ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-THPML130

APPLICATIONS OF A DISTRIBUTED BEAM LOSS MONITOR AT THE AUSTRALIAN SYNCHROTRON

P. J. Giansiracusa*, T. G. Lucas, M. Volpi, R. P. Rassool,
The University of Melbourne, Melbourne, Australia
G. S. LeBlanc, The Australian Synchrotron, Clayton, Australia
M. J. Boland, Canadian Light Source and Department of Physics and Engineering Physics,
University of Saskatchewan, Canada

Abstract

A distributed beam loss monitoring system, based on Cherenkov silica fibres, has been installed at the Australian Synchrotron. The fibres are installed parallel to the beam pipe and cover the majority of the length of the injection system and storage ring. Relativistic charged particles from beam loss events that have a velocity above the Cherenkov threshold produce photons in the fibres. These photons are then guided along the fibres to detectors outside of the accelerator tunnels. Originally the system was installed to determine its suitability for measuring losses at a future linear collider, such as the Compact Linear Collider, with single pass 150 ns bunch trains. This work builds on these results and attempts to use the system to measure loss locations with a circulating beam.

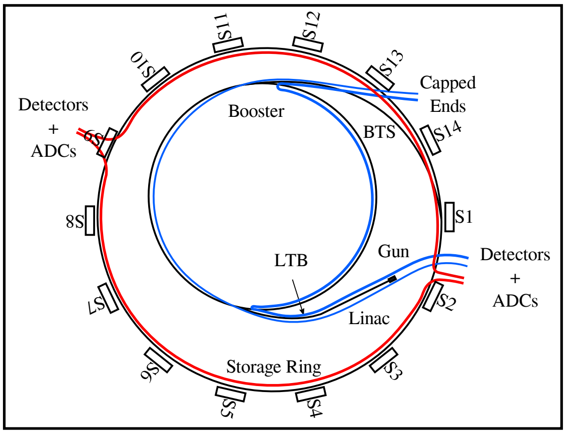

Figure 1: The locations of the fibres installed at the Australian Synchrotron. The red and blue lines how the position of the fibres installed on the storage ring and injection system respectively. Only a short section of the BTS transfer line is left uncovered.

INTRODUCTION

Beam loss monitors are essential for protection and efficient operation of particle accelerators [1]. A distributed beam loss monitoring system has been installed at the Australian Synchrotron. It consists of several silica fibres running parallel to the beam pipe that detect beam losses via the Cherenkov mechanism. Relativistic charged particles from beam loss events that have an energy above the Cherenkov threshold, $E_k > 186$ keV for $e\pm$ [2], produce optical photons in the fibres. These photons are then guided along the fibres to detectors outside of the accelerator tunnels. Originally the system was installed to determine the suitability of optical fibres for measuring losses at a future linear collider and its damping rings with single pass 150 ns bunch trains [3, 4, 5].

This work attempts to adapt the system and determine its suitability for measuring loss locations at a circular accelerator with circulating beam. In particular it is anticipated that the system can be used to determine the location of steady state losses and as a post mortem system to identify the dominant loss locations after beam dump events. The preliminary results of this investigation are presented here.

EXPERIMENTAL SETUP

The Australian Synchrotron is a 3rd generation light source. An injection system consisting of a thermionic electron gun, 100 MeV LINAC, a 3 GeV booster synchrotron and two transfer-lines, the LINAC to booster (LTB) and the booster to storage ring (BTS), provide beam to the storage ring. The storage ring is 216 m in diameter and a beam energy of 3 GeV is maintained with 500 MHz RF. In user beam operation 300 of the 360 RF buckets are filled with a nominal total current of 200 mA. Arbitrary fill patterns and signal bunch operation are also possible. The storage ring consists of 14 sectors each with a double bend achromat cell and a straight section [6].

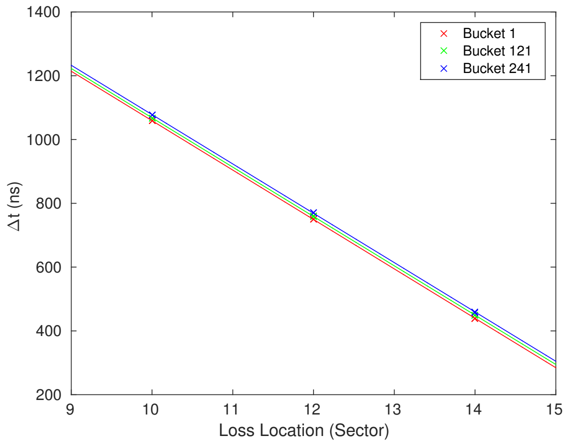

Figure 2: The target bucket's effect on the measured time difference, Δt, between the primary and reflected signal. For clarity the results for bucket 1 and bucket 241 have been offset by -10 and 10 ns respectively. It can be seen that changing the target bucket has no effect on the measured Δt.

---

* pgia@student.unimelb.edu.au

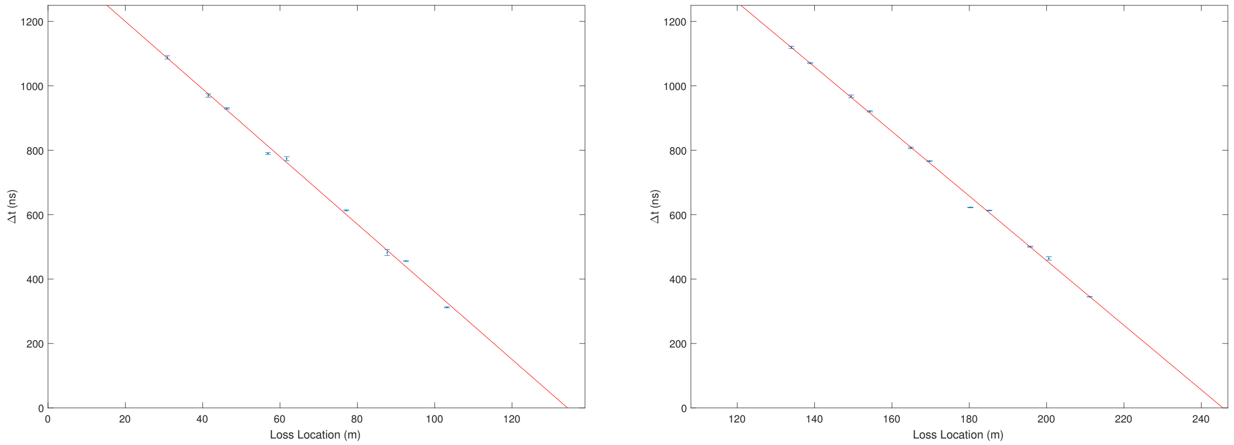

Figure 3: The measured Δt for each valve in the storage ring. Locations are given relative to the first valve in sector 1. The left plot shows the results for the fibre covering sectors 2 to 9 and the right shows the fibre covering sectors 9 to 2. The red lines show the lines of best fit. Deviations from the red lines are attributed to the physical placement of the fibres, often it was not possible to place them directly on the beam pipe.

Four 125 m silica fibres are installed such that they run on the inside of and parallel to the beam pipe and cover the majority of the system, as shown in Fig. 1. Insertion devices are installed in sectors 2, 3, 5, 8, 12, 13 and 14 and RF cavities, in sectors 6 and 7, and the fibres are routed around these as best as possible. Each fibre is made up of 245 μm silica (SiO_2), 200 μm core and 45 μm cladding, coated in a light tight sheath and then covered by a protective nylon jacket. Light is collected by Silicon photo-multipliers (SPMs) at all four ends of the two storage ring fibres, and at only one end of the injection system fibres. The unused ends are capped, to ensure no external light can leak in. The fibres have a refractive index of n=1.47 in the visible spectrum, thus the speed of signal in the fibre is v=c/n or approximately 2/3 the speed of light. As such the beam generating the losses is faster than the signal in the fibres, so signals at the downstream end are likely to pile up therefore all of the measurements in this work were preformed using signals recorded at the upstream end of the fibres. Signals produced by the SPMs are digitised with various analogue to digital converters (ADCs) at 2 GS/s and 8 bits or better.

To accurately test and calibrate the system a reliable method of generating losses at known fixed locations is required. This was done using beam scrapers and vacuum gate valves that can be used to block the path of the beam. The scrapers are located in sector 11 and the vacuum gate valves are two per sector in the storage ring and at several locations along the injection system. The locations of these devices are known to millimetre accuracy.

RESULTS AND PROCEDURE

Previous measurements of loss location made use of the event generation and timing system to determine the time of flight of events in the fibre with respect to the firing of the gun. This approach works well for leading edge measurements of first pass signals. However, it is based on the assumption that the target bunch in the train is producing the first loss seen by the detectors. So, if the loss is produced by a bunch other than the target bunch the reconstructed loss location is out by the time difference between the target bunch and the loss generating bunch. This effect in highlighted in the time resolution measurements in [3], where losses at the scrappers were induced by targeting different RF buckets to produce loss signals with different times of flight. Thus, a measurement method is required, that allows the loss location to be tied to a position along the fibre independent of RF bucket producing the loss and event system used to trigger the detectors.

Several methods of determining the loss location based solely on the observed signals in the fibre are under investigation. Here the results for a single method is presented, the measurement of the the time difference between the primary loss signal and its reflection from the opposite end of the fibre. It was found that the measured time difference, hereafter referred to as Δt, gave a result that was only dependant on the loss location. However, requiring the detection of the reflected signal results in a significantly lower sensitivity, limiting the systems use to large loss events or steady state processes where multiple signals can be averaged. To test for independence, losses were generated at three valves, in sectors 10,12 and 14, using a single bunch and targeting three different RF buckets, 1, 121 and 241, at each location. The resultant signals were digitised and the Δt was determined for each combination of valve and bucket by defining both a threshold and time window after the leading edge of the primary signal. Figure 2 shows the results of this test. For clarity the results corresponding to buckets 1 and 10 have been offset by 10 ns and -10 ns respectively. It can be seen that changing the target bucket has no apparent effect on the measured Δt at each location.

Following the successful test a calibration mapping loss location to the measured Δt was produced for entire storage ring that will be used to determine the location of unknown

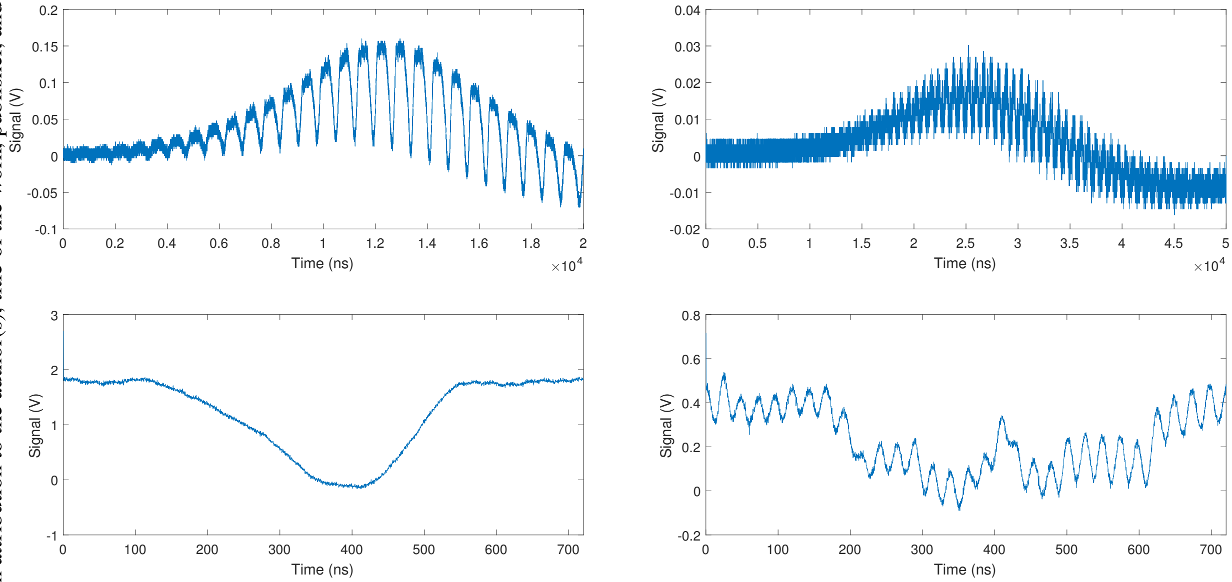

Figure 4: Examples of the beam dump signals captured using the distributed beam loss monitors. The upper two plots show the raw loss signals and the lower two plots show their corresponding turn by turn sum for user beam and single bunch fills on the left and right respectively.

losses. To do so each vacuum valve along the path of the beam was inserted in turn, several valves had to be skipped for various reasons, and targeted with a single bunch. The results for the fibres covering sectors 2 to 9 and 9 to 2 are shown in Figure 3 on the left and right respectively. A line of best fit is shown, it can be seen that some data points do not quite fall on the line. Since the valve locations are well known these small deviations are attributed to the routing of the fibre around various devices as mentioned earlier. Therefore, rather than use the fitted lines as the calibration, the measured loss locations are taken as known and a linear interpolation between any two points will be used to determine the loss location of unknown events.

After calibration, attempts were made to measure the dominant loss locations of a beam dump event. A reliable method of triggering a beam dump was required to do so. This was achieved by tripping the orbit interlock system which turns off the storage ring RF in the event the beam is deemed unstable by the BPM system. Rather than kicking the beam to trigger the interlock, which was found to be unreliable, a BPM offset parameter was set out of range tripping the orbit interlock and dropping the RF on command. Low stored currents of 4 mA for single bunch and 20 mA for multi-bunch were used to expedite testing and minimise radiation produced. The ADCs were set to trigger on the beam loss signal and the sample length recorded was adjusted to capture the entire loss event, which was found to occur over approximately 50 turns for multi-bunch and 70 for single bunch. Figure 4 shows two of the captured beam dump signals. As expected the signals show a clear periodic structure at the revolution frequency. Summing turn by turn reveals the steady-state loss pattern but blurs the finer details present in the raw waveforms. Current work is focused on developing a technique to better understand the observed waveforms and characterise and pair peaks in these and other waveforms where loss signals from multiple locations are present.

CONCLUSION

It has been shown that the time difference between the primary loss signal and its reflection in Cherenkov beam loss fibres provide a means of accurately determining loss locations along the length of an accelerator, which is independent of the triggering system and does not require knowledge of which bucket it producing the loss. A calibration mapping Δt to loss location for storage ring has been produced. Attempts at measuring the dominant loss locations of a beam dump have been made but as of yet have been unsuccessful. Further work is required to correctly characterise and pair primary and reflected peaks when multiple loss signals are present in the waveform.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the CERN Instrumentation team, particularly Dr. Barbara Holzer, Dr. Eduardo Nebot Del Busto and Maria Kastriotuo, who developed and installed the original fibre system at the Australian Synchrotron that this work is built on. Also thank you to the operators of the Australian Synchrotron for their help and willingness to generate losses. And thank you to Eugene Tan and Dr. Rohan Dowd for the helpful discussions.

REFERENCES

[1] Kay Wittenburg, “Beam loss monitors”, CAS 2008, CERN Accelerator School: Beam Diagnostics, Volume CERN-2009-005, pp. 294.

[2] Jacobus Willem van Hoorne. *Cherenkov Fibers for Beam Loss Monitoring at the CLIC Two Beam Module*. Tech. rep. 2012.

[3] E Nebot Del Busto et al. "Position resolution of optical fibre-based beam loss monitors using long electron pulses." In: *Proc. IBIC15* (2015), pp. 580–584.

[4] EB Holzer et al. *Measurement of Beam Loss at the Australian Synchrotron*. Tech. rep. CERN-BE-2014-010. Geneva: CERN, Sept. 2014. URL: `http://cds.cern.ch/record/1973063`.

[5] Maria Kastriotou et al. "An optical fibre BLM system at the Australian Synchrotron Light Source." In: *5th Int. Beam Instrumentation Conf.(IBIC'16), Barcelona, Spain, Sept. 13-18, 2016*. JACOW, Geneva, Switzerland. 2017, pp. 670–673.

[6] JW Boldeman and D Einfeld. "The physics design of the Australian synchrotron storage ring." In: *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 521.2-3 (2004), pp. 306–317.