MICE TARGET OPERATION & MONITORING

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Abstract

The MICE experiment [1] requires a beam of low energy muons to test muon cooling. This beam is derived parasitically from the ISIS accelerator at the Rutherford Appleton Laboratory. A novel target mechanism has been developed which allows the insertion of a small titanium target into the proton beam on demand, for the final couple of milliseconds before extraction.

The first operational linear drive was installed onto ISIS in January of 2008. Since then, it has operated for approximately 185,000 actuations. Studies have been performed of particle production and collection by the MICE beam-line, as well as verification of the reliability of the target drive itself. The target data acquisition system records not only the position of the target throughout the ISIS acceleration cycle, but also the outputs from beam loss monitors placed around the synchrotron. Data will be presented showing the stability of the target's motion and the correlation of beam loss and particle production with the timing and depth of the target's intersection with the circulating beam.

THE MICE EXPERIMENT

The Muon Ionisation Cooling Experiment (MICE) has been designed to practically demonstrate the principle of 'Ionisation Cooling' a theoretically sound but technologically unproven method of reducing the emittance of a muon beam. Ionisation Cooling is one of many new technologies that will be required to build a next generation high intensity neutrino source such as the Neutrino Factory. Muon cooling is achieved by passing the muons through a set of absorbers within the MICE cooling channel. Axial momentum lost by the muons within the absorbers is then replaced through the use of RF cavities. MICE should demonstrate a transverse emittance reduction in the muon beam by the order of 10% and will be able to measure the absolute value of the emittance of the muons to within 0.1%.

MUON SOURCE

The source of these muons for the MICE experiment will come from the MICE 'target mechanism' an electro-mechanical device that operates parasitically on the ISIS accelerator. ISIS is an 800 MeV proton accelerator that forms part of a neutron spallation source, situated at the Rutherford Appleton Laboratory in the UK, also home of the MICE experiment. This target mechanism, operating at a maximum frequency of 1 Hz, inserts a small titanium target into the ISIS proton beam on demand. The target remains outside the beam envelope during acceleration and then overtakes the shrinking beam envelope to enter the proton beam during the last 2 ms before beam extraction. The target interacts with the ISIS beam halo during these 2 ms to produce pions. Their subsequent capture and decay provides the muons for the MICE experiment.

THE TARGET DRIVE

The target drive is a brushless DC permanent magnet linear motor. This motor consists of a moving magnetic assembly that operates inside a set of 24 flat coils that are contained within the stator body. The magnetic assembly is attached to a long shaft connected to the target blade. This shaft is magnetically propelled by the interaction of the magnets with the stator coils. This is a demanding application; the target must accelerate at ~85 *g* and the components of the target system must remain compatible with the ultra high vacuum of the ISIS system. A second paper presented at the PAC09 conference discusses the target hardware in more detail and so this will not be repeated here [2].

MONITORING

The key parameters from the target system that are recorded by the target DAQ are; the target position, the ISIS beam intensity and the ISIS total beam-loss signal. These are shown in figure 1. Recently the signal representing the beam-loss produced in the vicinity of the MICE target has been added to the list of signals that are recorded by the DAQ.

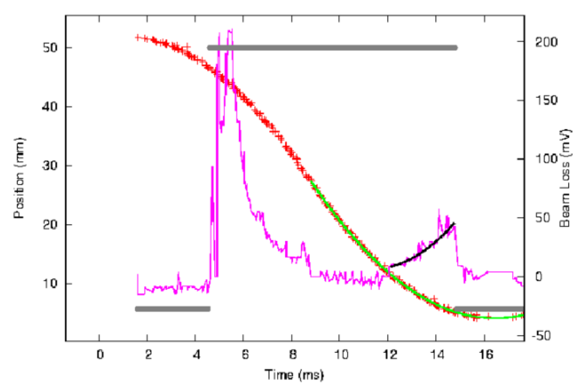

Figure 1: A screen shot of a typical target pulse. The inverted bell shaped curve represents the target's trajectory, the top hat represents the beam intensity and the noisy curve is the ISIS total beam-loss signal. The signal has been fitted where beam-loss has been caused by the MICE target.

The ISIS beam-loss signal is the summation of the electrical signals received from a series of gas ionisation chambers situated around ISIS. This beam-loss signal represents the rate of proton loss from the synchrotron and is usually expressed in mV. For a given rate of proton loss the strength of the beam-loss signal is dependent upon the proton energy. As the target is only inserted during the last couple of ms of the ISIS cycle the energy dependence can largely be neglected as the proton energy changes little during this period - typically at 800MeV the output signal scales as $3.8 \pm 1.9 \times 10^{-14}$ Vs/proton [3].

Figure 1 shows a screen-shot from the target display software showing the various signals discussed minus the local beam-loss signal. The beam-loss caused by the target insertion can be seen towards the right hand side of the trace just before the beam intensity drops to zero; this is indicated by the superimposed fit added by the software.

The beam-loss signals are very noisy and some aggressive post processing of these signals is required to obtain a value of beam-loss that is consistent with that reported by ISIS. The variation in the signal from actuation to actuation is large, on the order of 50% to 100% of the signal, and so a statistical analysis has to be done in order to obtain any useful information from this data.

TARGET STABILITY

Before the target was installed onto ISIS the importance of the repeatability of the target's trajectory for a given actuation depth was unknown. Stability of the target's trajectory is clearly desirable to minimise the variance in particle production for MICE. No active timing feedback is currently used during the actuation cycle because the accelerations involved would mean that any trajectory corrections would require current impulses that are beyond the capabilities of the present target power supply.

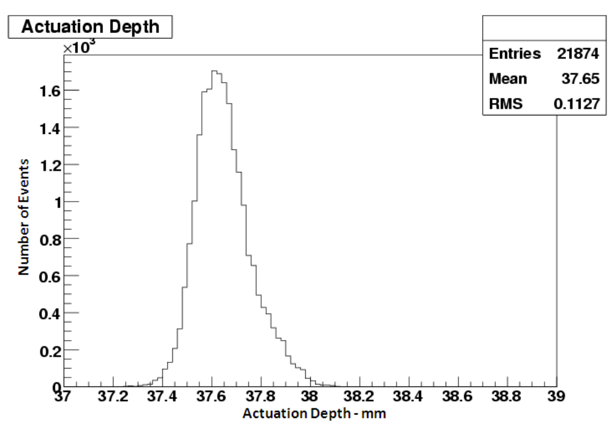

Figure 2: The variation in actual actuation depth for a fixed depth of insertion. The FWHM is ~300µm. This value is actuation depth independent and gives an indication of the mechanical jitter in the system. No active timing feedback is currently used during the actuation cycle due to limitations on the power supply.

Long term tests in the laboratory over many millions of actuations showed that a FWHM of 300 µm in the absolute position of the target was attainable. Due to limited running time only short continuous runs of a few thousand pulses at a particular actuation depth have been possible on ISIS. Figure 2 illustrates the repeatability of the target's motion for one of the larger data sets at a fixed actuation depth; it too shows a FWHM of approximately 300 µm.

BEAM-LOSS AS A FUNCTION OF TARGET ACTUATION DEPTH

Figure 3 illustrates how the measured beam-loss caused by the target changes as a function of actuation depth. As expected, the beam-loss increases significantly as the target is actuated deeper into the halo of the ISIS beam. As previously mentioned, the beam-loss caused by the target shows a large variation on an actuation by actuation basis. Given the relative stability of the target the cause of this was traced to variations in the beam position from pulse to pulse. The fluctuations in the beam position indicate that no significant benefit would be obtained by improving the repeatability of the target's motion.

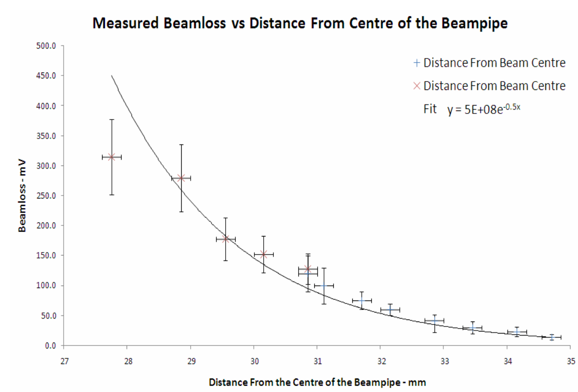

Figure 3: The mean measured beam-loss as a function of actuation depth. The target is being modified so that it can actuate deeper into the ISIS beam. This will be necessary to significantly increase the muon rate for MICE.

BEAM-LOSS AS A FUNCTION OF TARGET TIMING

The exact timing of a target actuation with respect to the beam cycle can currently be altered with a resolution of 100 µs. As shown in figure 4 this value approximately coincides with the jitter in the time that the target takes to get to the apex of its trajectory. Like the jitter in actuation depth, the time jitter could be corrected with the use of a suitable feedback algorithm and the addition of a higher power PSU; however the advantages of implementing such a system are not apparent.

Due to beam-time constraints it has not yet been possible to obtain enough data to map the beam-loss as a function of target timing. Obtaining this data and correlating it with beam-loss as a function of actuation depth would allow a time profile of the ISIS beam to be made at the location of the target. It is anticipated that the opportunity to acquire this data will be made available during a future commissioning run.

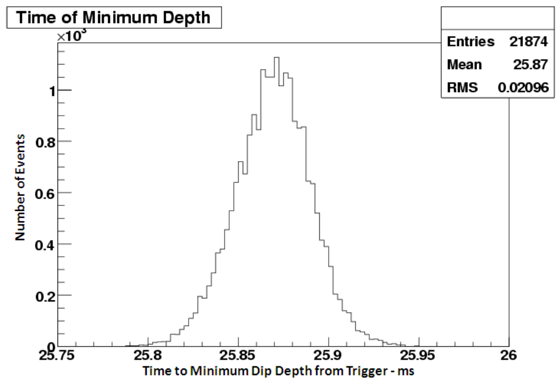

Figure 4: The jitter in the timing of the actuation with respect to the timing of the ISIS beam at a fixed actuation depth. The FWHM of the jitter is ~50 µs. The timing of the actuation trigger is controlled to a resolution of ~50 µS. The positional jitter in the ISIS beam suggests that no advantage would be gained by improving the timing control.

PARASITIC OPERATION

During operation the target has been run at an insertion rate of ~0.5 Hz whilst ISIS has been running from this frequency up to its normal operating frequency of 50 Hz. Operation of the target with ISIS running at 50 Hz has successfully shown that the target can operate on ISIS parasitically. This was demonstrated by dipping the target at a progressively later time in the ISIS cycle until clipping of the next ISIS pulse at beam injection was observed. For an actuation depth that initially provided 50 mV of beam-loss, there was a ~3 ms window between the optimum target insertion time and where injection losses on the next ISIS pulse were observed.

CORRELATION TO THE MICE MUON RATE

Whilst most of the discussion so far has centred on the concept of beam-loss, clearly what is important to MICE is the expected muon rate in the MICE cooling channel. MICE is being installed over six stages, the ultimate aim of a full emittance reduction measurement will not be possible until after all of the components have been installed in the final stage of construction. At this point a muon rate of 600 good muons per spill will be required to make the required emittance measurements in a reasonable time frame.

Simulations coupled with data obtained from the detectors installed in the MICE beamline indicate that the current muon rate is of the order of a few muons per spill [4]. The amount of beam-loss produced by the MICE target has been deliberately limited so far until a full understanding of the likely activation of the local environment and the disruption of the ISIS beam is understood. It is clear that the permitted beam-loss caused by the target will need to be significantly increased in the future so that it is possible to obtain the required good muon rates for MICE.

REFERENCES

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[4] Estimate of Protons on Target and Implications for Muon Flux in MICE. Marco Apollonio, Kevin Tilley. MICE note 204. April 2008 http://mice.iit.edu/micenotes/public/pdf/MICE0204/MICE0204.pdf