White Paper

Beechjet Landing Gear Down-lock Switches

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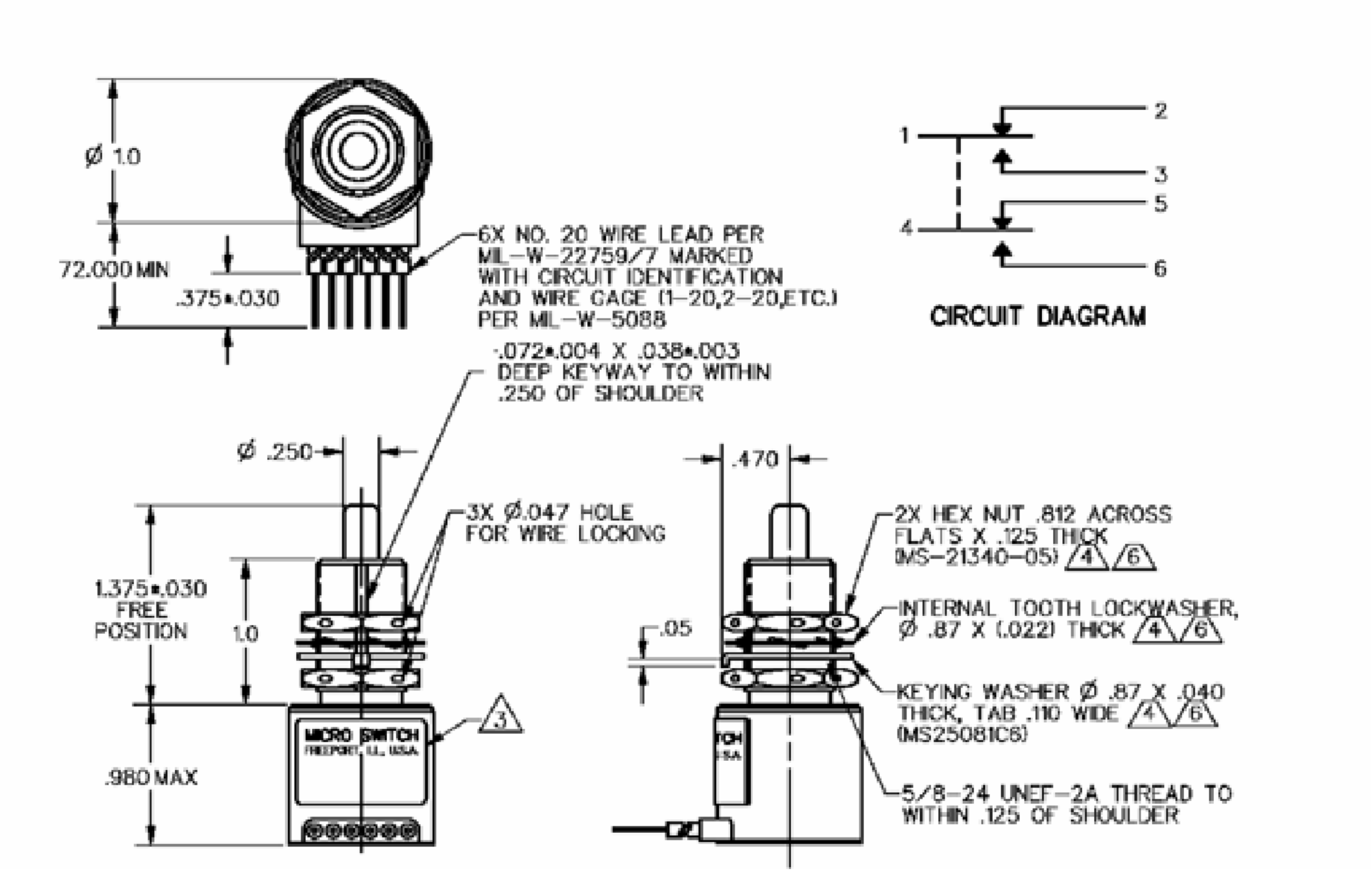
Background:

Beechjet field support reports a noteworthy number of field failures of landing gear switches. Normal gear extension fails to illuminate a gear down and locked annunciator. The down-lock switch assembly is confirmed failed by high resistance measurements between normally open contacts (terminals 1 and 3 in the annunciator lamp power path). The subject switch is a Honeywell 1EN1-6 (MS24331-1).

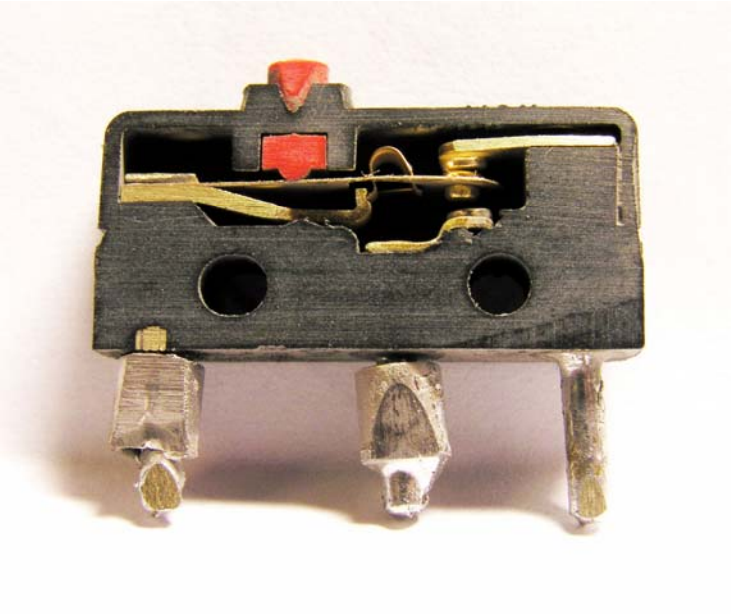
The cost of this failure escalates when pilots are required to use an emergency gear extension procedure that expends a nitrogen bottle and generates a need for servicing the hydraulic system.

Switch Description and Inspection of Field Returns:



The drawing above illustrates basic dimensional and wiring details for the 1EN6-1 switch assembly.

Three test articles were captured and tested for continuity between terminals N.O. contacts of the 1-2-3 switch while operating the switch plunger. The test fixture provides 100 mA constant current bias from a 4.5 volt supply. All three test articles showed open circuit on the NO contacts. After about ten cycles of the switch plunger, one of the three test articles exhibited a recovery of contact resistance on the order of 60-80 milliohms at the ends of the leadwires. The other two switches remained open irrespective of operating strokes to the assembly plunger. A photo to the left shows a switch returned from the field where the stainless steel outer shell has been cut away.



Two switches were opened for inspection. None showed any signs of corrosion or contamination.

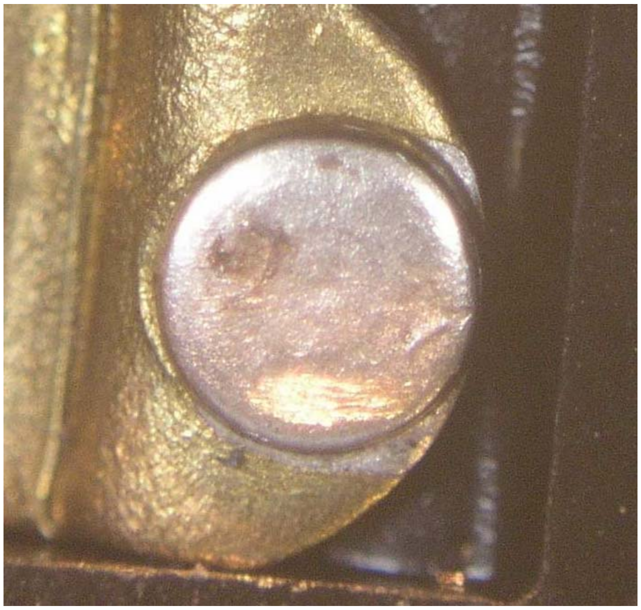
Rivets were drilled out and individual basic switches were separated from the assembly. A photo to the left illustrates a cut-away view of one of these switches.

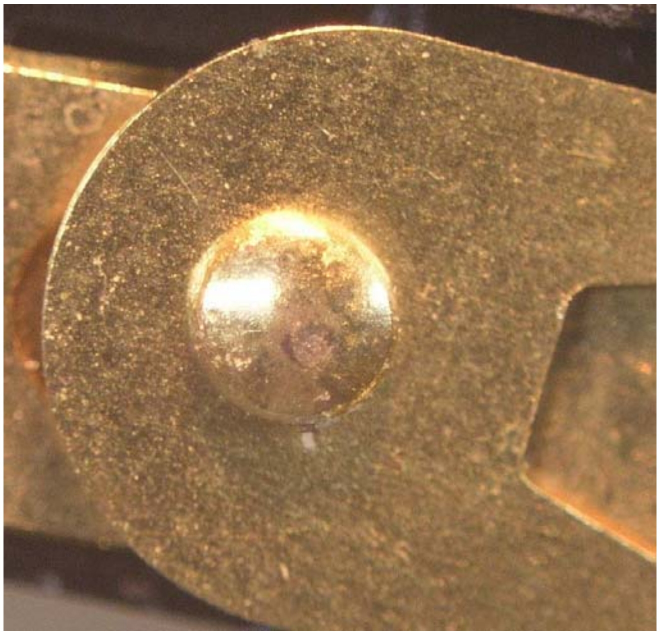
After cutting the side out of this switch, it appeared to operate normally. The over-center spring operated as expected in response to motion of the plunger. Sanding dust was rinsed out of the switch and the switch blown dry. Resistance measurements made earlier repeated. N.O. contacts had no continuity; the normally closed contacts measured 10-20 milliohms resistance.

The 4-5-6 switches removed for inspection all measured 10-20 milliohms on both N.O. and N.C. contacts.

Under the microscope, no metal transfer could be observed between N.O. contacts in profile. The switch was further disassembled for microscopic inspection of contact faces. These photos are typical of N.O. contacts of both failed switches.

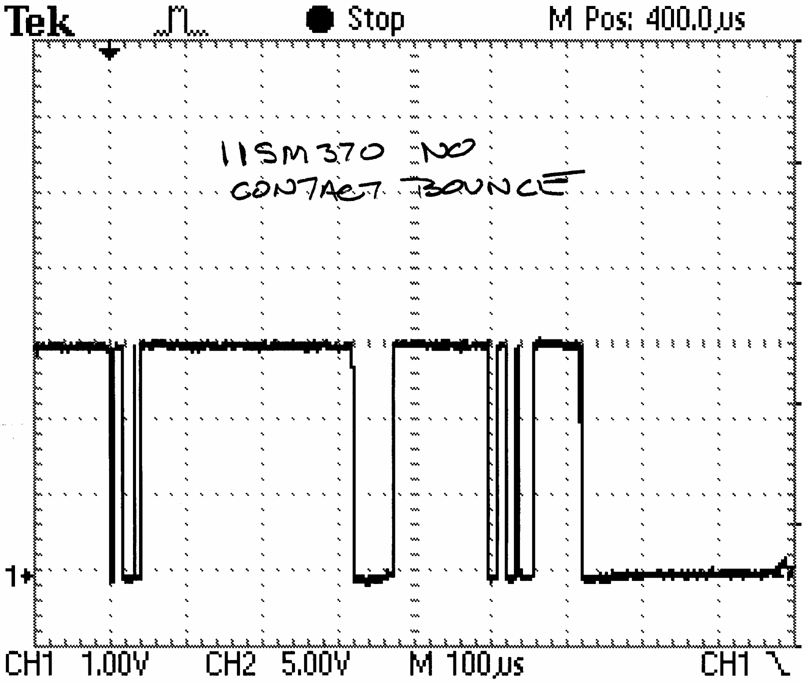
The photo to the right is typical of N.O. stationary contact on the failed switches. There is a darkening of the area inside a shallow ring of transferred metal where the contacts come together,





The photo to the left is the movable N.O. contact which shows an unremarkable wear spot.

The photo above is typical of the N.C. contacts of both the failed and normally operating switches. The contact on the right shows some darkening in the interior of the arcing pit but neither contact shows metal transfer.

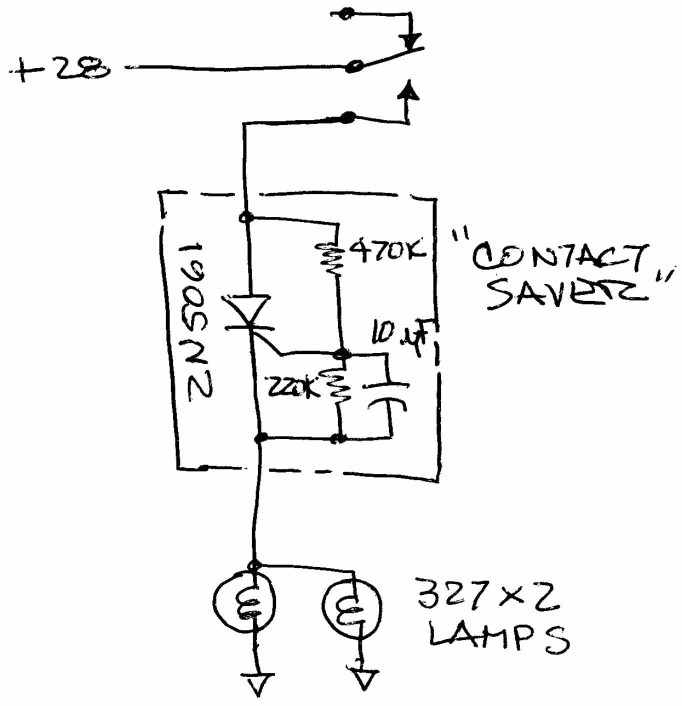


The working switches removed from the two test articles were tested for contact bounce. A plot on the left illustrates voltage across the N.O. contacts of a switch when actuated to the closed position.

This plot is typical of several operations and both switches. The contact hit at least 8 times over a period of 620 microseconds before becoming stable.

The Working Hypothesis

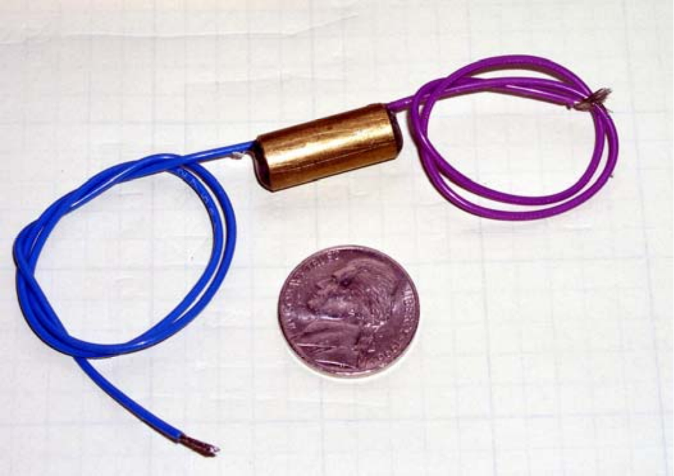
The failed contacts in all three switches drive two #327 lamps in parallel from a 28 volt bus. Inrush current for this lamp pair is on the order of 1.0 amps while the running current is only 0.08A total. Metal transfer observed is reminiscent of that observed while investigating sticking contacts on small crystal can relays used to control roll trim motors on the Beechjet. Tests have shown that the capacitive nature of the roll trim motor (high quality RFI filter on actuator motor leads) provides a sharp-edged inrush current not unlike that of an incandescent lamp. Further, tendency of a relay to stick is related to how many times the contacts bounce when closing.



The loss of contact performance on the down-lock indicator switch contacts may be related to high inrush currents that flow during the contact bouncing interval. A current trace taken on a pair of #327 lamps shows that an inrush current of nearly 1.0 amps is decays to half that value in about 500 microseconds . . . same order of time that the 11SM370 switch contacts are bouncing.

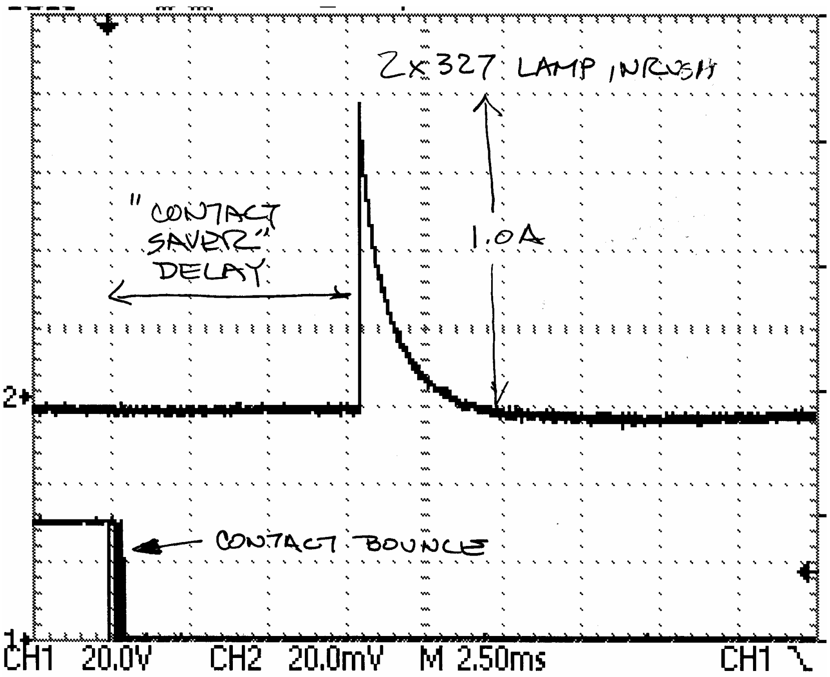
Contact bounce offers approx. 8x increase in opportunity for the effects of inrush current to degrade contact performance.

In years past, the author has made use of the circuit to the left to eliminate contact bounce noise. An SCR in series with the bouncing contact is triggered through an RC delayed gate bias.



A rudimentary prototype of the above circuit was crafted and potted into a short segment of brass tubing. The resulting assembly is compact and suitable for electrical splicing into the lamp circuit with mechanical support by tying into a wire bundle.

This circuit operates without need for separate supply or ground leads and is therefore easily added to the troubled lamp circuit.



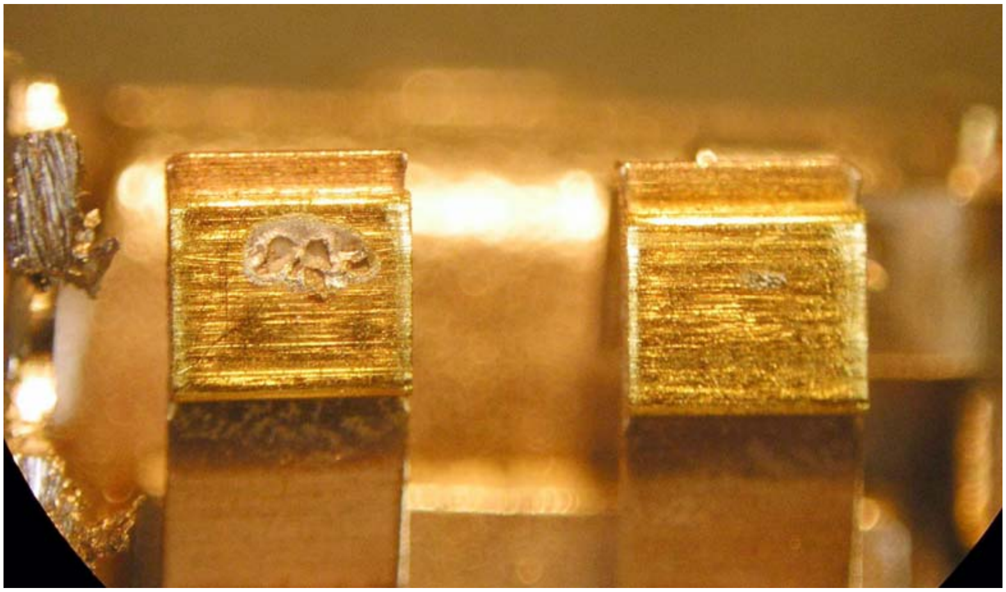
This plot illustrates the benefit of adding the proposed delay circuit. The lower trace shows contact closure and bounce while the upper trace plots circuit current.

Contact bounce happens in an UNLOADED condition over the previously observed 500-600 microseconds. Onset of lamp current is delayed by approximately 7 milliseconds. The "contact saver" has approximately 800 millivolts of drop in the ON state.

This delay allows closing contacts to become stable before they are loaded. Adding the "contact saver" to the lamp circuit will stop the metal transfer and arcing damage to the contacts depicted in earlier photos.

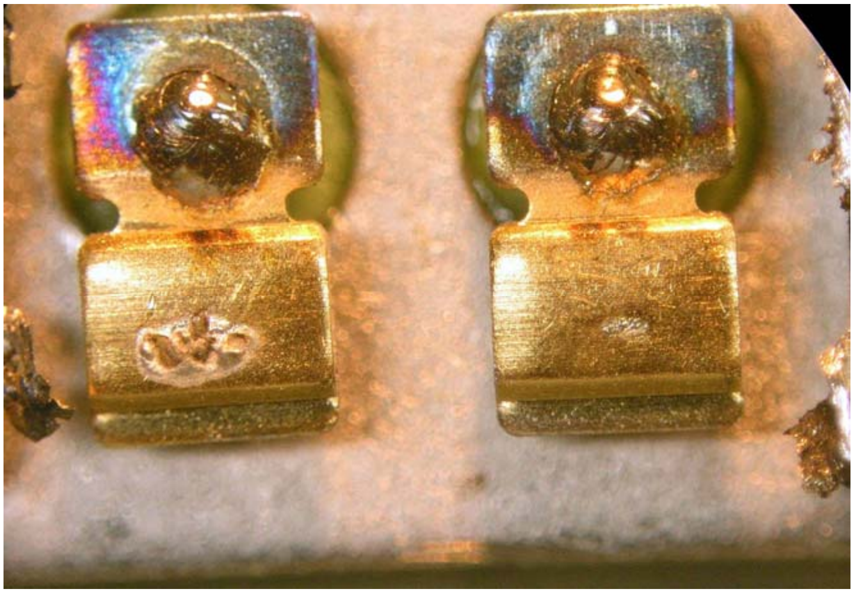
Bench Testing

A "contact saver" circuit has been added to a relay test fixture developed to investigate life associated with metal transfer between contacts on 5A crystal can relays. A failure-prone Deutsch relay was used as a test article.



In this view, the contact on the left shows pitting typical of relays suffering the failure mode demonstrated in Beechjet's roll trim system. This contact began sticking after 27,000 cycles.

The contact on the right was cycled stick-free for over 300,000 cycles.



This is a view of the stationary contacts on the same relay. Metal transfer on the 27K cycle contact is profound.

It is interesting that while metal transfer on the 300K cycle contact is very small, it is NOT ZERO. Under the 3d microscope, tiny separate mole-hills of metal can be seen rising from the contact surface.

Working Hypothesis:

The failure mode on SM series Microswitches was failure-to-make for normally open contacts. Failure mode for 5A relays was intermittent sticking. Both cases involve contact surface erosion accompanied by metal transfer. In the relay case, inrush currents were high enough to induce a light welding phenomenon while the landing gear switches simply suffered degradation of contact conductivity. For the moment, I'll suggest that the root cause of failure in both cases is based on stresses that occur during the bounce-time of contact closure exacerbated by the nature of current flow in onset of conduction. There is a strong correlation between tendency of particular brands of relays to bounce and a strong correlation for increased wear rates when the relay drives a long shielded wire (transmission line) terminated by a high inrush load (filter capacitor).

Adding an electronically delayed onset of inrush currents has an obvious benefit with respect to wear rates on the relays; I'll suggest similar benefits can be realized by including a similar circuit on the landing gear indicator circuits.

I contacted Honeywell on this matter. They responded with a suggestion that due to the low operating current of the annunciator lamps (0.08A) that gold contacts might be a solution. Except for the nearly 1 amp inrush current these lamps present to the switch, I would agree. The question I have for Honeywell focuses on the value of having some minimum current flow to keep oxides cleaned from the surfaces of silver contacts. If silver contacts of present switches never switch more than 0.08A, will they not degrade for reasons other than electrical wear and metal transfer?

It may be that a combination of gold contacts with the "contact saver" is the most elegant solution. I'll share this document with Honeywell with the goal of providing additional insight to our problem and formulation of their recommendations.

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Revision C Continuation:

Honeywell's next response suggested two documents from the Honeywell website:

Technical Bulletin #14, **Applying Precision Switches** downloaded from:

http://content.honeywell.com/sensing/prodinfo/basicswitches/technical/010172.pdf

and Technical Bulletin #13, **Low Energy Switching** downloaded from:
http://content.honeywell.com/sensing/prodinfo/basicswitches/technical/001008_3.pdf

Both documents are well written and I recommend them both as useful additions to the library of folks having an interest in this technology.

Several sections of these documents are relative to the landing gear switch failures under investigation, specifically:

Pages 16 through 19 of Applying Precision Switches speaks to sources and behavior of switch resistance. The author explains that switch resistance is directly related to resistance of the controlled load. E.g.: switches controlling high resistance, low current loads will exhibit a higher contact resistance than situations where the same switch controls higher current, low resistance loads. The explanation speaks of surface softening and melting on closing contacts.

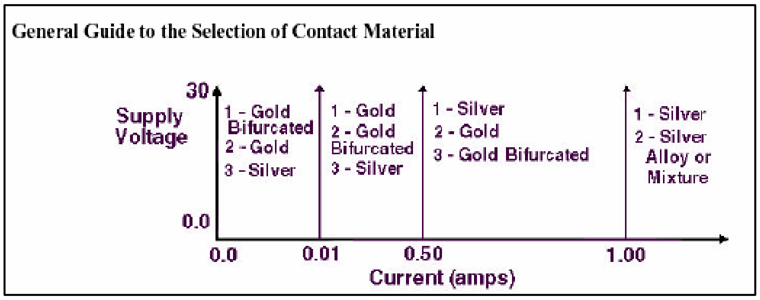
Consider two perfect sphere contacts just touching. Contact area between conductors is zero, electron flow between contacts at any magnitude has a very high current density. Depending on voltage drop across the not-quite-optimum contact resistance, activity at molecular scale causes heating of the material that will soften if not melt the surface material. As the two surfaces become less-than-spherical, the flat spots generated increase contact area and reduces contact resistance until temperatures drop below that required to induce surface deformation. It follows that higher current levels will produce larger contact areas and decreased contact resistance. This softening/melting phenomenon supports explanations of contact material transfer between contacts discussed in more detail on page 35. It also supports and explanation of contact "welding" or "sticking" on page 34. A section entitled "Closing the Circuit" on page 38 speaks to issue of contact bounce and metal transfer. It says that metal transfer can and does happen at ANY current level and that the condition can be exacerbated by contact bounce. This phenomenon was observed in the "contact saver" experiment cited earlier in this paper. A relay contact fitted with electronic mitigation of inrush current showed very little switching effects after 300,000+ cycles in a circuit that would normally be expected to stick the contacts in 1/10th that number of cycles. While contact erosion was small, one can still see a small cluster of very small mole-hills of contact metal under the microscope. Neither of these failure modes is present on switches subject to the current investigation. I've cited them here as interesting/useful data points for readers interested in expanding their working knowledge of switches and relays.

The failure mode under discussion is an "open" or very high resistance contact. Contact continuity issues are discussed beginning on page 19 under "The role of contamination in switch resistance". For the next few pages, a variety of contact contaminants along with their sources are discussed. The first contact photos on page 3 of this paper are those for failed, normally open contacts. I observe a darkened area on the stationary contact surrounded by a very small "crater rim" of transferred metal. It's not apparent to me what contamination mode is driving the high resistance failure. It may be useful to return one or more failed switches to Honeywell and/or take them to RAC's materials lab for closer examination. If the contamination is driven by environmental conditions, it has to be limited to that which is brought in by atmospheric breathing as a gas or vapor. In spite of their perch on the landing gear struts of aircraft, the failed switches were quite clean inside an free of any observable effects of contamination from the outside.

Choices of contact material begins on page 22 and discusses tradeoffs of common material choices. I've been under the impression that gold contacts were not appropriate for this application due to the 1.0 amp observed inrush current cited earlier on two-lamp annunciators. Technical Bulletin #13 is a sub-set of Bulletin #14 but on page 10 we find a general guide to the selection of contact material which I've excerpted below:

Here we see that while gold is the material of choice for continuous currents on the order of 10 to 500 milliamperes, it's only reduced to a second choice for currents in the 500 to 1000 milliampere range.

This suggests to me that gold contacts may be a better choice than the current silver. I believe it's dependent on knowing the exact nature of the contact failure. I'll gather up the failed switches and see if RAC's materials lab can lend some insight. I'll also contact Honeywell and see what services they're prepared to offer. Watch this space.


General Guide to the Selection of Contact Material