Problem with Limit Switches
Spartan IR Camera for the SOAR Telescope

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Abstract

Two limits switches on our mechanisms have failed. We review software and installation problems and the history of the failures. We conclude that the switches failed in infancy, not during a year of occasional testing in air and another year of cold tests in the instrument in vacuum. The only lifetime that the manufacturer has tested is that of the seal on the switch. It is 25,000 cycles, which is 2.5 times greater than the expected number of cycles for the most used mechanism. We take this to be an indication of the overall expected lifetime of the switch. Nonetheless, there is a risk that a switch may fail. To mitigate that risk, we recommend using the forward limit switches for backup, so that recovery from a broken switch can be done in an hour.

The rotation stages use the hermetically sealed switch 17HM6 from Honeywell (Figure 1). The movement of the arm is transmitted from the outside to the inside through the "wobblefram." There are two circuits, one normally closed, which we use, and the other normally open. Because the switch is meant for a wide temperature range, its housing is metal.

1 Summary of Problems

Two limit switches have failed, and we will discuss the history of that later. First, we list the operational problems that we discovered, in order that the history will be clearer.

Switch bounce To locate the position of the reverse limit switch, the rotation stage (1) backs up until the limit switch is depressed, (2) moves forward until the switch is not depressed, and (3) finds the limit again at a slower speed. FindReference.vi, the software from National Instruments, fails at step 1 if the

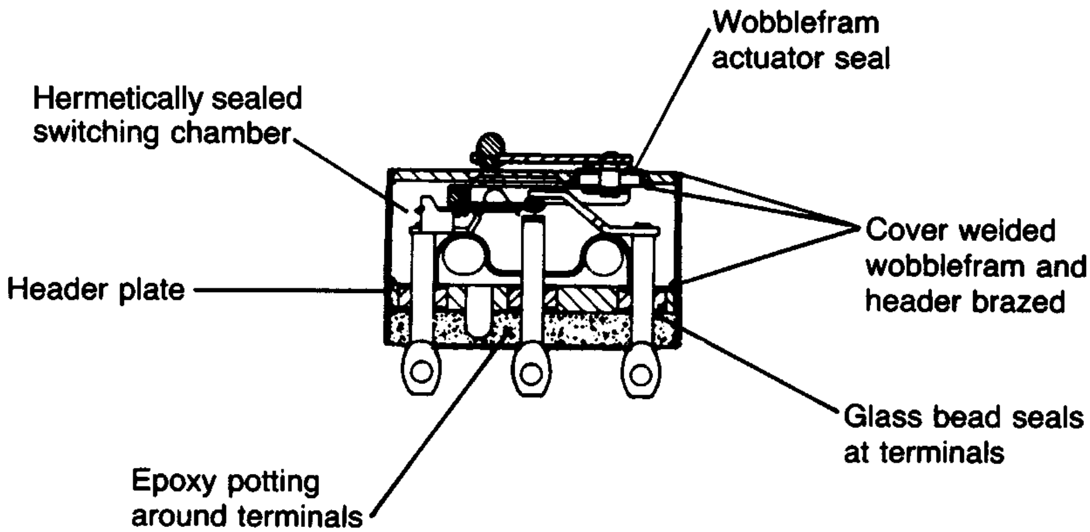

Figure 1: Drawing of the HM switch from honeywell.com.

switch bounces. Apparently, some part of the software knows step 1 finished, but some other part examines the switch during the bounce and determines that step 1 did not complete.

We wrote a replacement for FindReference.vi, which waits 100 ms at the end of each step to avoid the bounce.

Switch position A bumper on the moving part of the rotation stage depresses the switch, which is mounted on the stationary part of the rotation stage. For the switch to work well, the arm of the switch must touch the bumper where the slope on the bumper is not shallow. The spacing between the bumper and the switch is critical. If the spacing is too large, the contact is at a shallow point on the bumper, and the position of the limit becomes variable or temperature sensitive. If the spacing is too tight, the switch jams against the bumper.

We now install the switch with a feeler gauge: When the switch is depressed, the space between the arm of the switch and the body is the thickness of a sheet of paper (0.07 mm). The switch is as close to the bumper as possible without jamming.

2 Switch Failure History

Two switches, one on rotation stage 098 and the other on 099, failed. The other problems turned out to be due to switch bounce or improper positioning.

2.1 Acceptance Test of the Rotation Stages

During acceptance test of the rotation stages in 2004, we tested the reverse limit switch at 77 K by immersing the rotation stage in liquid nitrogen.

000 No problems.

075 No problems.

097 No problems.

098 "In both the warm and cold repeatability tests there is an outlier for both sets of data. The RS home switch seem to get stuck on when homing or testing home during the cold run. The RS would try to back off the switch but the software indicated that it never turned off. It seems to be something electrical because it was fixed when the limit connector was pulled out and then put back in. The Home switch was also triggered once when moving away from home."—log of 2/19/2004.

The normally-closed switch became open when the switch was not depressed.

098 after switch was replaced No problems.

099 "When testing for the amount of backlash cold, the numbers were not consistant. They ranged from 2 to 95."—log of 3/4/2004.

This indicates the switch did not disengage reliably. Nonetheless, we accepted this switch because it did engage at the same location.

100 "The RS would stop when the home switch was triggered but there would be a delay before the home switch indicator would come on."—log of 2/24/2004.

100 after bumper was replaced "This RS had a behavior when cold. While approching home the RS would stop at a position like the home switch was triggered but the indicator in NI-MAX would not come on. The RS would be told to move again and the home switch would then be triggered. Also it was observed that there would be a delay between when the motor stopped like the home switch was triggered and the indicator came on in NI-MAX. This problem was decided not to be major because the RS is still repeatable and this behavior is on the order of a couple of microsteps away from actual home."—log of 6/8/2004.

We now know that the problem here is switch bounce.

2.2 Cold Test 1

099 This rotation stage was used for the 2-eyed detector mechanism. The switch failed during 2 of the 4 times the instrument was cooled down. The switch, normally closed, opened when it was first depressed, and it stayed open until the instrument was warmed up.

2.3 Cold Test 2

099 8/25/06: Reverse limit switch stayed open, but it closed sometime overnight.

Reverse limit would stay open at 77K, even when the reverse limit was not engaged. This switch was indeed broken.

100 Finding reverse limit was timing out, which means the software could not complete the task. The position of the reverse limit was bimodal with a separation of 1000 steps, which is very large.

When we opened the instrument, we discovered that the spacing between the switch and bumper was too large.

2.4 Test of switch in 099

We tested the switch by itself. The switch was mounted on a wooden stick so that it could be immersed in liquid nitrogen. Another stick was used to depress the switch.

Testing the normally-closed (NC) section of the switch These tests were done before the switch housing was punctured.

Cool to 77K from room temperature with switch released At 77K, resistance is 1 Ohm, but sometimes, depressing and releasing the switch causes the resistance to be 180 Ohm.

Cool to 77K from room temperature with switch depressed The switch is open. After releasing the switch, and the switch remains open.

Warming Cool to 77K from room temperature with switch released. While warming up, the resistance is erratic, sometimes infinity.

Testing the normally-open (NO) section of the switch The normally-open section works at 77 K.

Puncture hermetic seal The NO circuit works. The NC section has a higher resistance at 77 K. The resistance decreases if the switch is depressed with more force and released. Sometimes when the force is light, the switch stays open when the force is removed.

The tests show that the switch is broken.

After the hermetic seal is punctured, the switch still does not work properly. The hypothesis that ice insulates the contacts is not viable. An alternative hypothesis, that the contacts became corroded, is viable.

3 Information from Honeywell

3.1 Information

I spoke with David Hill of Honeywell about the 17HM6 switches.

He suspects that the problem with the switch on rotation stage 099 is moisture. Other customers report this. The switch is sealed with air in the factory, which is air conditioned. Switches made in summer will have more moisture.

Their primary concern is hermeticity. They test whether the seal cracks.

They test operation at –40 C.

The temperature specification from the drawing of the HM176 switch is "For use in temperature range –300F to 500F." They test whether the seal cracks after cooling to –300 F (89K). They do not test operation over the temperature range.

The lifetime without seal fracture is 25,000 switch closures.

3.2 Implication

Honeywell's experience is not directly applicable to our application. They are primarily concerned about keeping contaminants out of the switch. Seal failure is catastrophic for them.

For us, seal failure is not a concern, since the switch is in vacuum. The amount of air inside a switch is the same as the amount diffused through the o-rings of the instrument in an hour.

The switch on the filter wheel, the most-used mechanism, must operate for 10,000 closures over a 10-year lifetime.[1] This is 2.5 times less that Honeywell's lifetime based on seal failure. We expect that seal failure and not switch function is the limiting parameter. Therefore the switch should operate mechanically for the lifetime of the instrument. Whether it operates electrically is a separate issue.

4 Mitigation

We believe that the two switches that failed did so at infancy and that much of what we perceived to be switch problems actually turned out to be switch bounce, fixed by changes in the software, and improper installation. We have not had a new failure since acceptance testing of the rotation stages.

The bad switch on rotation stage 098 was replaced during acceptance testing, and we have no more on it.

The bad switch on rotation stage 099 was not working properly at the very beginning. It showed an unusual behavior (but not failure) during acceptance testing in 2004, which was done by immersion in liquid nitrogen. It is unclear whether the contacts on the switch degraded between acceptance testing in March 2004 and use in the cold instrument in January 2006. It failed on 3 of the 5 cool-downs inside of the instrument. It failed during most of Cold Test 2, but worked at the end of the cold test. We replaced it after Cold Test 2.

We tested the original switch on rotation stage 099 extensively. The normally closed circuit is stuck open when cooled with the switch open. Its resistance is erratic when cooled with the switch closed. The normally open circuit is fine.

The original switch on rotation stage 099 is not fixed by puncturing the hermetic seal. Therefore the problem is not solely condensation of water. The contact for the normally-closed circuit has been damaged: the resistance of the normally-closed circuit is erratic, whereas that of the normally-open circuit is stable.

It is likely that the switches will work mechanically for the lifetime of the instrument. Honeywell's test shows that the seal works for 2.5 times the expected number of cycles for the switch in the filter wheel over the 10-year lifetime of the instrument.

However, switch failure is a possibility, and replacing a switch requires warming the instrument (2 days), opening the instrument (2 days for an expert), cooling (2 days), and more time if the rotation stage must be realigned.

[1] The filter wheel must turn 90° for 90,000 times over a 10-year life Baker & Loh, 2006, Lifetime Tests of the Mechanisms, Spartan IR Camera for the SOAR Telescope. We estimate that the astronomer will check positioning at most after 10 movements of the wheel.

To mitigate that risk and enable recovery without opening the instrument, three schemes are possible.

Wire the normally-open circuit to back up the normally-closed circuit For the bad switch on rotation stage 099, the normally-open circuit did not fail. The normally-open circuit will be wired. If a switch fails, a jumper must be changed, and a software configuration file must be changed. Recovery from a broken switch takes an hour. The use of the normally-open circuit does not work if both circuits fail.

Use forward limit switches for backup The forward limit switch can be used as a completely redundant backup for the mask wheel, big filter wheel, and little filter wheel. The forward limit switches may not be used as is for the two mechanisms that move the mirror arms, because the antibacklash springs are engaged only near the reverse limit and the position where the mirror is in the light path. A new antibacklash spring/stop must be made for the two arms. The old one has an antibacklash spring on one leg for the in-path position and a stop on the other leg for the out-of-path position (Figure 2). The new one will have antibacklash springs at both the in-path and out-of-path positions. The software will have to compensate for the backlash, since the mechanism must move in opposite directions to insert the mirror in the light path and to locate the forward limit.

Use the hard stops to backup of all mechanisms This is simple to implement: to find the hard stop, run the mechanism in the reverse direction for 90 s. However, there is a serious drawback. Since there is no indication of when the hard stop is encountered, there is no way to know whether positioning is lost.

The first scheme requires realigning the three wheels, since adding a wire to each switch can only be done by removing the rotation stages. The switches can be removed for the mirror arm mechanisms without removing the rotation stage. Realignment and wiring will take 2 weeks work. Testing is an additional week.

We recommend the second scheme because it will take less time. No wiring needs to be added. Installing the antibacklash spring/stop takes a day, since realignment is not needed. Testing takes a week.

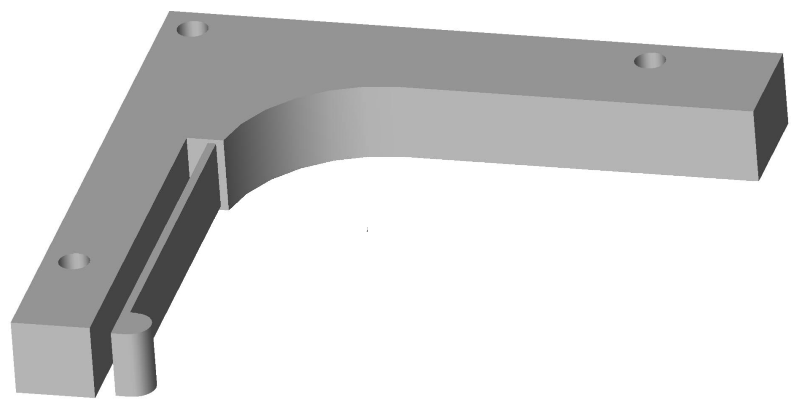

Figure 2: Old antibacklash spring/stop for the mirror arms. The new one will have antibacklash springs on both legs.