POMPOMS: COST-EFFICIENT POLARITY SENSORS FOR THE MICE MUON BEAMLINE *

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Abstract

The cooling effect in MICE (Muon Ionisation Cooling Experiment) will be studied with both positive and negative muons, reversing the electrical input to the magnets by physically swapping over the power leads. Ensuring the actual operating polarity of the beamline is correctly recorded is a manual step and at risk of error or omission. We have deployed a simple system for monitoring the operating polarity of the two bending magnets by placing in each dipole bore a Honeywell LOHET-II Hall-effect sensor that operates past saturation at nominal field strengths, and thus return one of two well-defined voltages corresponding to the two possible polarities of the magnet. The environment in the experimental hall is monitored by an AKCP securityProbe 5E system integrated into our EPICS-based controls and monitoring system. We read out the beamline polarity sensors using a voltmeter module, and translate the output voltage into a polarity (or alarm) state within EPICS whence it can be accessed by the operators and stored in the output datastream. Initial tests of the LOHET-II sensors indicate they will still be able to indicate beamline polarity after radiation doses of 900 Gy (Co60).

INTRODUCTION

MICE (the Muon Ionisation Cooling Experiment [1], [2]) is a technology demonstrator of the ionisation cooling of muon beams for muon collider or neutrino factory applications. Muons created by pion decay are transported from the ISIS synchrotron to the cooling channel along a short beamline that includes two bending magnets.

The cooling effect needs to be studied with both positive and negative muons, and we therefore wish to change between the magnetic polarities of the beamline magnets. At present, this must be done by inverting the polarity of the electrical input to the magnets and is accomplished by physically disconnecting and swapping over the power supply cables. Ensuring that the actual operating polarity of the beamline is correctly recorded in the output datastream is at present a manual step and thus at risk of error or omission.

We have deployed a simple system known as **POMPOMs** (**P**air **O**f **MICE** **P**olarity **O**rientation **M**onitors) for monitoring and recording the operating polarity of the two bending magnets (and by inference the other beamline elements), by placing in the dipole bores a pair of Hall-effect sensors that are operating past saturation at nominal field strengths, and thus return one of two well-defined voltages corresponding to the two possible polarities of the magnet.

In this paper we will briefly describe the sensor characteristics and radiation tolerance, and the readout system.

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SENSORS

Behaviour

We are using the low-drift variant (SS94A1E) of the LOHET-II range from Honeywell Inc. [3]. These are designed for use as analogue position sensors and have a linear response in the ±50 mT range, with the output clamped to a fixed voltage at higher fields. By locating the sensors within the beamline magnets such that the local field will be over 100 mT under normal running conditions, we expect to see only four discrete output voltages:

- high output (positive field)
- mid-range (magnet off)
- low output (negative field)
- zero (supply fault)

The input supply is 12 V to allow for any voltage drop in the cables, and to provide plenty of dynamic range for distinguishing the different output states.

We have checked the sensor response over the ±500 mT range using a 4” electromagnet (Newport Instruments Type A) and Hirst GM04 gaussmeter [4]. Figure 1 shows the response of two sensors, labelled #1 and #2. It can be seen that the devices have a linear response in the nominal working range and hold precisely to a fixed value at higher fields save in the transitions, which show a slight overshoot for positive fields and a more rounded-off response for negative fields. Figure 1 also shows the outputs of the sensors once installed in the dipoles – known as D1 and D2 – of the MICE beamline: the response is consistent right out to ±1.7 T (the slight increase in output voltage is likely to be due to the supply voltage being marginally higher – about 0.1 V).

Location

Although the original intention was to deploy only one sensor on D2, concerns about a single point of failure have led us to install two, with the second on the other dipole as an extra check against having the bending magnets set to deflect particles in opposite directions.

For now the sensors have been mounted on plastic “wands” projecting into the corner of the magnet bore (Figure 2), with the sensor aligned such that it sees a positive magnetic field when the dipole is steering positively-charged particles along the MICE beamline, and a negative field when negatively-charged particles are desired.

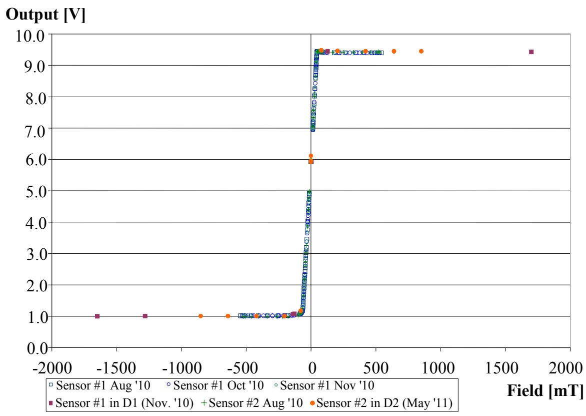

Figure 1: Sensor response in lab tests and in beamline. The error bars are smaller than the symbols at this scale.

This method of installation has the advantage that the probes can still be removed without any permanent damage or modification to the magnet, but it does leave the sensor exposed to the beam, and also D1 (and thus sensor #1) is located inside the ISIS vault and so also exposed to extra radiation from the synchrotron and MICE target operation.

Figure 2: POMPOM #2 installed in D2. The sensor PCB itself is the white chip to the right of the final cable-tie.

Radiation Tolerance

A preliminary study of the radiation tolerance of the LOHET-II sensors is in progress to assess possible damage to the sensors.

A spare sensor (#3) has been exposed (unpowered) on several occasions to a dose of 300 Gy of gamma rays from a ^{60}Co source, and the response measured as before. As can be seen in Figure 3, there is a slight change to the slope in the designed operating range and to the high clamping voltage, but a significant change to the form and level of the lower (negative field) clamping voltage which then recovers somewhat within a month.

The most recent data were taken just a few hours after irradiation to a cumulative dose of 900 Gy, and the output could be seen to be still drifting as the device recovered, hence the variability in those results.

Since the role of the POMPOM is merely to indicate the polarity, the damage caused by the 900 Gy unpowered exposure is tolerable as the output range indicating a negative field can simply be broadened to span the 1 to 3 V range without introducing any ambiguity.

READOUT

The environment in the experimental hall is monitored using a modular AKCP securityProbe 5E system [5], which is based on selecting from a variety of plug-in "dongles" that sense air temperature, water leaks, etc. and which has already been integrated into the MICE EPICS-based controls and monitoring framework. We thus read out each polarity sensor using an AKCP digital voltmeter dongle added to our existing environment monitoring system, and translate the sensor output voltage into a polarity state (or alarm state) within EPICS [6] whence it can be accessed by the operators and inserted into the MICE output datastream.

Figure 4 shows the EPICS stripchart of the POMPOM output during a test exercise in March 2011. Initially both dipoles are powered, set up for a “negative” beamline, and both outputs give the corresponding value (1 V). The magnets are then turned off whilst the electrician changes over the supply leads; once turned on both sensors indicate that the MICE beamline is set for work with positively-charged particles.

The translation from an output voltage to polarity is done within EPICS, resulting in a process variable directly indicating the magnet state.

CONCLUSIONS

We have deployed a system for monitoring the polarity of the MICE beamline based on low-cost COTS sensors read out by an existing monitoring system, minimising development effort. The Honeywell LOHET-II sensors provide a stable well-defined output well beyond their nominal operating range that can readily be mapped to magnet status.

Very recently we have become able to irradiate sensors whilst they are powered just as they are in the MICE beamline. An undamaged sensor (#5) showed no obvious change in response after a dose of 300 Gy. We plan to extend this test, and compare with sensor #1, which has been exposed to the environment within the synchrotron for 6 months now.

The change in response of the sensor to a negative field provides a crude measure of device damage due to irradiation.

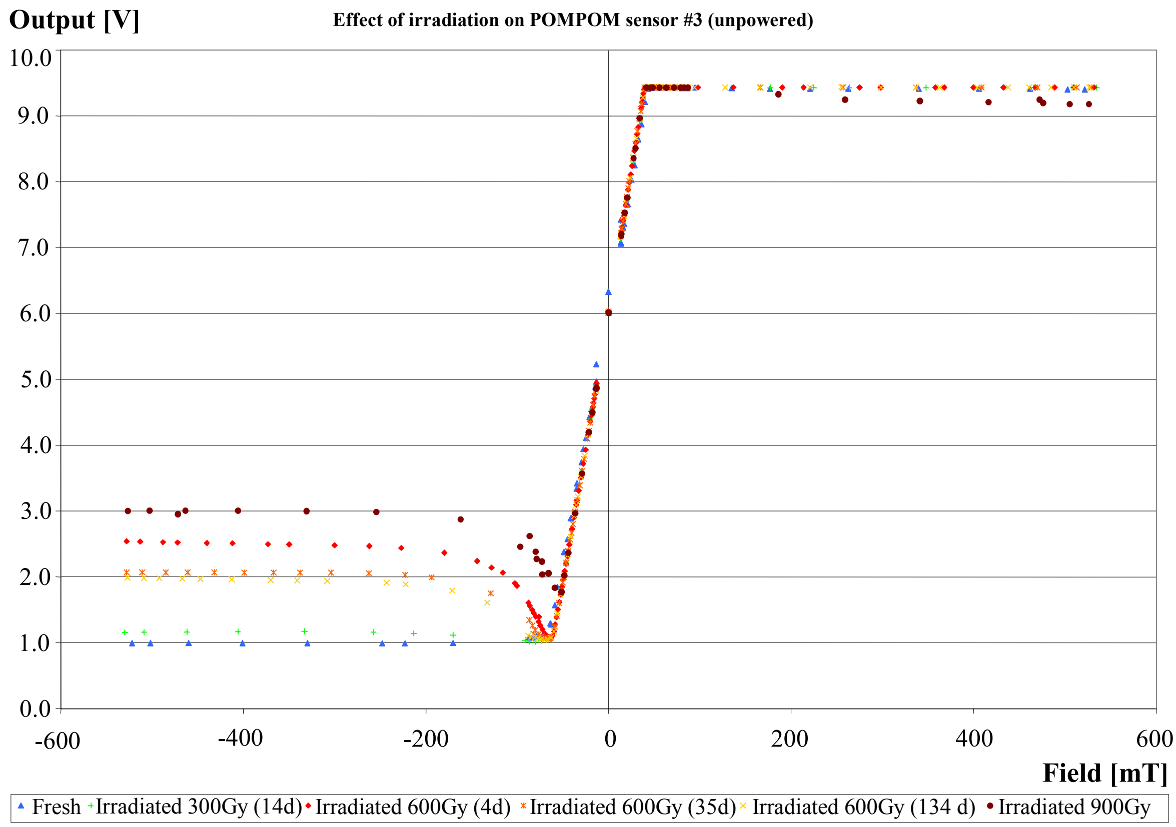

Figure 3: Effect of successive 300 Gy irradiations (^{60}Co) on sensor #3. Intervals between exposure and measurement are given in days, where relevant. The immediate effects of the second dose (to 600 Gy) abate within a few weeks, but the remaining damage lasts for months. The final (900 Gy) results were taken just a few hours after the irradiation; the scatter is from the real changes in device response with time as it recovers.

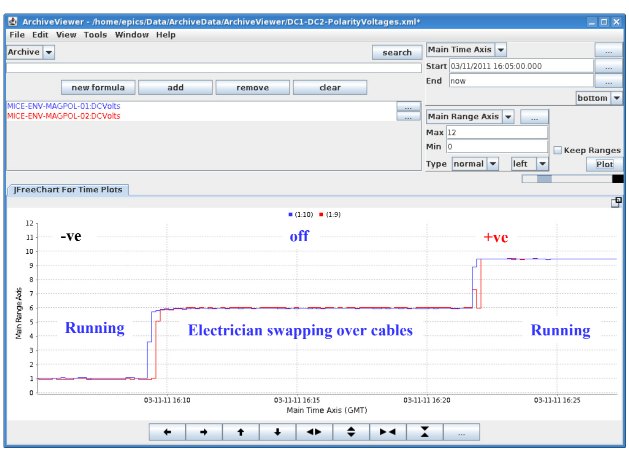

Figure 4: Stripchart showing POMPOM raw outputs during a changeover of supply polarity.

ACKNOWLEDGEMENT

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