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INTEGRATION OF OPTICAL BEAM LOSS MONITOR FOR CLARA

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Abstract

The detection of beam loss events in accelerators is an important task for machine and personal protection, and for optimization of beam trajectory. An optical beam loss monitor (oBLM) being developed by the Cockcroft Institute at Daresbury Laboratory required integration with the rest of the controls and timing system of the site's electron accelerator, CLARA (Compact Linear Accelerator for Research and Applications) [1]. This paper presents the design and implementation of an inexpensive solution using a Domino Ring Sampling device from PSI. Signals from the oBLM are acquired and can be processed to resolve beam loss events to a resolution of 0.2m.

INTRODUCTION

Beam losses refer to fractions of the beam which deviate from the nominal beam trajectory and impinge on accelerator components. Beam Loss Monitors (BLMs) are radiation detectors located along an accelerator line in order to observe particle showers. Unlike conventional beam loss monitors, which detect beam loss at discrete locations, oBLMs can detect along the whole length of the machine. This provides much better localisation of beam loss events [2].

An oBLM system consists of a fibre placed along a beamline with photodetectors and readout hardware at the end of the fibre. The operating principle of an oBLM is based on Cherenkov radiation generated as a result of electromagnetic radiation crossing the fibre. This occurs when the particle beam hits any obstacle. The flash of Cherenkov radiation travels down a quartz fibre and is then detected by a silicon photomultiplier. By comparing the arrival time of the response from either end of the fibre it's possible to localise the position of the beam loss relative to the middle of the fibre.

Since the group velocity of the pulse of Cherenkov light in the quartz fibre is approximately 2/3rd the speed of light, the distance of the beam loss event from the middle of the fibre is given by the equation:

$$D = \frac{1}{3}\Delta T c \quad (1)$$

Where ΔT is the difference in the arrival time of the pulse at either end of the fibre (see Fig. 1) [3-4]. The magnitude of the response is proportional to the amount of charge lost.

oBLM Signal

The impulse response from each detector of the oBLM is a damped 20MHz oscillation (see Fig. 2). Multiple beam losses result in a signal that is the sum of impulse responses with different delays and magnitudes. These delays and magnitudes must be determined and processed to gain information about the locations and sizes of beam losses.

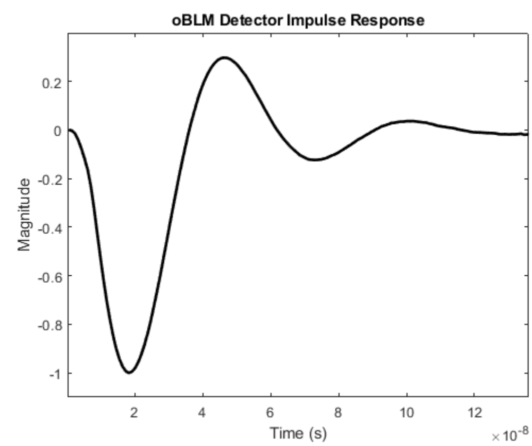

Figure 2: oBLM detector impulse response.

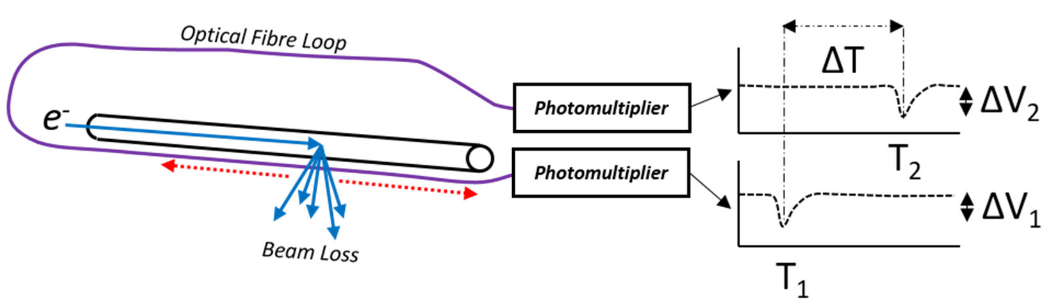

Figure 1: Principle of operation. Cherenkov radiation causes peaks in the voltage from a photo multiplier, the amplitude and delay of which is proportional is to the magnitude and position of the loss respectively.

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SYSTEM INTEGRATION

Data Acquisition

A data acquisition system (see Fig. 3) was required that would be able to reconstruct the signals from the detector and provide sufficient timing resolution to resolve beam loss events to individual components on CLARA. The DRS4 evaluation board, produced by PSI was chosen because of its high sample rate, up to 5.12Gsps, and comparatively low cost of €1200 [5]. Components of the accelerator are separated by as little as 0.2m on CLARA so the system needed to be able to resolve to 1ns or better see Eq. (1). While the existing data acquisition hardware used for CLARA which samples at 250Msps would have been sufficient to reconstruct the signal, a sample clock synchronous with the trigger and interpolation would have been required to achieve the 1ns timing specification. The high sample rate achieved by DRS4 avoids this complexity. This was an important factor given the small amount of time available to work on this project.

The evaluation board comprises of a switched capacitor array which buffers analog signals, an ADC to sample the buffered signals and an FPGA to control the board. The device also has a trigger input and is communicated with over a USB connection. The board is supplied with a user interface and a library for integration with other software.

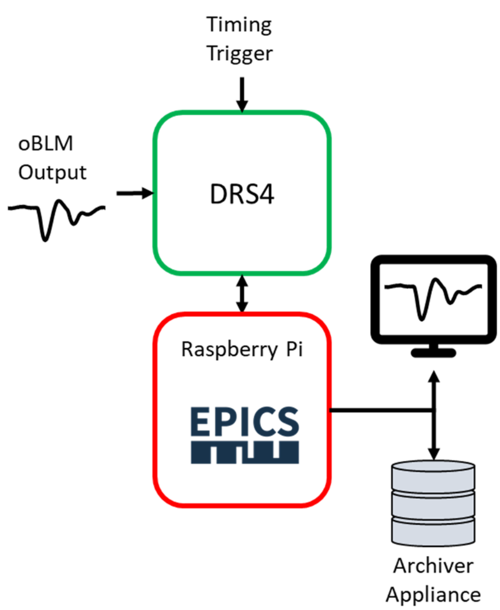

Figure 3: Data acquisition system.

Control System Interface

The distributed control system EPICS is used for CLARA. A Raspberry Pi 3+ was used to host the DRS4 evaluation board and connect the device to the rest of the controls network [6]. This was achieved by writing a support module using the Asyn Port Driver C++ base class and the user library for the DRS4 supplied by PSI [7]. The support module exposes basic functionality of the device, allowing a user to initialise the board and read data from the channel buffers. It is interrupt driven, updating EPICS PVs when new data is available. It has been shown to operate up to 100Hz.

Once data is acquired it is made available over the EPICS network via an Ethernet connection and presented to machine operators in a user interface. It is also archived using the EPICS Archiver Appliance and timestamps, synchronised using the Network Timing Protocol (NTP), provide sufficient resolution to synchronise oBLM waveforms with other data about the state of the machine [8-9].

COMMISSIONING

Four oBLM fibres were placed around the CLARA front end beam line of different diameters. Two fibres of 600 µm core in North and East orientation, and two of 400 µm core at South and West (see Fig. 4) Multiple fibres allow the direction of the loss to be determined and provide a more robust measurement of timing of the loss, different sensitivities increase the dynamic range of the device. The data acquisition system was connected to the oBLM and configured to sample at 5.12Gsps, with acquisition triggered by the timing system supplied by Micro Research Finland (MRF).

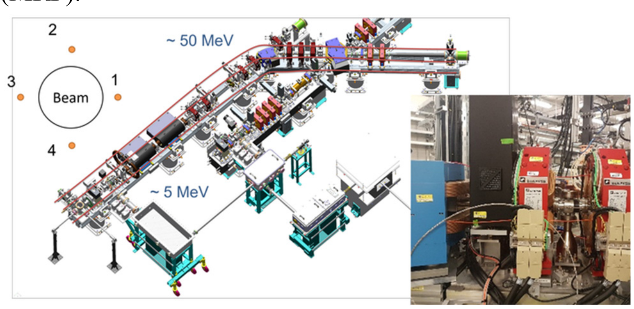

Figure 4: Quartz oBLM fibres laid over CLARA front end in North, South, East and West orientation.

Commissioning the device involved inserting screens or other devices at known positions along the accelerator and observing the response on one end of each of the four fibres. The delay of the impulse response for each position was recorded and used to provide a calibration value for that fibre. This accommodated for minor differences in the path lengths and positions of the fibres along the accelerator since they were laid over the machine and not held in a consistent arrangement (see Fig. 4).

A user interface was then designed that showed the response against a diagram of the machine showing the positions of different components (see Fig. 5). This allows for operators to interpret the oBLM response data and make a judgement about where beam losses are occurring.

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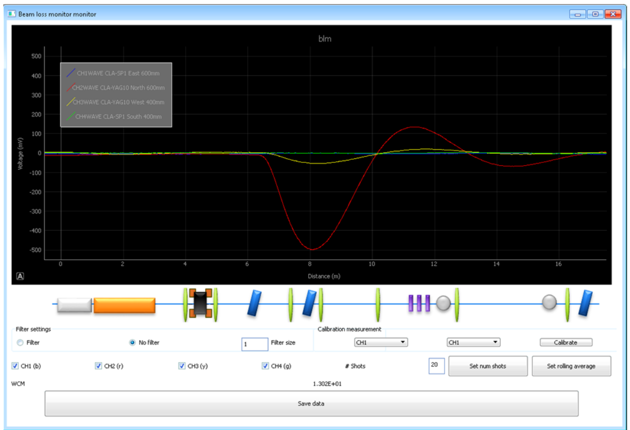

Figure 5: Response from Screen 05 inserted shown on user interface against a scaled diagram of the machine.

FUTURE PLANS

Commissioning produced a system that proved useful during exploitation. It helped operators to find losses when steering the beam and setting up the machine. There are a number of areas that can be improved.

Firstly the device required an external bench power supply and included no power supply regulation or protection. At some point the device was given the wrong supply voltage and failed. Planned updates to the oBLM will address this.

Secondly the length of the fibres and the sampling window (200ns) limit the length of the machine that can be monitored. By reducing the sampling rate to just over 1Gsps, the system will be able to monitor 200m of fibre covering the full length of the machine. The lower sample rate will still easily reconstruct the signals and achieve the 1ns timing specification to give the position resolution required.

Processing of the signals from either end of the fibres was not implemented because it was possible to calibrate the system by causing losses at known positions by inserting screens. For applications where this isn't possible, calibration that is independent of the system being observed will be important and this process should be investigated.

Finally more work is needed to process the signals to reduce both the importance of the operator in the amount of data produced. For example, for each shot of the beam eight waveforms are saved, two from each channel representing the time and amplitude vectors. This produces 65Kb of data in total per shot causing problems in data storage and retrieval. Waveforms must be analysed by the operator along with the calibrations and diagram of the machine to estimate the position of the beam loss. Further work is needed to design a method to process these waveforms and give the position and magnitude of the losses. This is challenging because of the duration and oscillations of the impulse response. The ability to resolve closely spaced losses is limited by the width of the response. When the responses from multiple losses overlap they become difficult to resolve, see Fig. 6. Improvements to the readout electronics and implementation of deconvolution filters are both being investigated to address these challenges.

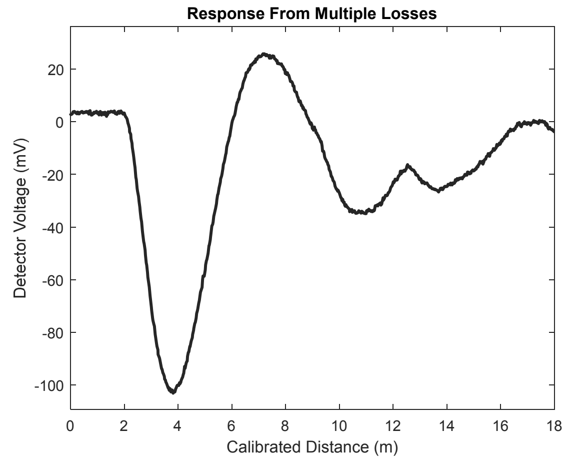

Figure 6: Response to 4 screens inserted at various lengths along the beam. Smaller responses are masked by the tail of the other responses.

CONCLUSION

Integration of an oBLM was achieved with a DRS4 evaluation board controlled by a Raspberry Pi. The system was integrated into the EPICS control system allowing data to be archived, compared to other diagnostics on a shot to shot basis and presented to users in an interface. Calibration of the device was performed in commissioning and the system proved useful throughout exploitation. Further work is needed to improve the device and this is ongoing.

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