FIBER BEAM LOSS MONITOR FOR THE SPRING-8 X-FEL: TEST OPERATION AT THE SPRING-8 250 MEV COMPACT SASE SOURCE

X.-M. Maréchal [#], JASRI SPring-8, Kohto 1-1-1, Sayo-cho, Sayo-gun, Hyogo 679-5198, Japan
T. Itoga, Y. Asano, XFEL Project, Kohto 1-1-1, Sayo-cho, Sayo-gun, Hyogo,679-5178, Japan.

Abstract

Fiber-based beam loss monitors (BLM) have attracted much attention in recent years. Among them, systems using the detection of the Cerenkov light generated by the secondary charged particles hitting an optical fiber set along the vacuum chamber, offer the possibility to detect beam losses with a very fast response time (less than a few ms) over long distances, good position accuracy and sensitivity at a reasonable cost. For the undulator section of the SPring-8 X-FEL, radiation safety considerations set the desirable detection limit at 1 pC (corresponding to a 0.1% beam loss of the initial 1 nC/pulse) over more than a hundred meter. We report on the test operation of a fiber-based BLM carried out at the 250 MeV SPring-8 Compact SASE Source (SCSS), a 1/16th model of the future X-FEL.

INTRODUCTION

The SPring-8 X-FEL consists of a 400 m long linac and 120 m long undulator lines, for a total length of 700 m. [1]. Beam losses are an important radiation safety issue: Radiation safety considerations set a 0.1% beam loss limitation in the undulator section of the 8 GeV SPring-8/XFEL which means a desirable detection limit of 1 pC/bunch for the detector over more than a hundred meter. Beam losses are also a concern for the lifetime of the permanent magnets of the in vacuum undulators. The in-vacuum short period undulator, developed at SPring-8 [2], is one of the three key technologies used to minimize the size of the facility: With a gap of a few millimetres, the magnets are close to the electron beam, and therefore more susceptible to demagnetization induced by stray electrons. Fiber-based beam loss monitors offer the possibility to detect beam losses over long distances in real time, with good position accuracy and sensitivity at a reasonable cost. A feasibility study using a beam-based approach was chosen to characterize fibers of different diameters, numerical aperture and index profile by measuring the signal strength, attenuation and dispersion of the system [3].

In the following, we report on the test operation of a beam loss monitor at the SPring-8 Compact SASE Source (SCSS) [4], a 1/16th model of the future SPring-8/XFEL. The SCSS has a maximum electron energy and repetition rate of 250 MeV and 60 Hz respectively. In parallel numerical studies have also been carried out to evaluate the performances of the BLM at 8 GeV [5].

SET-UP

The fiber used for the test is a 32 m long Fujikura SC400/440 fiber whose characteristics are close to those of the fiber to be used for the SPring-8 X-FEL BLM (Table 1). Both fibers are coated to limit the noise from ambient light. The Cerenkov signal is detected with a Hamamatsu H6780-02 photomultiplier (PMT; Minimum wavelength: 300 nm; Maximum wavelength: 880 nm; Equipped with a FC connector to minimize insertion losses) at both ends. Two coax cables lead the signal outside the shielding wall to a constant fraction discriminator (ORTEC 935: 200 MHz CFD with a pulse pair resolution: < 5 ns) and a multi-hit time to digital converter (CAEN V1290N: 16 channels multi-hit TDC with 5 ns Double Hit Resolution). A trigger signal from the accelerator master oscillator is used as time reference. The optical fiber was set along the accelerator vacuum chamber between the C-band accelerator section and the beam-dump (Fig. 2), covering more than 26 meters of the test accelerator. In the following only the data from the upstream PMT are presented.

Table 1: Main characteristics of the fibers used for these experiments and to be used for the SPring-8 X-FEL BLM.

Facility	Length [m]	N.A.	Attenuation [3] [dB/km]
SCSS	32.4	0.209	11
X-FEL	121.4	0.219	7.9

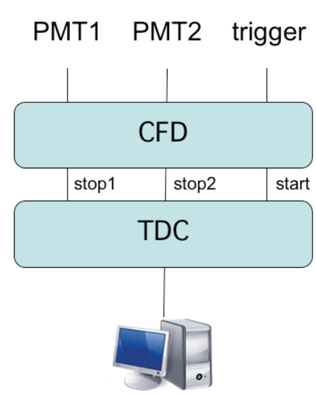

Figure 1: Schematic of the BLM detection system.

[#] marechal@spring8.or.jp

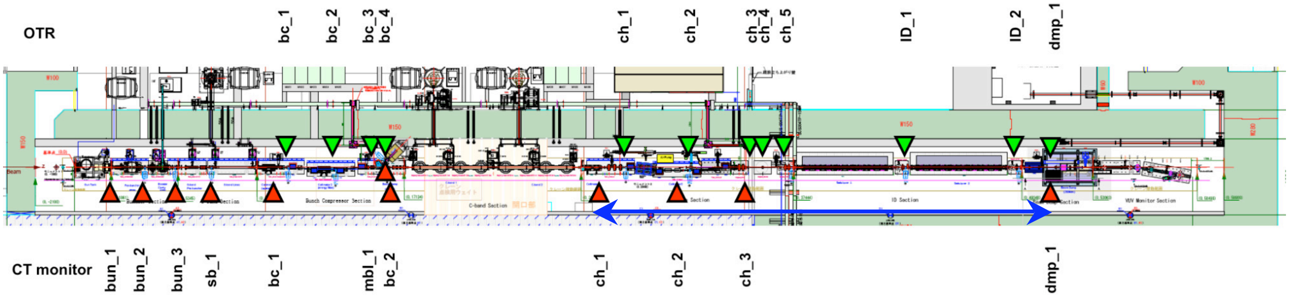

Figure 2: Experimental Set-Up. The SCSS with the location of the OTR screens (Green triangles) and CT monitors (Red triangles). The electron beam runs from left to right. The blue arrow shows the length covered by the fiber.

CALIBRATION OF THE SYSTEM

The beam losses generated by the insertion of the screen of an optical transition radiation (OTR) monitor into the beam path were used to calibrate the BLM and obtain the position of the beam loss from the time given by the TDC. Figure 3 shows the position measured as a function of the position of the OTR. Preliminary results give a one sigma of 1.5 m for the position accuracy.

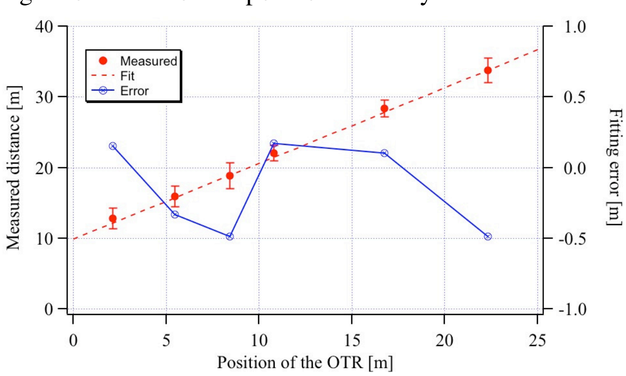

Figure 3: The calibration curve (Red dotted line) with the difference between the fit and the measured values (Blue).

In the set-up used for the test, the fiber detects the dark current (charge ≈ 12 pC) generated in the upstream C-band accelerator structure (Figure 4). The dark current is lost in the chicane before the undulators. The dark current comes in a long pulse, with a typical width of several hundreds ns (FWHM ≈ 300 ns equivalent to 36 meters): Therefore some dark current events can be counted as a beam loss at an unrealistic position. The TDC threshold was set at 30 mV, and later raised to 40 mV.

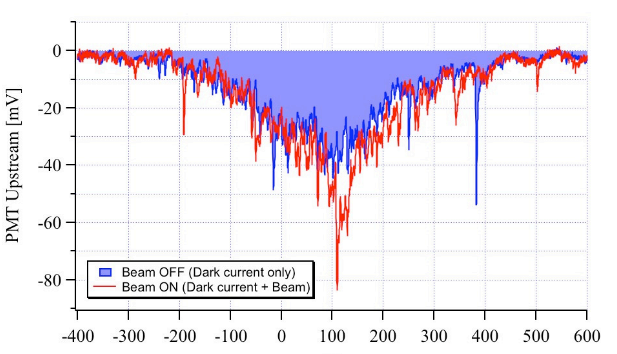

Figure 4: Raw signal from the PMT (Oscilloscope) without (Blue: Dark current) and with (Red: Dark+beam) the electron beam. The peak at 80 mV corresponds to a typical beam loss in the chicane which is actually undetected by the CT monitors.

TEST AT THE SCSS

Typical results (offline analysis) are presented in Figure 5 for two days of operation, both at full mode and 20 Hz: Machine study (Left) and user operation (Right). The top figures show the BLM counts (TDC threshold of 30 mV for April 26^{th} and 40 mV for May 17th), the middle figures show the beam current measured by the CT monitors (CH_1, CH_2 and DMP_1). The bottom figures show the beam loss between the CT monitors. While the BLM operates on a shot by shot mode, the counts have been integrated over 2 minutes and 40 cm for the sake of clarity. As explained above, given the low threshold value, the low background (≤ 10 counts) includes counts coming from the long pulse of the dark current: On the 17^{th}, the counts obtained before 9:30 am are due to the dark current originating from the C-band (RF ON, No beam). The loss points are clearly visible and follow the change in operating conditions (April 26^{th}):

- Changes in beam intensity result in beam losses extending into the undulators (From noon to 1pm) or increased beam loss just before the beam dump (Between 6 pm and 7:15pm)
- Insertion of OTR screens.

In contrast the user operation shows, after the initial tuning, a regular loss pattern (loss in the chicane).

CONCLUSION

A prototype of the BLM has been tested at the SCSS. Preliminary results give a one sigma of 1.5 m for the position accuracy. The performances of the BLM are limited by the present set-up (High threshold level due to the dark current). Further developments include improvements of the position resolution accuracy, a real time and online version of the detector counts analysis, as well as tests of a flash analog-to-digital converter in place of the TDC.

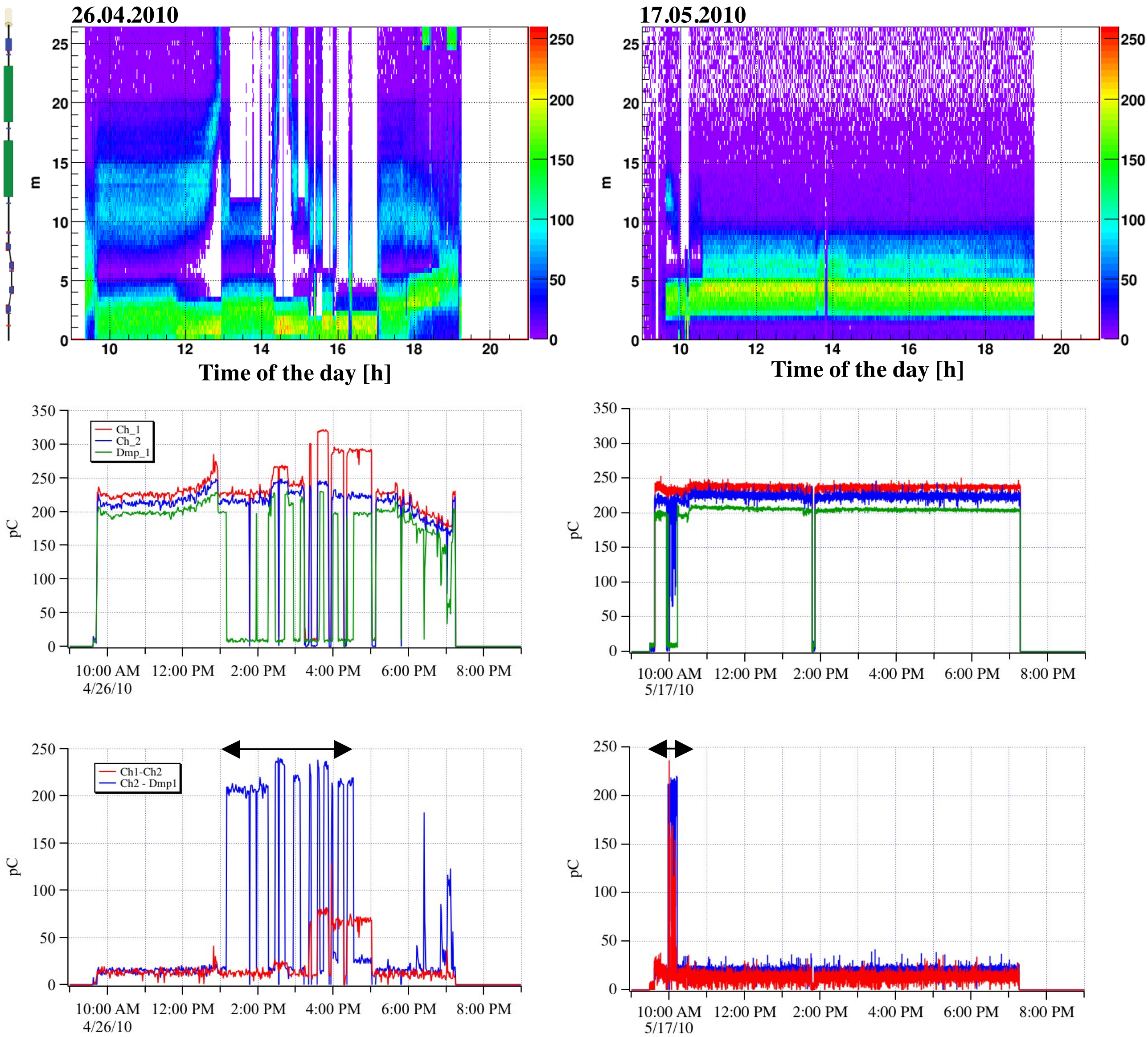

Figure 5: Top: Beam loss detector counts. Middle: Beam current as measured by the CT monitor. Bottom: Beam loss measured between the CT monitors. The horizontal scale for all graphs corresponds to the hour of the day (From 9 am to 9 pm, with a shutdown after 7 pm) for April 26th (Left: Machine study, CSR experiments, Full mode, 20 Hz) and May 17th (Right: User Beam, Full mode, 20 Hz) 2010. The left scale of the top graph (in m) corresponds to the position of the beam loss, a schematic view of the SCSS being given for reference (Blue: Bending magnets; Green: Undulators; Ivory: Beam dump). The colour scale of the top graphs (0~250) gives the number of counts detected within 2 minutes and over a 40 cm span. Threshold: 30 mV. The arrows show the beam losses generated by the insertion of OTR screens.

REFERENCES

[1] http://www.riken.jp/XFEL/eng/index.html

[2] T. Hara, T. Tanaka, T. Tanabe, X.-M. Maréchal, S. Okada and H. Kitamura, "In-vacuum undulators of SPring-8", J. Synchrotron Rad. 5 (1998) 403

[3] X.-M. Maréchal, T. Itoga and Y. Asano, "Beam based development of a fiber beam loss monitor for the SPring-8/X-FEL", Proc. of the DIPAC09 workshop, 25-27 May, 2009, Basel, Switzerland.

[4] T. Shintake et al, "A compact free-electron laser for generating coherent radiation in the extreme ultraviolet region", Nature Photonics 2, (2008) 555 - 559

[5] X.-M. Maréchal, T. Itoga and Y. Asano, "A Fiber Beam Loss Monitor for the SPring-8/X-FEL: ", these proceedings.