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OPTICAL BEAM LOSS MONITOR BASED ON FIBRES FOR BEAM LOSS MONITORING AND RF BREAKDOWN DETECTION

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Abstract

Standard beam loss monitors are used to detect losses at specific locations which is not a practical solution for loss monitoring throughout the whole beam-line. Optical fibre beam loss monitors (oBLMs) are based on the detection of Cherenkov radiation from high energy charged particles having the advantage of covering more than 100 m of an accelerator with a single detector. This system was successfully installed at the Australian Synchrotron covering the entire facility for beam loss measurements. Successful measurements were also demonstrated on the Compact Linear Accelerator for Research and Applications (CLARA), UK with sub-metre beam loss resolution. oBLMs are non-invasive monitors for the detection of the beam loss and RF breakdown within particle accelerators, which has been developed by the QUASAR Group based at the Cockcroft Institute/University of Liverpool, UK in collaboration of D-Beam Ltd, UK. This paper discusses the overview of the system, the incorporation of the monitor into the accelerator diagnostic system, calibration experiment of oBLM and future plans for the system.

INTRODUCTION

The operation of a particle accelerator depends on the understanding of the behaviour of the particle beam which includes the accidental or deliberate loss of the beam as it traverses the machine. Beam loss monitoring is an essential asset not only for the operation of an accelerator, but also for machine safety and radiation shielding. Optical fibre beam loss monitors (oBLMs) are based on the principle of detecting Cherenkov photons which are generated in an optical fibre by energetic charged particles originating from beam loss in an accelerator beamline. Using a photosensor coupled to one end of the optical fibre to detect these Cherenkov photons, arrival time information can be used to calculate the location of beam loss [1]. oBLMs can provide protection for long accelerator beam-lines from damaging beam losses by covering large lengths (~100 m) using a single unit, whilst providing ~10 cm resolution on loss locations; making these monitors an attractive cost effective solution for machine protection. oBLMs have been successfully installed and calibrated for their performance at the Australian Synchrotron Light Source facility and are integrated into routine operations [2].

oBLMS have also been installed and tested for RF cavity characterization at the dogleg line in Compact Linear Collider Test facility 3 CTF3, CERN, Switzerland [3] and the front end of CLARA (Compact Linear Accelerator for Research and Applications), a Free Electron Laser (FEL) test facility at Sci-Tech Daresbury (STFC, UK) [4]. These tests have further confirmed the usefulness of oBLMs for detecting dark currents generated during the conditioning of RF structures. Based on these results, a new novel diagnostic system has been developed with multiple capabilities such as to locating the beam loss and RF breakdown within particle accelerator, housed in a single device.

OVERVIEW OF OBLM

The oBLM is an advanced machine protection system based on optical fibre technology, which uses silicon photomultipliers (SiPMs) coupled to the fibre ends. SiPMs are an array of avalanche photodiodes operating in Geiger mode. The insensitivity of SiPMs to external magnetic fields makes them more suitable for accelerator areas where several magnetic components are essentially present for controlling the particle beam, e.g. undulator sectors. This property of SiPMs aids in the design of a compact system with little shielding requirements. These compact systems are easy to install without interfering with the existing infrastructure of an accelerator. The aim is to turn the oBLM in to a general machine protection tool which can produce proactive temporal, angular and spatial information in unprecedented detail of beam loss and RF breakdown occurring along a beam-line, using a single device. The targeted temporal resolution achievable with this sensor will be able to pre-empt a RF breakdown event and allow machine protection procedures to act in advance of any damaging effects. The objective of this work is to develop a smart sensor diagnostic tool which is low in cost, requires low maintenance, and provides non-invasive high resolution measurements to aid machine protection. The integration of this diagnostic system to a pre-existing accelerator control system is very simple as demonstrated at Australian Synchrotron [2] and CLARA [5].

CURRENT INSTALLATION AT BEAM AREA 1 OF CLARA, UK

This diagnostic system is currently installed at beam area 1 (BA1) of CLARA for future test of the system. The schematic of the beam line is shown in the Fig. 1 (middle). Two 600 µm core optical fibres have been installed along the beam line, as shown in Fig. 1 (inset right). The end of the optical fibres is coupled to the sensor unit shown in Fig. 1 (inset left). This installation will enable several online and novel experiments e.g. measurements of energy gain in novel acceleration experiments via calibration of a dipole magnet and scintillation screen.

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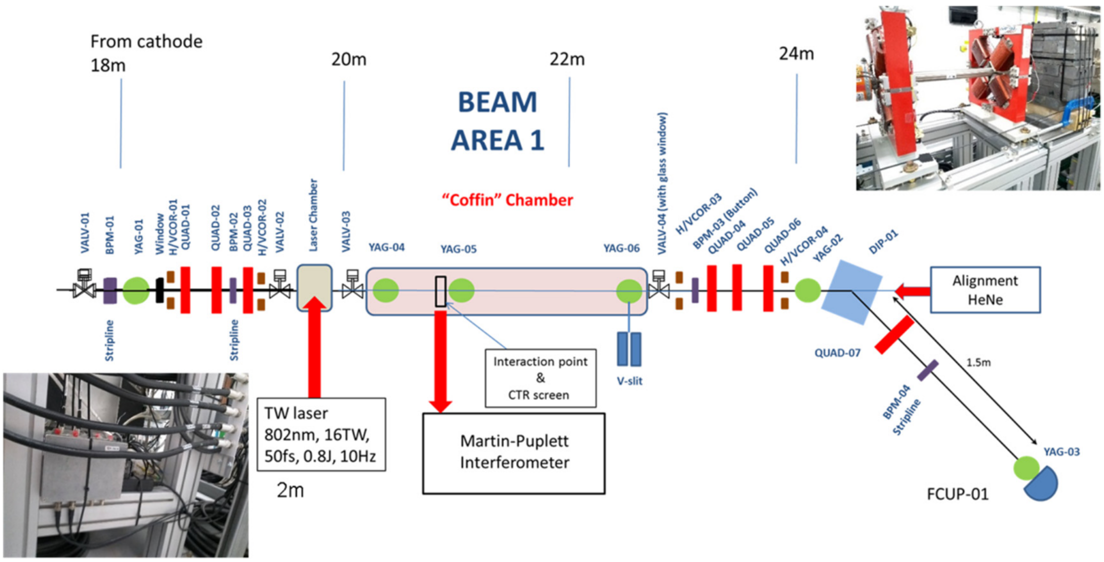

Figure 1: Two fibres of oBLMS on the CLARA beam area 1. The schematic in the middle is the beamline where two fibres are installed parallel to one another. The photograph (inset left) shows the sensor unit/fibre coupling and the photograph (inset right) shows the fibre location along the beam line (black cables near the bottom of the red quadrupole magnets).

The BA1 has a dedicated beam line for user experiments with a large (2.3 m long), easily accessible vacuum chamber and a set of standard diagnostic components as shown in Fig. 1. Current installation will be used to provide additional online information regarding the beam losses due to various components installed in the BA1. The reason for installing two optical fibres is to obtain more information on the angular origin of the losses and also along providing a cross-check on the reliability of each individual oBLM device.

CALIBIRATION EXPERIMENT OF OBLM FOR CLARA PHASE 1 BEAM-LINE

For the verification of the oBLM system and for generating calibration for loss locations, four such units with two different core fibres were installed within CLARA phase-1 beam-line [5]. CLARA front end contains 2.5 cell RF photocathode gun and a 2 m S-band (2998.5 MHz) accelerating structure which provides electron beam with maximum 50 MeV beam energy.

Figure 2 shows the signals generated for one loss location at the CLARA front end with various beam currents using the oBLM system. For calibration and providing a reference time/distance for the signals, the experiments were performed by detecting losses from multiple known locations, deliberately introduced at regular intervals along the beam-line. YAG screen insertions and collimators were used as elements for deliberately causing beam loss aided by steering the electron beam with the help of a dipole magnet. Figure 3 demonstrates the peaks due to various losses at four different locations. This calibration depends on several factors such as the precision of the trigger device, deviation of the fibres from the beam pipe, and the signal digitization.

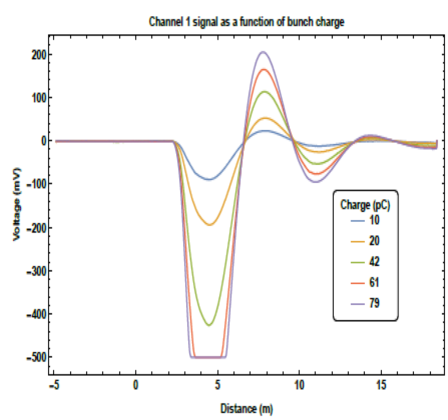

Figure 2: Variation in the signal generated by an oBLM for varying beam charges at one loss location in the CLARA front end.

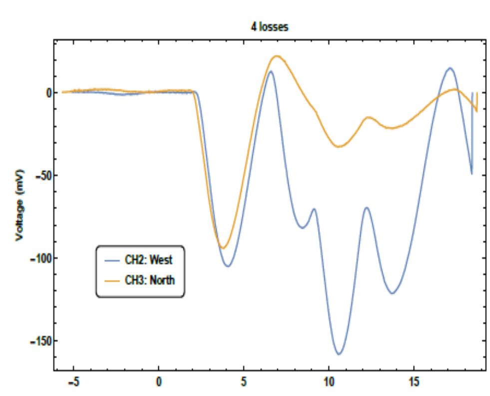

Figure 3: Variation in the signal generated by OBLMS for varying beam charges at four different loss locations simultaneously placed in the CLARA front end.

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Three YAG screens and one collimator were used for the four point calibration. The level of the signal indicates the relative level of the loss from the obstacles. Similar measurements were also performed for two and three loss locations within the beam-line. Some signal overlap was observed for signals obtained for more than one loss locations. The reason for the overlap is the long decay time of the current pulse generated by the SiPM. This is some tens of ns for the current system. Due to this long decay time, the pulse arriving within this time frame is either lost or appears as shoulder peak to first peak, which hinders the path of achieving better loss location resolution in current system. Currently, the oBLM sensor has demonstrated loss location (peak position) resolution of ~10 cm. Further modifications and testing will be carried out to improve the spatial resolution of oBLM sensor which will allow upgrading the sensor unit before the next CLARA run.

FUTURE PLANS

The resolution of the oBLM technology will be improved in near future as a collaboration work with D-Beam [6]. This work will be conducted under the project recently sanctioned by STFC under the innovation partnership scheme for Fellow-on-Fund

A test setup development work has also begun on a ns pulsed laser system which can be coupled to the opposite end of the oBLM optical fibre and be used for online testing and calibration. An image of the current pulsed system is presented in Fig. 4.

Figure 4: ns-pulsed laser prototype for online testing and calibration of the OBLMS system.

The new improved system will undergo a series of accelerator facility based tests to compliment the system installed at CLARA BA1. These will include a system at MAX IV (Lund, SE), looking at beam loss in transfer lines and RF losses in normal conducting cavities, and a possible installation at IUAC (India), looking at RF losses in superconducting structures.

The results from these measurements will guide further usability and turn-key improvements of the current oBLM sensor.

CONCLUSION

The oBLM has proven itself as a versatile tool for beam loss detection inside an accelerator beamline. This paper has demonstrated that an oBLM can also monitor the beam losses occurring at several locations simultaneously. The potential of the oBLM, including a comprehensive and quantitative study into the localization of RF breakdown and quench is planned in the near future.

Ensuring that losses are kept to a minimum is a crucial part of effective machine operation and the advances have made in this area will ensure that any future FEL facility will benefit from the coverage of the accelerator with oBLMs. We will be able to deliver oBLMs at more economical price compared to standard technology. An oBLM system is particularly advantageous in undulator regions of FEL facilities, since the system is not sensitive to magnetic fields and synchrotron radiation and should be able to provide the information about the properties of the propagating beam and intra-beam dynamics.

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