Comparative Analysis of Reed Switches and Hall Sensors at Cryogenic Temperatures: An Argument for a Cost-Effective Alternative for Cryogenic Applications

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Abstract. Hall sensors are commonly used as a non-contact way to relay positional data inside a cryostat to an external motion controller. However, cryogenic Hall sensors can be cost prohibitive and require peripheral electronics to interface with the motion controller. Here we contrast the accuracy and reliability of non-contact reed switches in cryogenic environments against the commercially available cryogenic Hall effect sensors. Accuracy for both units was optically measured using a wheel cooled down to 77K, while reliability and yield was determined by cooling multiple units down to liquid nitrogen (77K) and liquid helium (4.2K) temperatures. Lastly, we argue that the lower cost and ease-of-implementation of reed switches make them better suited for cryogenic motion control applications.

1. Background

Switches are often used in motion control applications to indicate home positions, limits of travel, or positions-of-interest within the range of motion. Cryogenic systems also feature motion control, but many switches stop functioning properly at cryogenic temperatures. Magnetic switches are of interest since they are non-contact, minimizing component wear and contamination inside the vacuum chamber.

Figure 1. *Example filter wheel assembly controlled by motor with position feedback from mechanical switches*

Often with systems developed at IRLabs, cryogenic Hall sensors are used as magnetic switches in cryogenic motion control applications, however, these sensors do have some disadvantages. Because they are precision sensors for measuring magnetic fields, they add additional costs and functionality not necessary for the application. Furthermore, Hall sensors output a small analog voltage that needs amplification and conversion into a switch output for the motion controller.
Because of the high unit costs and extra implementation costs, this paper investigates using non-contact magnetic reed switches as an alternative. Reed switches are commonly used in room-temperature motion control applications and are actuated by magnets like a Hall switch. Unlike Hall sensors however, there is no need for separate electronics to convert the analog output—the outputs of reed switches are two wires that are ready to connect to IO pins on most commercial motion controllers.

2. Methods

This paper conducted two tests to characterize the performance of the switches:

2.1 Position Comparison Test
The goal of the Position Comparison Test was to measure the repeatability of the Hall sensor and reed switch and compare their performances. Both a cryogenically rated Hall sensor and a reed switch were connected to a motion control system controlling a wheel with a magnet. The motor controller used the switch feedback to set an initial home position. The repeatability of the switch was then measured utilizing an optical microscope and a target on the wheel, with position resolution of 0.1 microns. The switches, motor, and magnet wheel were mounted into a Dewar cooled to liquid nitrogen temperature for this experiment. The Dewar was also temperature cycled between room temperature and 77K multiple times to verify the switches remained repeatable after these thermal cycles.

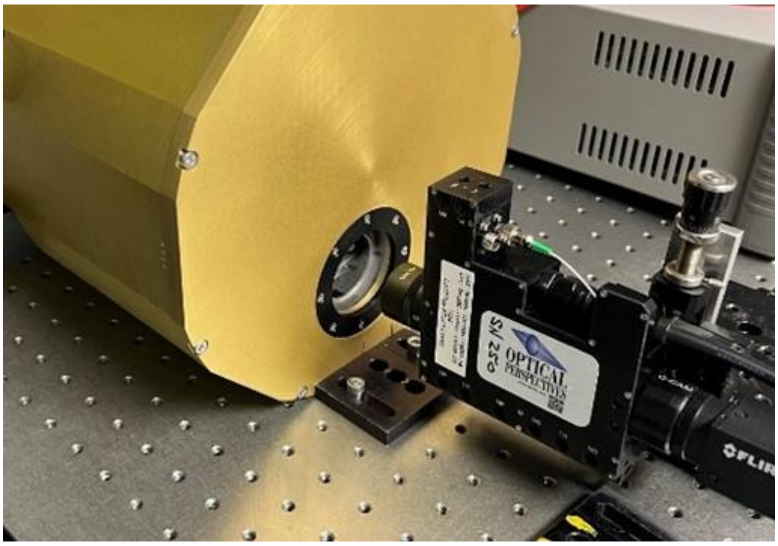

Figure 2. *Position Repeatability Test Experiment Setup showing the Optical Measurement Tool measuring target inside dewar*

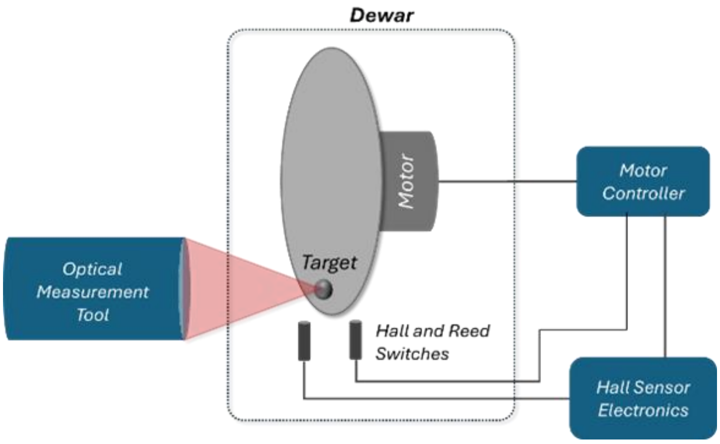

Figure 3. *Position Repeatability Test Experiment Schematic*

The outputs from the reed switch were connected directly to one of the digital inputs on the motor controller. The Hall Sensor required an INA317 amplifier to buffer and amplify the approximately 20mV voltage across the Hall sensor when the magnet is in position. An LM339N comparator was also added to turn the signal into a switch signal for the motor controller. A battery was used for the circuit due to excess noise observed affecting the accuracy of the switch.

2.2 Bulk Test

The goal of the bulk test was to test multiple reed switches to get an estimate of a failure rate after cooling to cryogenic temperatures. The switches were initially cooled down to liquid nitrogen temperature, then down to liquid helium temperature (4.2K). In total, ten reed switches were wired inside the test Dewar. The switches were oriented so a rotating shaft housing magnets could cyclically actuate the switches. Switch performance was confirmed by measured change in resistance across the reed switch leads when manually moving the magnets in and out of position. Picture below shows the interior of the test Dewar after wiring the reed switches.

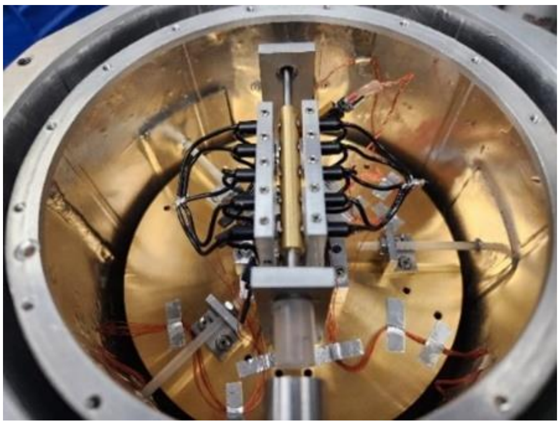

Figure 4. *Inside of Bulk Test dewar*

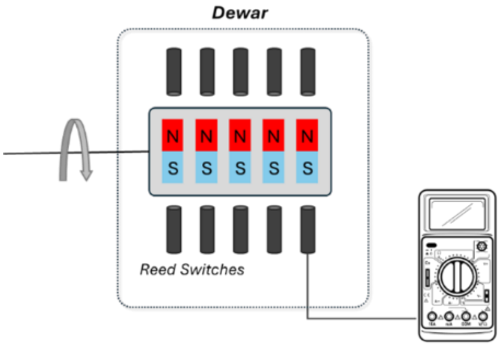

Figure 5. *Experiment schematic of Bulk Test dewar*

3. Results

3.1 Position Comparison Test

Data sets consisted of first homing the motor using the switch input, zeroing the target and optical measurement tool, moving the wheel away, and then re-homing the motor. The measured position offset was then recorded. This was done for both the reed switch and hall effect sensor. Between data sets, the system was allowed to warm to room temperature before being cooled again to 77k. The experiment was temperature cycled 9 times in total, with at least thirty data points recorded per sensor per session.

The Position Comparison Test showed the reed switch performed as well as the Hall sensor. Each data point consisted of homing the motor using the switch input, zeroing the target and optical measurement tool, moving the wheel away, and then re-homing the motor. For each of the nine system temperature cycles preformed, thirty data points were captured for each of the sensors. Between experiments the test dewar was allowed to warm up to room temperature and cooled back down to 77K.

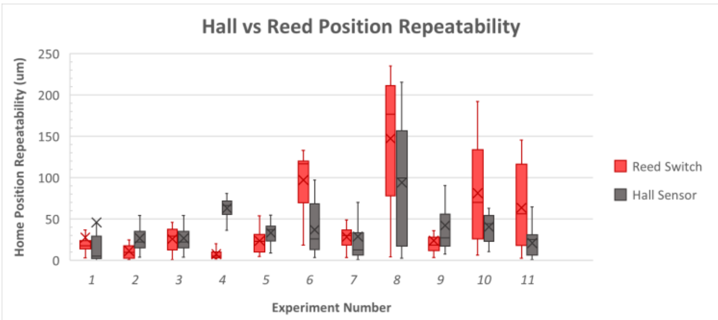

Figure 6. *Hall sensor vs reed switch position repeatability data*

While the data collected shows variability in the repeatability of the switches, both are viable options for applications requiring ±150um precision. It was also observed that temperature has an impact on switch repeatability, as seen in Experiment 4. Hall Sensor data for this experiment was taken while the dewar had run out of LN2 and was warming up (temperature inside dewar was at 98K). We suspect that the varying temperatures effect on the magnetic field may account for a large portion of the repeatability error.

During the testing of the switches, it was observed that the position after each homing would sometimes consistently increase, not randomly distribute about a mean point. For instance, Experiment 9 showed a large consistent increase in the displacement in the same direction for both the reed and Hall switches.

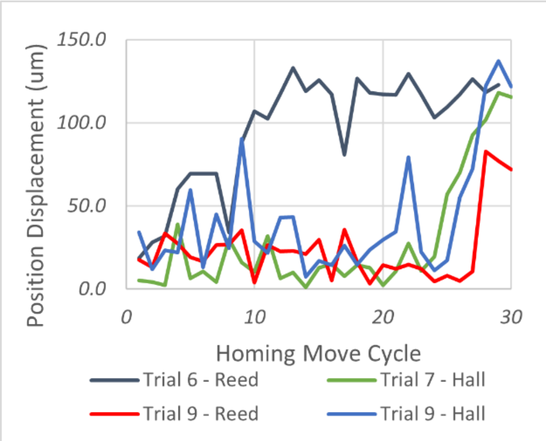

Figure 7. *Data showing steady increase in position displacement over the course of one experiment*

Because the change in the position displacement occurred in the same direction and was observed with both the reed and Hall switch, we believe this indicates a systemic error in the data taken in those experiments. Experiments 8, 10, and 11 show larger changes in home position repeatability, however, the change in position again increased over the course of data collection.

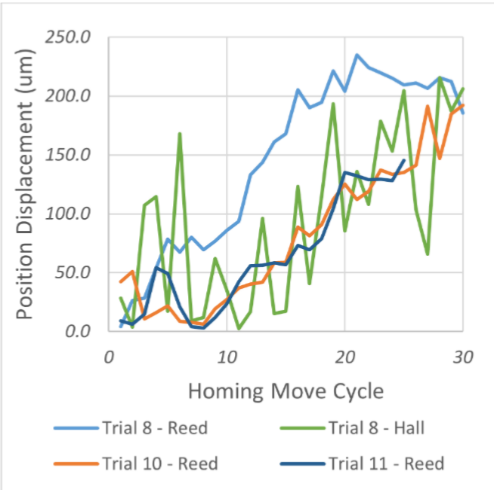

Figure 8. *Data from Experiments 8, 10, and 11 showing a similar increase in displacement over the experiment*

It is suspected that the steady change in position away from the starting location may be due to thermal change impacts, possibly from heat generated by motor. Initial data suggests that waiting for the assembly to return to steady state temperature (5 minutes) before performing

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another home sequence improves the position repeatability, but more data needed to show this conclusively.

3.2 Bulk Test

The Bulk Test dewar contained ten reed switches at the start of testing. During the initial testing of the reed switches, one switch failed at room temperature. Another switch failed when cooled down to LN2 temperature, resulting in a 20% failure rate of the reed switches in the Bulk Test. However, the reed switches that passed the LN2 test also passed the LHe test, indicating that switch failure may follow a “bathtub curve,” (Ohring, 1995) with larger failure rate at the beginning of cooling, and lower failure rate after multiple thermal cycles.

4. Discussion

The Position Comparison Test showed no significant difference in accuracy between the Hall Sensor and the reed switch. After multiple cycles there wasn’t any apparent degradation in performance of either the Hall Sensor or the reed switch. Some experiments later did show change to position repeatability, but it’s not clear if it is due to switch degradation or some potential heat introduction into the experiment.

The Hall sensor approach to building a motion control switch adds extra cost and development time, without much benefit. Cryogenic Hall sensors can be an order of magnitude more expensive than reed switches, and additional time is required to design and debug the amplifier/comparator circuit for the experiment. In most cryogenic motion control applications, Hall sensor switches could be replaced with a reed switch without any loss in performance.

The Bulk test also showed a failure rate of roughly 20% when cooling down the reed switches. However, after doing an initial cooldown, the switches do appear to continue working at cryogenic temperatures. Based off the initial data, it appears some “freeze-in” testing may be necessary to find switches that fail early.

Based on the results mentioned, magnetic reed switches could be a good alternative for motion application (at or above 4.2K) that require a home switch, limit switch, or position with accuracy to within ±150um.

Future areas of study should investigate reed switches in high-vibration environments from cryocoolers, and the long-term reliability of reed switches.

5. Acknowledgements

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References

[1] Ohring, M., 1995. 15 - FAILURE AND RELIABILITY OF ELECTRONIC MATERIALS AND DEVICES. In: *Engineering Materials Science.* s.l.:Academic Press, pp. 747-788.