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OPTICAL BEAM LOSS MONITORS BASED ON FIBRES FOR THE CLARA PHASE 1 BEAM-LINE*

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Abstract

Fibre based Optical Beam Loss Monitors (oBLMs) are on-line devices used in-situ to measure losses along a beamline. The technology is based on the detection of Cherenkov radiation, produced inside quartz fibres placed alongside the beampipe, from the interaction of secondary showers generated from losses hitting the vacuum pipe. This contribution presents ongoing developments of an oBLM system installed along the Compact Linear Accelerator for Research and Applications (CLARA). The oBLM system consists of 4 channels which allows for sub-metre loss resolution with two dimensional coverage along the entirety of the beam line, as opposed to conventional localised BLM systems. The system was first commissioned to measure dark current from the injector. The ability of the system to locate longitudinal positions of known beam loss locations has also been measured and has shown excellent agreement. We present measurements acquired from the detector during regular operation and during dedicated beam tests. We also discuss the incorporation of the monitor into the accelerator diagnostics system and its use in assisting accelerator characterisation and performance.

INTRODUCTION

oBLMs are a unique, comprehensive, and low-cost solution to detect beam losses within different accelerators [1]. A typical oBLM system contain of two main components, one or more fibres running along a beamline and fast sensor at the end of the fibre. The fast sensor captures the Cherenkov light, which is produced inside the quartz fibre as a charged particle crosses the fibre. Charged particle showers are produced when a beam loss originating from a beamline impacts with machine parts, including the beampipe. For electrons, the threshold energy to produce Cherenkov radiation in a quartz fibre is 175 keV [2]. Light produced in the fibres is then converted to an electrical signal by front-end readout electronics utilising fast high-speed analogue-to-digital converters. When compared with standard beam loss monitoring methods, an oBLM can monitor the entire beamline and localise the losses with a sub-metre loss resolution instead of detecting losses only at specific locations. The resolution is defined by many factors including the digitisation rate. On-line oBLM systems can be integrated with the machine and personnel protection systems of an accelerator reducing the probability of losses not being detected early and thus the oBLM system ensures safer operation.

CLARA is a Free-Electron-Laser (FEL) test facility under construction at Daresbury Laboratory [3]. CLARA is based on a 250 MeV electron linac designed to produce short, high-brightness electron bunches. The oBLM system has been installed on the CLARA front end, which contains a 2.5 cell RF photocathode gun and a 2 m S-band (2998.5 MHz) accelerating structure, resulting in a maximum beam energy of 50 MeV.

For ensuring the detection of a range of beam loss intensities, four oBLM units with two different core fibres have been installed in the area marked in Fig. 1 by red lines within the CLARA front end. The following four fibres were installed: two of 600 µm core on the locations 1 (east) and 2 (north) and 400 µm core on the locations 3 (west) and 4 (south) (see the marked locations on Fig. 1). Combining four sensors instead of one, the oBLM system achieves several goals. Firstly, the use of different core fibres increases the dynamic range of the measurements by ensuring different sensitivities to losses. Secondly, it can provide more information on the origin of the losses and their levels and thus diagnose serious beam orbit deviations. Thirdly, four oBLMs provide a cross-check the reliability of each oBLM device.

The sensor unit [4] contains silicon photomultipliers (SiPMs) as photosensors, a transimpedance amplifier and power supply. It has four fibre inputs (FC/PC), the power input (15 V), and four outputs as readouts (BNCs). SiPMs are an array of avalanche photodiodes operating in Geiger mode (Hamamatsu). Unlike standard photomultiplier technology, SiPMs are insensitive to magnetic fields and hence do not require additional shielding. This allows for compact installation of the oBLM system without impeding other systems. In this case, the oBLM systems were placed behind the gun.

Previously, the oBLM has proven itself as a useful tool for detecting dark current during the conditioning of the CLARA RF structures and it can provide further information into the sources of RF breakdown. Measurements were obtained parasitically during CLARA commissioning [5]. As the next step, the oBLM was tested as a beam loss monitor during first beam transport commissioning through the CLARA front end.

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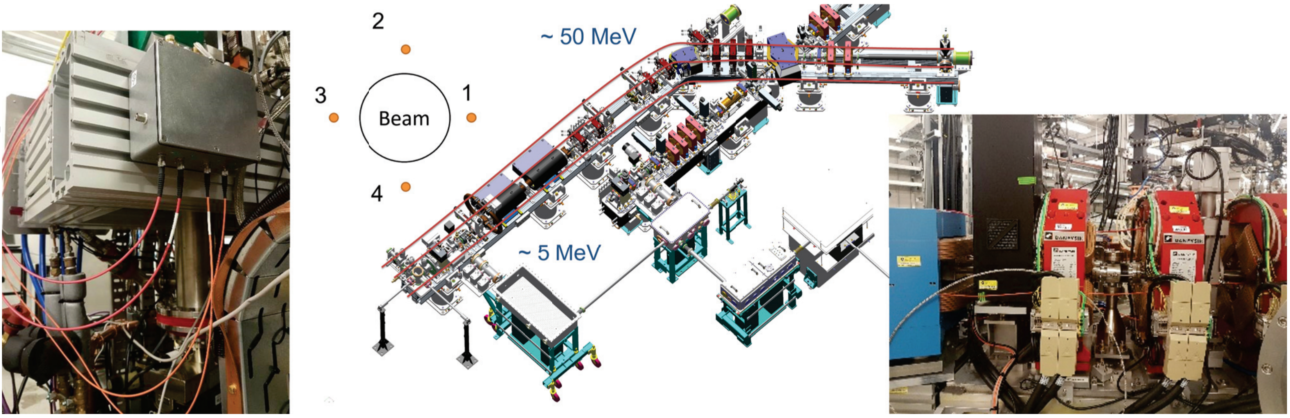

Figure 1: oBLM fibres (red lines) on the CLARA front end. The location of four fibres with respect to the beampipe is shown on the inner picture. The sensors are located upstream of the gun. The inner photographs show the oBLM sensor unit (left) and the fibre locations along the beamline (right).

The timing of the beam loss signals from the fibres is crucial to determination of the longitudinal location of the loss. During the tests some inconsistency was observed in triggering the recording of the fibre signals. The triggering issue can be resolved by using a single fibre looped back to the sensor unit to record the upstream and downstream signals results from a single loss point, and the following results were obtained from a looped fibre.

EXPERIMENT

During beam commissioning of the oBLM system, CLARA was operated with a maximum beam energy of around 5 MeV/c, and with bunch charges of up to 250 pC and generally above 100 pC (as measured on the wall current monitor at the exit of the 10 Hz photocathode gun). The bunch length in the front end is estimated to be several picoseconds [6].

Initial commissioning of the CLARA front end in September 2017 had produced low bunch charge (~75 pC), which made oBLM experiments problematic. With the replacement of a new cathode in 2018, the bunch charge was higher which facilitated detection of losses from the core beam, as distinguished from dark current losses [7].

For the verification of the oBLM system and for providing a reference time/distance for the signals, the experiments were performed by detecting losses from known locations such as the YAG screen insertions and collimators, as well as using the spectrometer dipole for steering the beam, as seen in Fig. 3. The precision of the measured loss location depends on many factors such as the precision of the trigger system, deviations of the fibre from the beam pipe, and the signal digitisation.

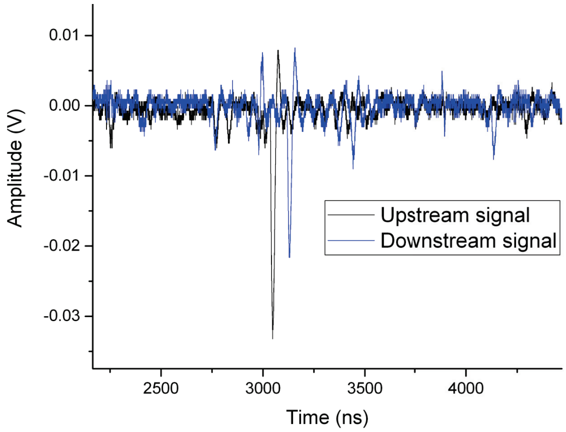

Figure 2: Fibre beam loss signals demonstrating the time shift between upstream and downstream signals (see text) indicating a loss point at 1.7 m from the beginning of the fibre (a beam diagnostic screen is inserted which is at 0.98 m from the photocathod). This indicates a 0.7 m shift between the beginning of the fibre and the beginning of the beam line.

The diagnostic stations on CLARA contain plate-collimators as well as YAG screens. After the linac there is a dedicated thick collimator used for mitigating dark current (this consists of a copper block with four tapered apertures with diameters of 3 mm, 6 mm, 10 mm and 14 mm). Three YAG screens and collimators were used to generate losses within the beampipe at known locations to calibrate the oBLM system using both upstream and downstream signals. Generally speaking, the upstream signal is weaker than downstream one, but provides for higher spatial resolution. The downstream signal is stronger as the secondary showers are directional and produce higher intensity showers in the direction of the electron beam. Capturing both signals with the same trigger allows the loss position to be calculated based on a time shift between signals and a known length of the fibre.

Figure 2 shows the obtained signals with the first screen (at 0.98 m from the electron source), where the time delay indicates a loss point at 1.7 m from the beginning of the fibre. The data from two other screens has been used for the same verification; these screens are located at 4.09 m and 5 m from the electron source, and the obtained beam

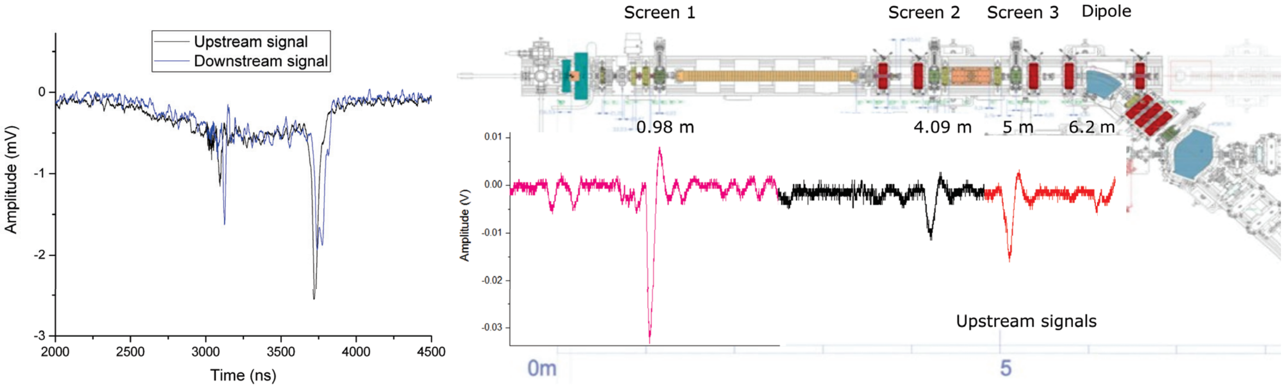

Figure 3: Multiple beam loss measurements in the CLARA front end. The signals on the left show the upstream and downstream signals obtained from the losses occurring on the dipole (at 6 m from the beam source), through which the beam was transported. The schematic picture on the right illustrates the multiple loss points which were tested with the oBLM system; these include screens at 0.98 m, 4.09 m, 5 m, a collimator at 4.7 m; samples of the signals observed at each loss point are overlaid.

loss signals indicated loss points at 4.73 m and 5.7 m from the beginning of the fibre. These measurements indicate a shift of 0.7 m between the fibre and the beamline, which may arise from the section of fibre which runs to the sensor unit. The level of the signal demonstrates the relative level of the loss from obstacles.

IMPLEMENTATION OF THE DIAGNOSTIC

We are working on integrating the oBLM into the controls system to allow for synchronous data acquisition and immediate on-line loss monitoring.

An example of the information which can be constantly monitored using the oBLM system is presented in Fig. 3 which shows both the combination of upstream and downstream signals on the left side and a beamline map of multiple losses on the right.

To implement this as a live system firstly, calibration of the position of the losses using obstacles at known locations will be performed as described above. Then the timing of either of the upstream or downstream signals can be used to indicate loss location along the beamline. The resolution of this measurement is influenced by the digitisation rate. The resolution of the upstream signal is 5 times better than the downstream.

Both signals will be incorporated into the system to increase the dynamic range of the measurements and perform calibration whenever required.

CONCLUSION

The oBLM has proven itself as a useful tool which can be used for sub-metre loss resolution with two dimensional coverage along the entirety of the beamline for the accelerators as well as for detecting dark current from RF structures. The oBLM was tested during beam commissioning in 2017-2018, indicating that an oBLM can provide information on the longitudinal positions of losses. The finalisation of the development of such a system is planned with the incorporation of the monitor into the accelerator diagnostics system and its use in assisting accelerator characterisation and performance, for example as a useful diagnostic in enabling orbit control through small apertures. Ensuring that losses are kept to a minimum is a crucial part of effective machine operation and the advances we have made in this area will ensure that any future UK FEL will benefit from the coverage of the accelerator we are able to deliver and at a cheaper price compared to standard technology.

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