# Relays : Failures occurring & Lessons learnt

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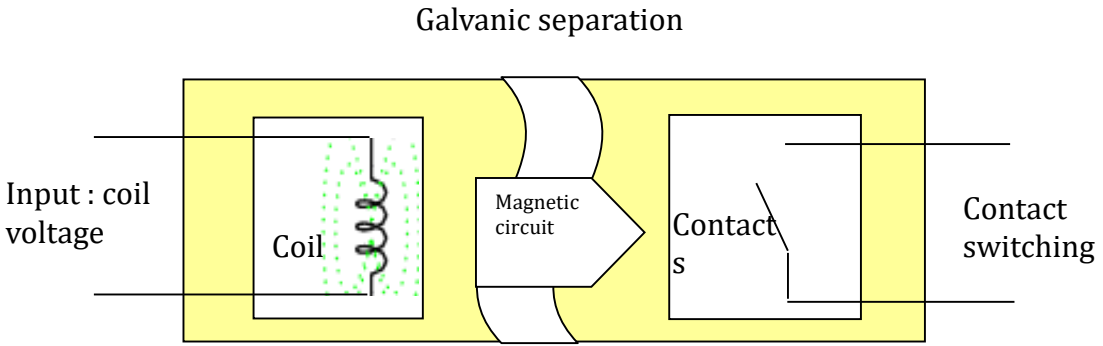
# Definition

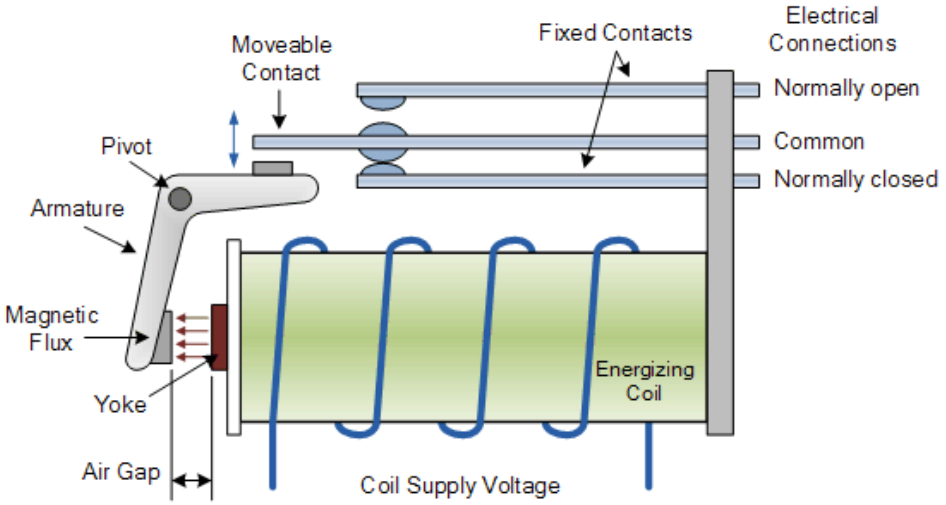
Engineers' Relay Handbook:

"An electromechanical relay is an electrical switching device. Its function corresponds to a mechanical switch, which is electrically actuated. The main advantages of electromechanical relays are the electrical isolation of the driving system and the load side, the insulation resistance of open contacts, as well as the low resistance of the closed contacts."



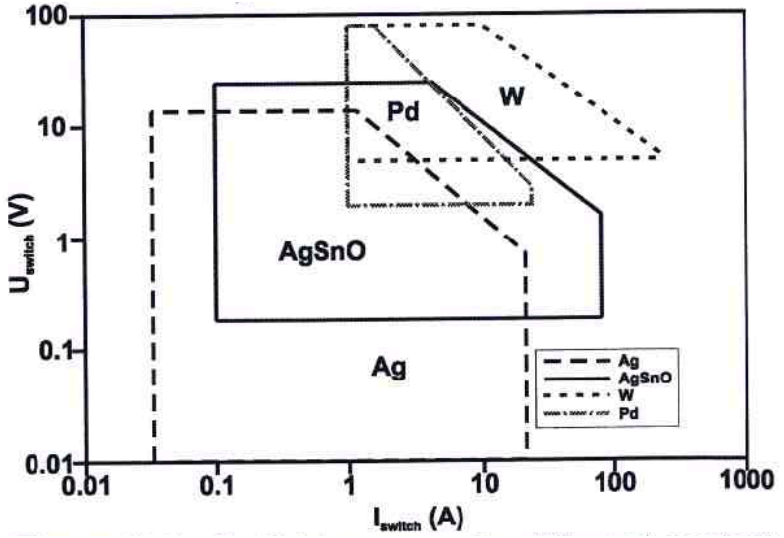
# Control

The actuator or motor is based on magnetic circuit formed by coils with or without magnet that converts electric energy into electromagnetic force used to actuate the contact side.



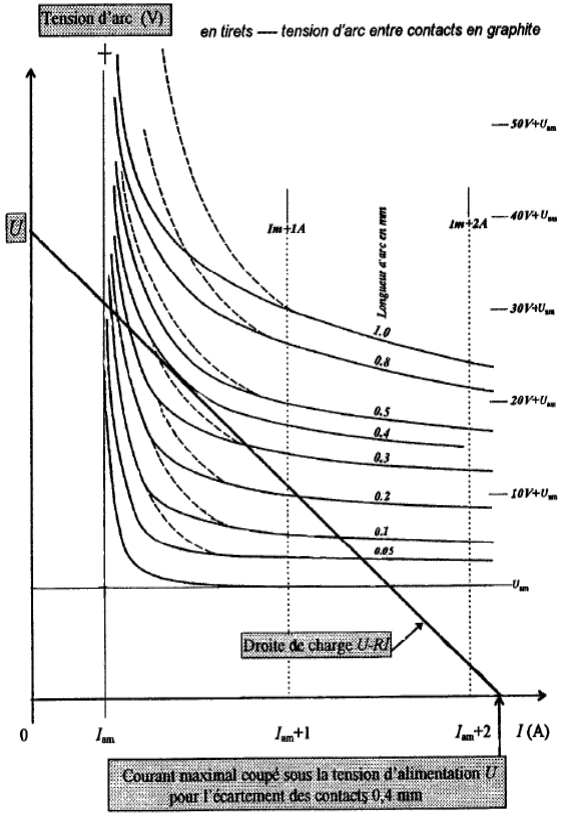
# Contact

The choice of the contact material depends on the switching capability of the relays. In general, a trade off is made between low resistance material and abrasive resistance. In space application, contact are usually made with silver for low current, silver oxide for high current and tungsten for high voltage.



# Tuning and arcing

The settings of the relays are based on the Holm curves and take into account several elements like the contact materials, the contacts gap, the internal gas inside the cavity, the pressure, etc.



## 17.2 RELAYS, ARMATURES

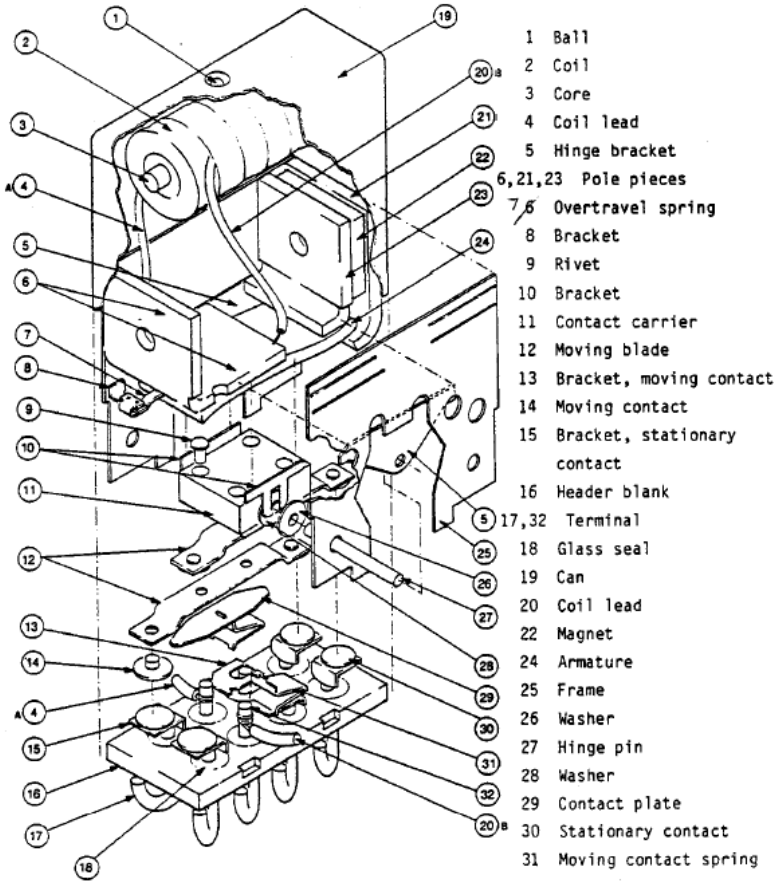



FIGURE 8. Typical armature relay.

# Failure mode

**Table E.1.2—The mode of failures for electromagnetic relays (from Fujitsu components Engineering Reference Relays)**

| Parts | Stress | | | | |
|---|---|---|---|---|---|
| | Status | Environment | Duration | Failure symptoms | Mode of failures |
| Contact | Voltage, current, surge voltage | Temperature, humidity, dust, gas, external vibration and external shock | Long duration without a break, Intermittent | • Transfer and wear of contact metal due to arc discharge<br>• Weld and bridging of contact<br>• Sticking of contact<br>• Corrosion (oxidation, sulfurization, etc.)<br>• Foreign matter (dust, etc.)<br>• Deposits | • Poor release (welding, locking)<br>• Poor contact<br>• Increase in contact resistance<br>• Noise<br>• Change in operate/release voltage and operate/release time<br>• Poor dielectric strength |
| Winding | Voltage, current, surge voltage | Temperature, humidity, dust, gas, external vibration and external shock | Long duration without a break, Intermittent | • Corrosion<br>• Galvanic corrosion<br>• Foreign matter (dust, etc.)<br>• Voltage fluctuation<br>• Vibration of lead wire | • Breakage of coil, short-circuit of coil<br>• Burning of coil<br>• Poor working release operation<br>• Change in operate/release voltage<br>• Change in operate/release time beat<br>• Malfunction |
| Structural parts (spring, sliding parts, insulation, etc.) | Voltage, current, surge voltage | Temperature, humidity, dust, gas, external vibration and excessive external shock | Long duration without a break, Intermittent | • Slip-off and wear of contact piece<br>• Fatigue and creep of spring<br>• Abnormal wear and loosing<br>• Seize<br>• Deterioration of organic material<br>• Deposition of worn contact material powders<br>• Corrosion and galvanic corrosion<br>• Foreign matter (dust, etc.) | • Poor contact<br>• Poor release operation<br>• Change in operate/release voltage<br>• Change in operate/release time<br>• Degradation in insulation resistance<br>• Poor dielectric strength |
| Enclosure | | Temperature, humidity, dust, gas, external vibration, external shock, and chemicals | Long duration without a break, Intermittent | • Damage by external force<br>• Change in chemical properties | • Damage |

# Observed failures

| Parts | Stress | Failure mode | Root cause |
|---|---|---|---|
| NA | NA | No switching (intermittent) | Not identified |
| NA | NA | Bad contact resistance | Not identified |
| NA | Vibration | No switching (intermittent) | Not identified |
| NA | Thermal cycling | No switching in a limited temperature range | Bad command using pick up voltage instead of command voltage |
| NA | NA (in orbit) | No switching | Bad command |
| NA | Shock | No switching | Bad command (too short) |

# Observed failures

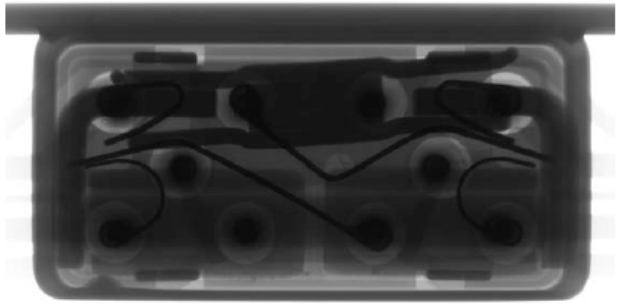
| Parts | Stress | Failure mode | Root cause |
|---|---|---|---|
| Enclosure | Soldering of wire | Loss of hermiticity | Glass seal damage due to thermal shock |
| Contact | Arcing | Welding of contact, intermediate position | Welding of contact due to discharge then stress on structural part and finished in intermediate position |
| NA | Shock | Change of position | Too high shock stress in the weak axis of relay |
| Structural part | Random vibration | No switching | Cold welding |
| Structural part | Vibration | No switching (intermittent) | Displacement of structural part |
| Contact, structural ? | Thermal cycling, cleaning | No switching or increase of latch voltage | Welding, and/or other |
| Winding | Dissolution of wire | Breakage of coils | Manufacturing |

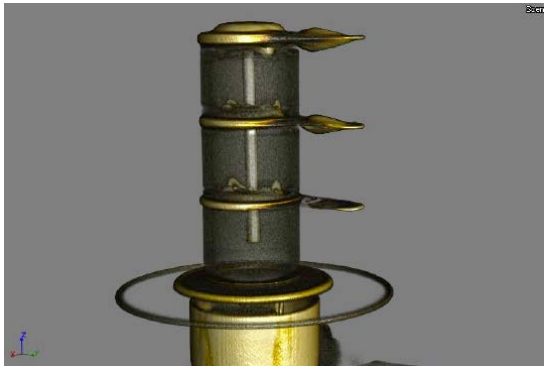
# Failure analysis

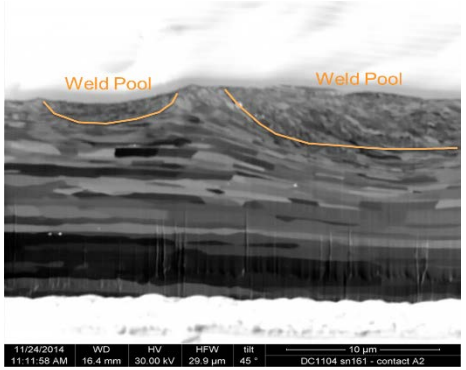
Failures' analysis of relays are tricky

- Complex device with many pieces'part (40 to more than 100)
- Risk of losing the defect

Interest of new methods (Xray, tomography, FIB)







# Root cause of observed failures

On 13 observed failures:

- 3 are due to bad commands
- 1 is due to bad handling of the relay (soldering)
- 5 mechanical stress are either the cause or a contributing factor
- 8 real failures of the relay

**5 (≈40%) of the observed failures may have benn avoided if better knowledge of relay was used.**

# Observed failures

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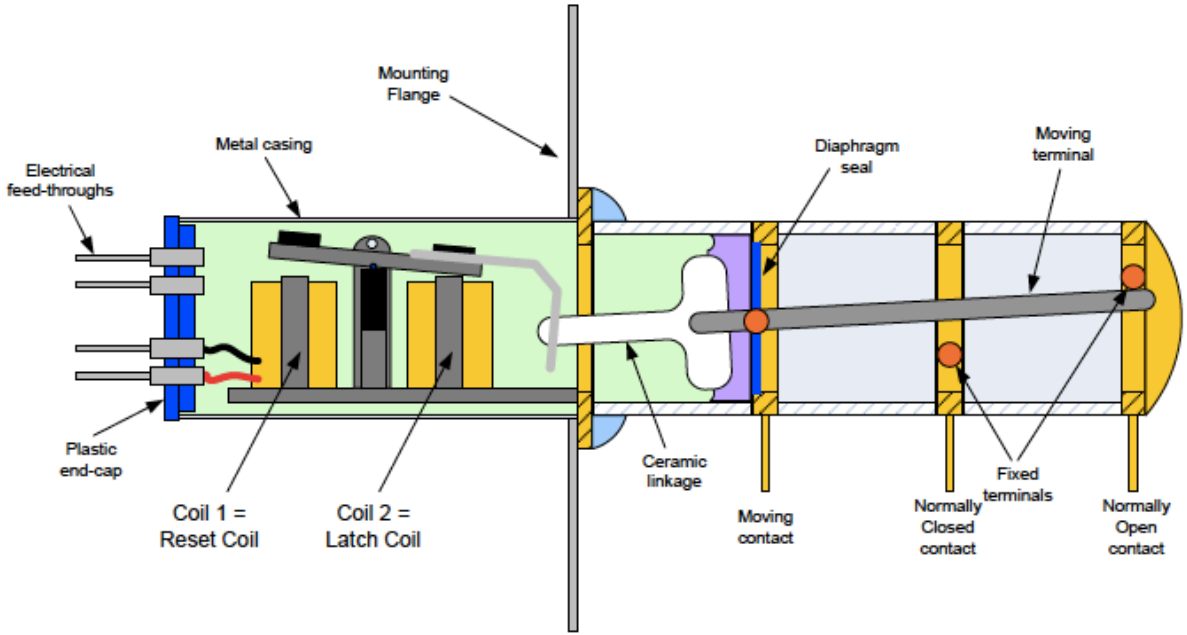
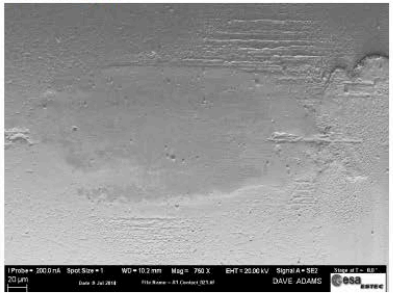
# High voltage relay



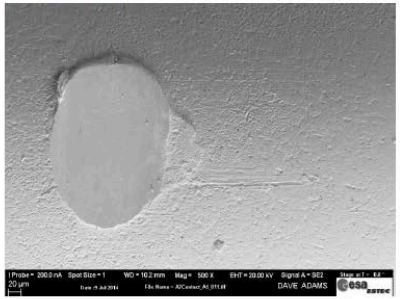
# High voltage relay: contact stuck

SEM image of indentations at contact A2/A1

**A1 side (W)**



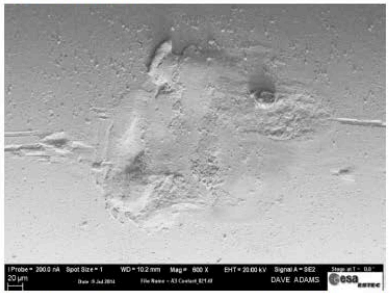
**A2 side (Mo)**



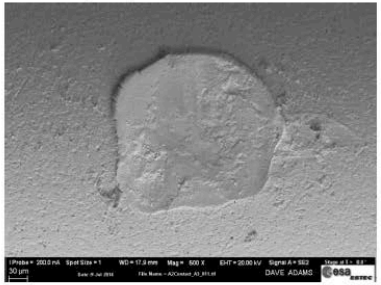
Flat and smooth surface areas, metal push in border for softer material (Mo) – As expected

SEM image of indentations at contact A2/A3 (i.e. stuck contact)

**A3 side (W)**



**A2 side (Mo)**

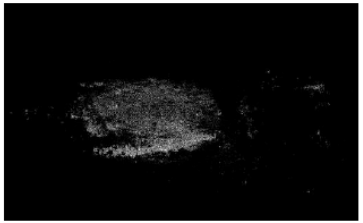


Rough surface areas suggesting sticking/welding of the 2 contacts

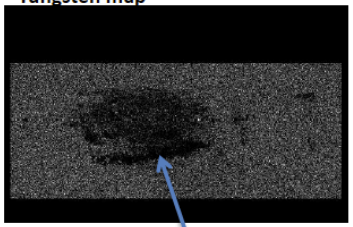
# High voltage relay: contact stuck

SEM/EDX Element Mapping on A1 side (W) at the contact A2/A1

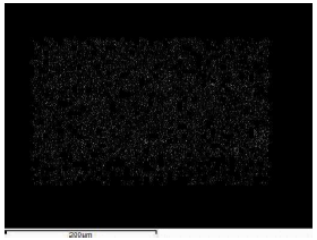
Molybdenum map



Tungsten map



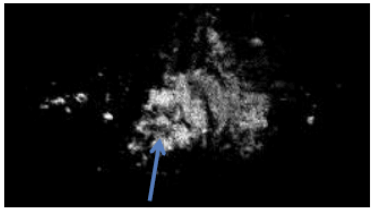
Oxygen map



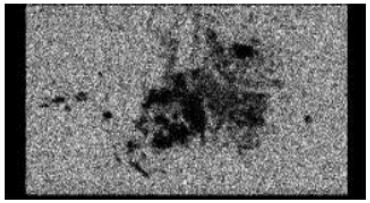
Molybdenum found homogeneously on contact area except on the edge of contact area.
Oxygen is homogeneously spread on the surface.

SEM/EDX Element Mapping on A3 side (W) at the contact A2/A3 (i.e. stuck contact)

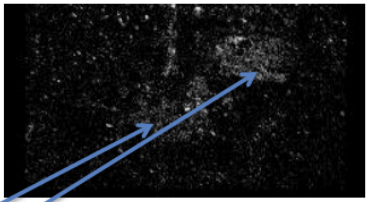
Molybdenum map



Tungsten map



Oxygen map



Evidence of transfer of Molybdenum in contact area
Some area with oxygen concentration suggesting oxidation of Tungsten

# High voltage relay: increase of latch voltage

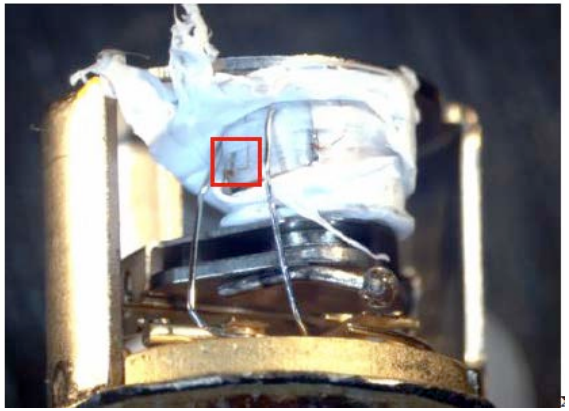
# High voltage relay: increase of latch voltage

Actuator side not in hermetic package then vacuum may induce displacement but also cleaning process may cause damage to the gel.

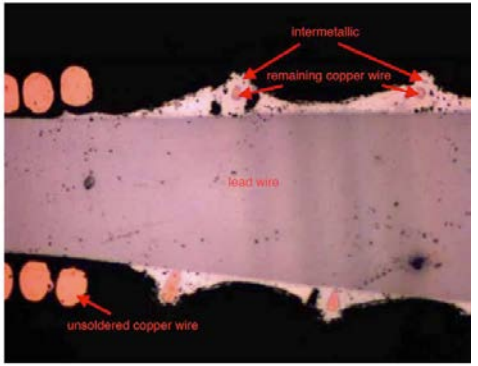
- Methyl silicones were found on the actuator that showed anomalous behavior.
- The reference relays both likely cleaned with Dowclene PX-16S did not show methyl silicone absorptions.
- Analysis of the silicone gel with FTIR transmission spectroscopy indicated that the gel is composed of methyl silicone.
- Dowclene PX – 16S extracted significant amounts of methyl silicones from the dielectric gel

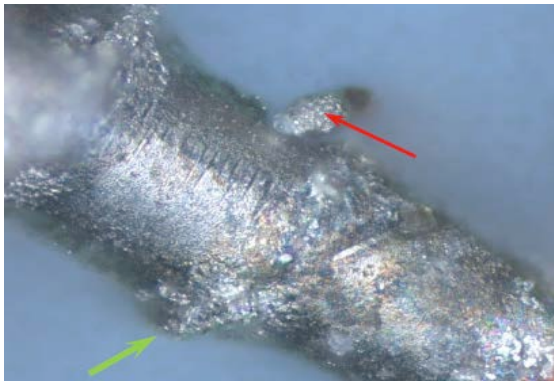
A special thanks to Nat Carthew and Michele Brondi (ESTEC lab)

# ESA alert on TL26 relays



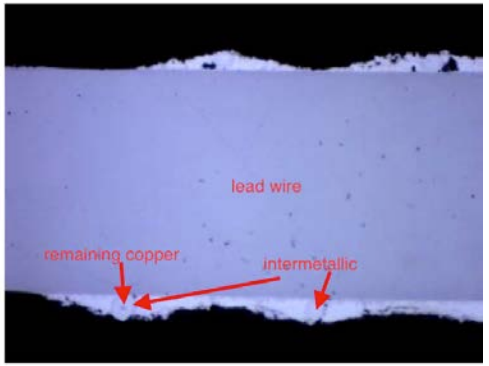
The failure was observed during TVAC cycling at equipment level. The relay failed to switch on at the first attempt on the second cold plateau (-30°C).



The failure of the relay was caused by a severe reduction in the diameter of the thin coil copper wire where it enters the solder joint connecting it to the internal contact wire.

This reduction in diameter is caused by the dissolution of the copper into the Tin/Silver solder.



# ESA alert on TL26 relays

## ESA alert recommendations

## New procurement of ESCC qualified TL26 relays:

parts with DC1611 or later shall be preferred.

## Stock Parts

Parts shall be 100% screened by five (5) Monitored Temperature Cycles (-65°C/+125°C) followed by electrical tests at 25°C as per table 2 of ESCC Detail Specification No. 3602/002.

## Mounted parts

Parts with lot Date Codes identified as Category 2 in Annex 3 shall be subjected to thermal cycling as specified below:

- Minimum 5 cycles
- Minimum delta temperature of 70°C measured on the relay case. For example, thermal cycles at board level between -20°C to 50°C, Lower delta temperature values are not relevant.
- Duration and transition rate of cycles are not considered as important parameters.
- The relay shall be switched at high and low temperature during the last cycle of the sequence.

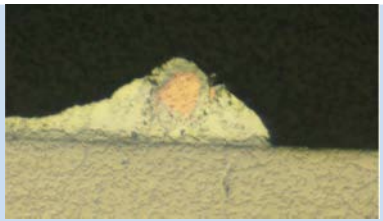
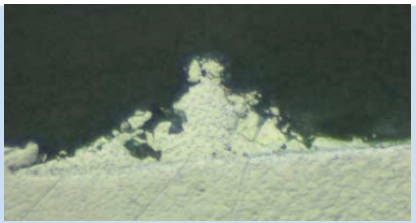
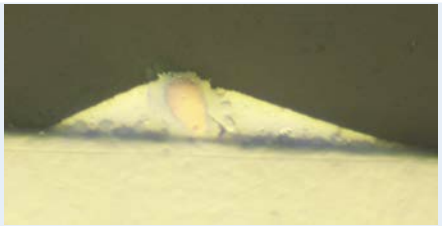
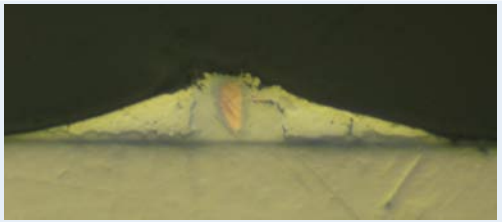
# ESA alert on TL26 relays: where are we today?

## New procurement of ESCC qualified TL26 relays

Parts are 100% screened by five (5) Monitored Temperature Cycles (-65°C/+125°C) followed by electrical tests at 25°C as per table 2 of ESCC Detail Specification No. 3602/002.

## Modification of process

Modification of solder material to include copper

| | Before coil life | After coil life |
|---|---|---|
| Old process |  |  |
| New process |  |  |

# Lesson learnt and recommendations

Failures occurred sometime or


- Bad command signal: **do not use latch and reset voltage limit**
- Beware of **mechanical stress: relay are more sensitive in certain direction** then try to use this information to place the relay
- No switching failure may be intermittent: implement the possibilities to send **command signal several times**
- Failure analysis is difficult and need to be carried with care using up to date investigation methods