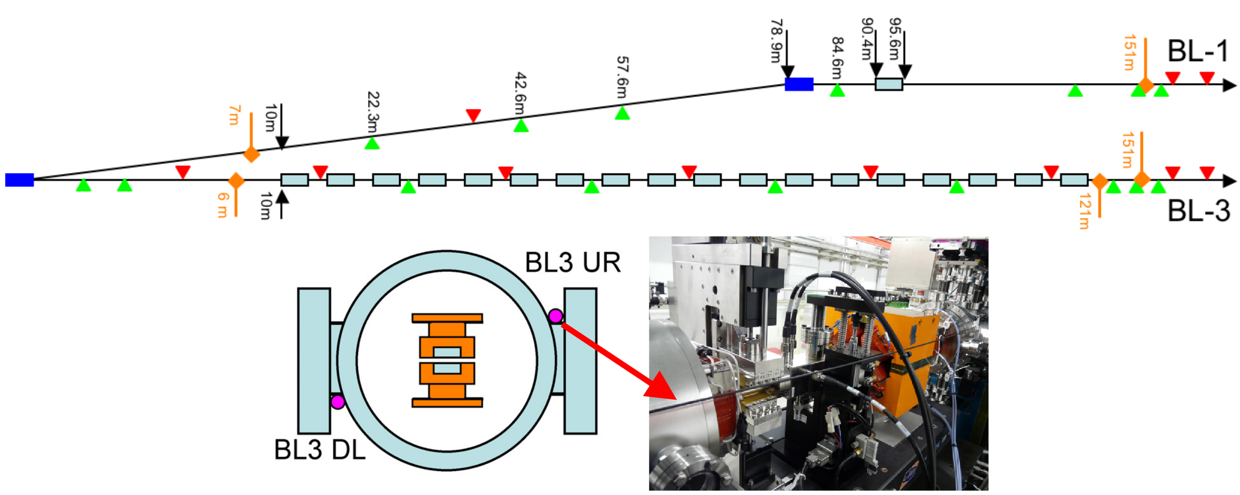

Figure 1: Top: Layout of the beamlines, the electron beam goes from left to right, and is sent into BL-1 (bottom line) or BL3 (top line) with the switching bending magnet (in blue, deflection angle 3º). The distance between the two beamlines is 6 meters at its maximum. The green triangles show the position of the optical radiation transition screens, the red ones, the current monitors. The light grey structures represent the undulators. The start/end positions of the fibers are shown with the orange markers. The distances refer to the length of the fiber. Bottom: The fiber installed on BL-3 (BL3 UR: red arrow). The fibers are set on the vacuum pump flanges (BL3 UR, BL3 DL in pink).

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In the following, we present the CBLM set-up along with some results of the first few months of operation at the SACLA. Prevention of radiation damage, especially demagnetization of the undulator magnets, is also of the highest importance [3]: The magnets of the in-vacuum type undulators are within a few millimetres of the beam and can suffer a direct hit, by miss-steering of the main beam or from the beam halo. SACLA's CBLM served as an early warning tool and played a major role during the commissioning, thanks to its ability to detect losses over the whole 110m length of the undulators.

SET-UP AND USER INTERFACE

The SACLA CBLM consists of three SC400/440 (120m x 1, Signal attenuation 7.8 dB/km; 150m x 2, Signal attenuation 6.8 dB/km) fibers set along the vacuum chambers (Fig. 1). The position of the fibers was chosen by taking into account the constraints imposed by the structure of the in-vacuum type undulator (such as vacuum pumps and flanges in the horizontal plane) and the distribution of the secondary particles generated by a beam loss. All fibers have a FC connector at both end (ease of connection, low insertion loss) and are coated to limit the noise from ambient light. The Cerenkov signal is detected with Hamamatsu H6780-02 photomultipliers (PMT, Minimum wavelength: 300 nm; Maximum wavelength: 880 nm; Equipped with a FC connector) connected at the upstream end of the fiber (with respect to the direction of the electron beam). The signals from the PMTs are transmitted by fifty meter long coaxial cables to a flash analogue-to-digital converter (CAEN V1729A, 4 channels, 14 bits 2GS/s) located outside the shielding wall of the undulator hall. The accelerator master oscillator serves as the time reference to determine the position of the beam loss.

Figure 2 shows the loss monitor graphical user interface, as available in the SCLA control room. It gives the raw ouputs from the PMTs, in other words, uncorrected for the light attenuation, as shot by shot events. The top part of each graph shows a simplified drawing of the beamline (Red: OTR screen monitor; Blue: Bending magnet; Green: Undulator). A log scale is used to visualize small beam losses, and for that purpose the signal is offset by 8 mV. This screen shot has been taken as the beam was sent into BL-1 (Top graph). It is interesting to see that the BL-3 DL fiber, the closest to BL-1 but still 6 meters at its maximum, detects some of the beam losses happening on beamline 1 (Small bumps at 50, 75 and 85 meters). BL-3 UR, mostly located in the shadow of the vacuum chamber of the in-vacuum type undulators does not detect any loss, except for an isolated event at 45m. All data are stored in a database and can be plotted on a shot-by-shot hourly or daily basis for further analysis.

BEAM COMMISSIONING

Beam commissioning started on February 21st 2011. After some tuning, the electron beam was sent into beamline 3, and the gap of the undulators was closed. Figure 3 shows a single shot taken with BL-3 UR fiber. Values have been corrected for attenuation. The gap of the first five undulators is 15 millimeters, and the undulators 7 to 18 have their gap full open (40 mm). As the gap of the undulator 6 is being closed down to 5.3 mm, a significant part of the electron beam hits the upper and lower jaws of this undulator. As a result, significant beam losses are detected in the following sixth undulators. The strongest loss signals are detected at the end and in between the undulators.

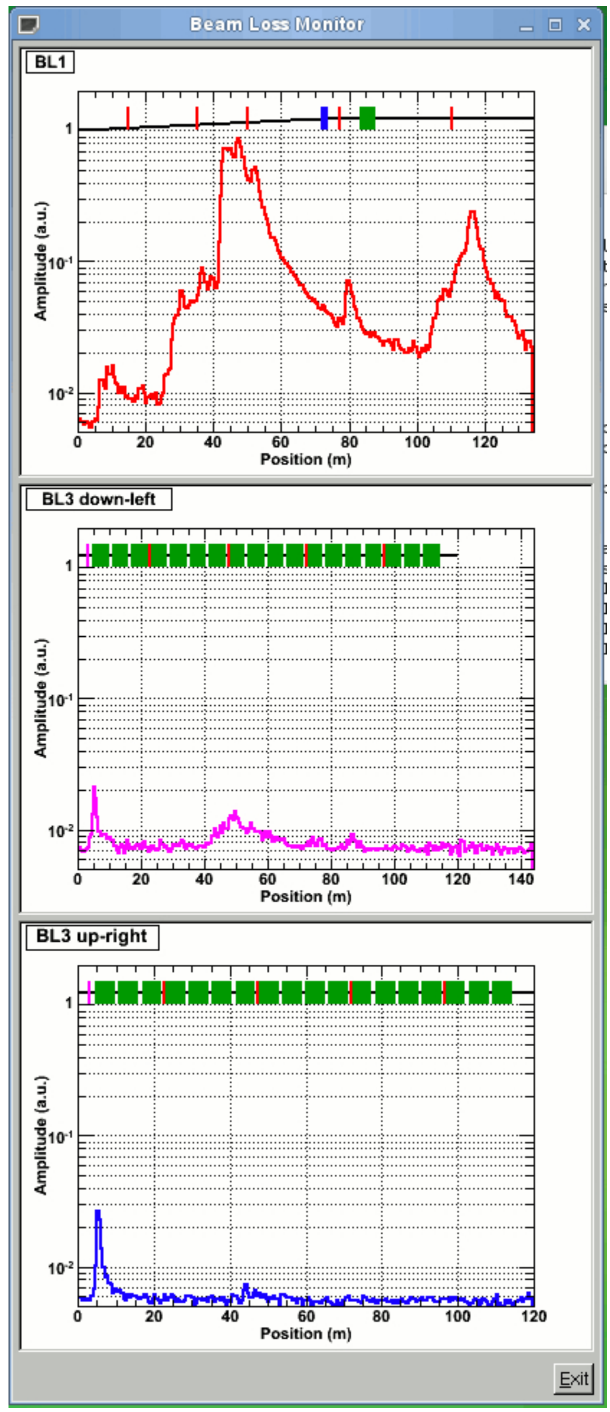

Figure 2: The CBLM graphical user interface.

The total beam loss measured between the switching bending magnet and the beam dump is 79 pC, part being lost in the chicane upstream of the undulators, part as the beam hits the undulators jaws, and part further downstream (such as the beam dump bending magnet). If we assume that all is lost when the beam hits the undulators jaws (i.e.: overestimation of the beam loss), this means that at least an 11 mV signal is generated per pC lost in the undulator. Even with the attenuation of the signal in the fiber over the 110 meters of the undulators (signal divided by 6), the signal can still be detected by the PMT. In other words, the sensitivity of the CBLM is below 1 pC over the 110 meters of the undulators.

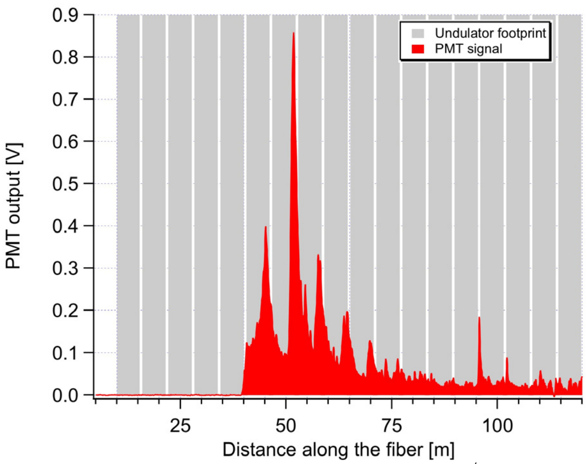

Figure 3: Beam commissioning, March 31st 2011. Signal from the BL-3 UR PMT corrected for attenuation. Part of the beam hits the upper and lower jaws of sixth undulator and generates a shower of secondary particles detected over more than 30 meters. Beam energy: 7.06GeV.

COMPARISON WITH HALO MONITOR

The sensitivity of the CBLM can also be evaluated from the beam loss generated by the halo monitor [4]. Installed 1.5m before the first undulators, it consists of two (upper and lower) diamond blades (with RF fingers) cutting into the halo to measure it. As a part of the halo hits the RF fingers and the diamond blades, a shower of particles can be detected downstream. Fig. 4 shows a typical signal measured by the two fibers installed into BL-3. The charge detected by the halo monitor (2 fC, upper blade) is just above the noise threshold (1.5 fC). For the lower blade no charge is detected. All undulators are open at full gap (40 mm). The strongest beam losses are measured between the undulators, but significant contributions are detected within the first undulators themselves. The beam loss generated by the halo monitor can be detected over more than half the total length of the undulators (≈ 50m).

Given the amplitude of the signal measured, and taking into account the attenuation of the fiber, one can reasonably estimate that the sensitivity of the CBLM could be well below the femto coulomb level (0.3 fC) over the 150 meters of the fibers.

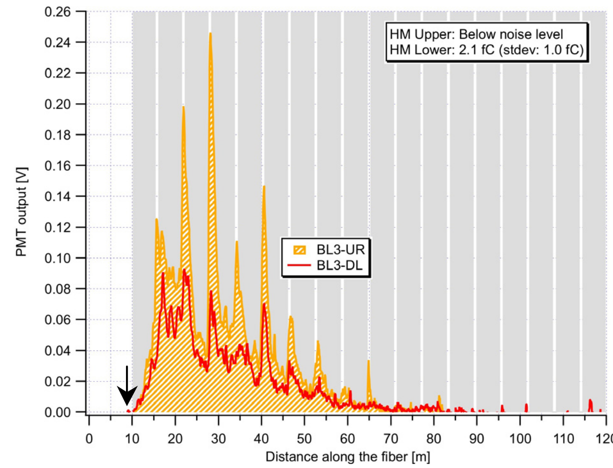

Figure 4: Beam loss detected as the halo monitor is inserted into the beam to measure the beam halo. The data have been corrected for attenuation. The position of the halo monitor is shown by the arrow, and the corresponding small signal at ~ 8.5 m. Beam energy: 7.4 GeV

CONCLUSION

The SACLA Cerenkov beam loss monitor is based on long (150m), large core (400µm) fibers, and provides to the XFEL operators a clear picture of the beam losses in real time and on a shot by shot mode. As the only tool able to detect and locate precisely (<1m) beam losses over the 110 meters of the undulators, it has play a major role during the commissioning of the facility (Minimizing the beam loss on the undulator magnets).

Insuring that a beam loss as low as 1pC could be detected over the whole length of the fiber has been a critical issue for the monitor development. Results from the first few months of operation show that the SACLA CBLM can detect beam losses from 0.3fC to 1pC over the full 150m length of the fiber, and therefore succeeded in reaching its targeted sensitivity.

REFERENCES

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