Relay failures induced by the growth of tin whiskers. A Case Study.

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Abstract:
The electronics industry for decades utilized pure tin-plated finishes. This protective coating was resistant to oxidation and corrosion while providing good solderability characteristics. Other driving factors for its use were primarily related to economics. In efforts to maximize profits without compromising performance (or so it was believed), manufacturers turned to tin-plated finishes to replace precious metal finishes or previously utilized tin-lead plated finishes. An added benefit was reduced lead in the waste stream and reduced complexity of disposal.

The phenomena of tin whisker growth has been previously experienced by a number of users, examined, and studied by quite a few metallurgists. "Tin Whiskers are very thin, single crystal fibers, with large length-to-diameter ratios and constant cross-sectional area. These whiskers can grow only from the surface of pure tin and when internal stress exists. The growth process is a means of stress relief, however annealing alone may not be sufficient to totally relieve these internal stresses. Alloying of the tin will eliminate the potential growth of tin whiskers. Dependent upon the spacing away from the adjacent components / conductors and the whisker growth potential, shorts created by tin whiskers are another potential failure mechanism."[1] Such failure experiences and root-cause determinations have led to the prohibition of pure tin-plated components by the Military and NASA. The following case study is provided as a reminder of such issues associated with the use of pure tin plating in electronic components and its affect on component reliability.

Background information on component utilized:

The subject component evaluated in this analysis is a single pole double throw (1FORMC) hermetically sealed octal-base plug-in relay. It is supplied with silver-cadmium contacts rated at 5A Max at 120VAC / 30VDC and a sensitive DC coil.

Utilized for close to 25 years, the demonstrated field reliability for this particular type of relay had previously been very high.

Overall view of relay

Reported Failure Mode:

Three relays were reported to have failed by an overseas electric power company. The customer indicated that energized relays inadvertently closed without the proper control signals. Such condition contributed to a false contact closure condition, which in turn produced unnecessary alarm protection signals initiating a plant shutdown. Working with the customer, arrangements were made for the return of the suspect relays for confirmation and root-cause determination. In addition, details of application and environmental conditions prior to failure were obtained.

Analysis / Confirmation:

The suspect relays were installed in an assembly and tested at the bench level. Such electrical characteristics as, coil resistance, coil pick-up, coil dropout voltage and current levels, normally closed contact resistance and normally open contact resistance was measured.

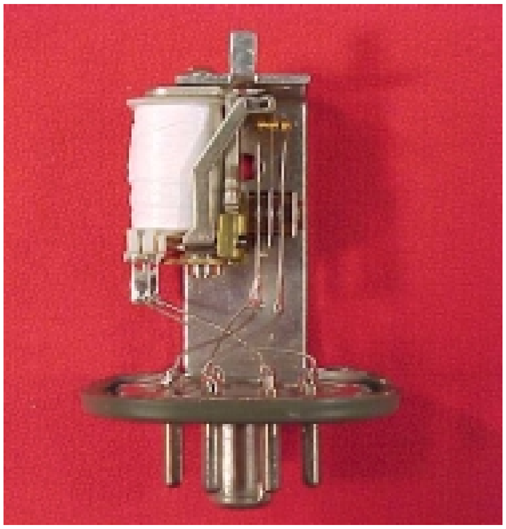
Two out of the three relays were confirmed as displaying some type of a shunt path across contacts in their open state. Results obtained are illustrated in Table I.

Table I. Initial Electrical Results

ID	Date Code	Relay State	Normally Closed Contact Resistance	Normally Open Contact Resistance	Observations/Results:
#1	911002	De-Energized	0.012 Ω	35.4 Ω (∞ Ω expected)	Shunt path detected when both contacts are in open state.
		Energized	7.118 Ω (∞ Ω expected)	0.1 Ω	
#2	9049m	De-Energized	0.087 Ω	∞ Ω	Relay appears to function properly.
		Energized	∞ Ω	0.1 Ω	Resistance values are as expected.
#3	911201	De-Energized	0.084 Ω	∞ Ω	Shunt path detected on N.C. contact
		Energized	28.10 Ω (∞ Ω expected)	0.1 Ω	while in open (energized) state.

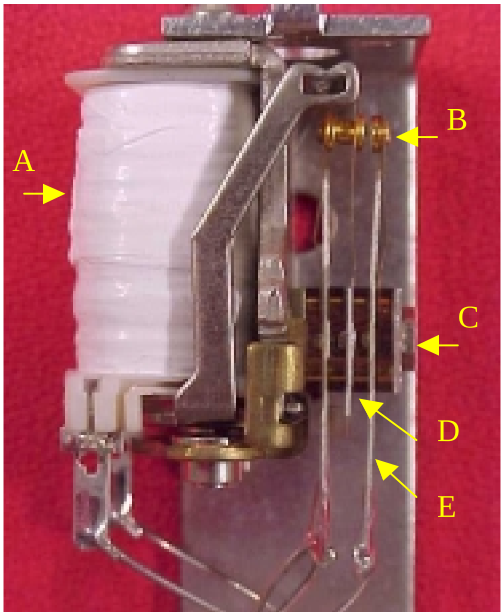
While monitoring the contact resistance of both the normally closed & normally open contacts, relays #1 and #3 were exercised 10 times. No changes from the initial readings were observed. The same low resistance readings were consistently obtained. Relay #2 was exercised 150 times with no changes from the initial readings observed. No abnormalities were detected. Reported failure mode could not be confirmed.

Internal-visual examination of Relay #1 was performed. Microscopic examination (up to 40 X) did not reveal any evidence of abnormalities such as debris, poor or intermittent solder connections, solder flux, misaligned contacts, evidence of cracked glass insulators, or lead migration between the base pins & relay case.



Higher magnification of relay assembly:

Depicted at right are internal components of relay.



A = Coil assembly.

B = Normally Closed & Normally Open Contacts.

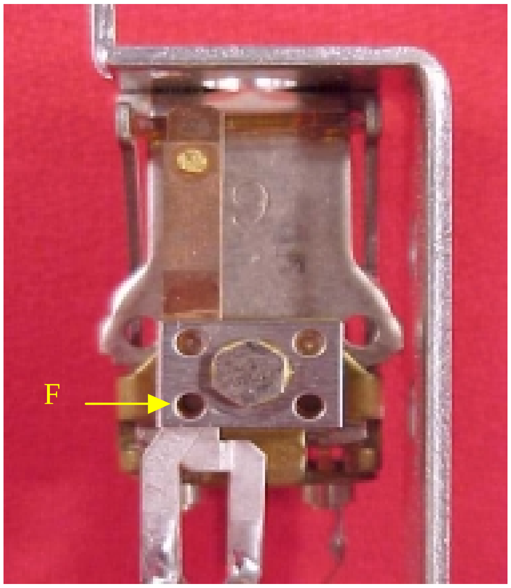
C = Contact support arm mounting assembly.

D = Area D – Contact support arm insulator. (Discussed later in report).

E = Contact support arms (3 total).

Right angle view:

Illustrated is the contact support arm mounting assembly (C in above photograph). Contact support arms are visible extending from bottom of insulator assembly.



F = Insulator guide hole & keyed insulator assembly. Assembly is held in position by hex bolt. Area detail is discussed later in report.

On Relay #1, it was demonstrated that after a spark was induced across the contacts (closing & opening), the resistance values seen across open contacts returned to expected values. Relay #1 was cycled 100X while monitoring the contact resistance. All contact resistance values remained within specification. Table II compares initial resistance values and those obtained after inducing a spark.

Table II Relay #1 Contact Resistance

ID	Condition	Relay State	Normally Closed Contact Resistance	Normally Open Contact Resistance	Observations/Results:
#1	Initial	De-Energized	0.012 Ω	35.4 Ω (∞ Ω expected)	Shunt path detected when both contacts are in open state.
		Energized	7.118 Ω (∞ Ω expected)	0.1 Ω	
#1	After Spark	De-Energized	0.02 Ω	∞ Ω	Resistance values are at expected levels. Spark eliminated shunt path.
		Energized	∞ Ω	0.1 Ω	

Relay #1 & #2 were left energized for 68 hours and then retested. No changes in contact resistance values were noted. Both relays were then exercised 100X while monitoring the contact resistance values. Again no changes or abnormalities were noted, and all contact resistance values were at expected levels. Insulation resistance values measured between the base pin & case, and across open contacts demonstrated that the insulation resistance properties of the glass insulators, and contact support arm insulators, were well above the 1,000 MegOhms minimum spec. Insulation resistance values obtained at 500 VDC were above 10,500 MegOhms.

Supplier Analysis Results:

Both relays were returned to the supplier for analysis. Coil resistance, pull-in, dropout, operate & release times was confirmed to be within specification. Relay #1 displayed contact resistance values within specification while energized and de-energized. No abnormal contact resistance values were detected since the previously induced arc appeared to have removed possible traces of a shunt path.

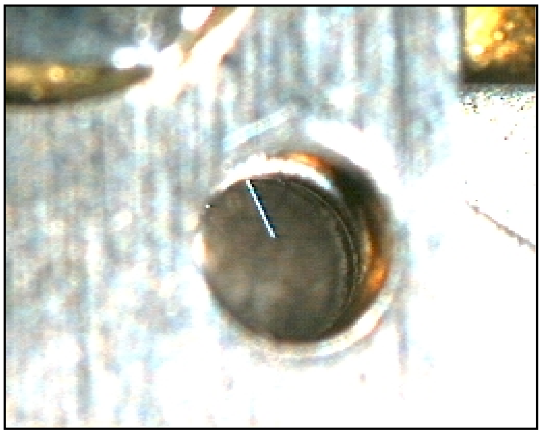
Relay #3 was confirmed by the supplier as displaying a resistance value of 28.3 Ω across the normally closed contact (while in open state). Real time x-ray methods were utilized to examine internal components and operation of the relay. No abnormalities were detected.

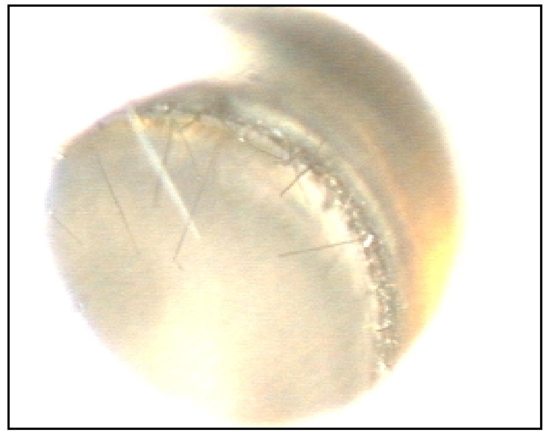
Indicating a poor insulating property across the normally closed contact gap, at 20 VDC an insulation resistance of < .5KΩ was detected on the normally closed contact while the relay was energized. Microscopic examination of the external components revealed a grayish-white residue on the glass insulators. The header leadwires utilized to jump the contacts and the pin terminals were cut. The contact resistance remained at 28.3 Ω. This eliminated the insulators and the grayish-white residue as the potential source for the shunt path.

Utilizing high magnification, examination of the internal components revealed the growth of extremely small diameter tin whiskers at the N.C. terminal and on the inside of one insulator guide hole. The following photographs provided by the supplier illustrate the tin whisker growths.

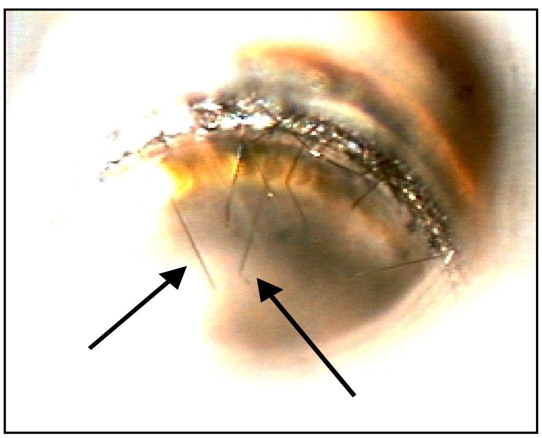
Log# 990 30008

Presence of "Tin Whiskers" inside one of the insulator alignment cavities

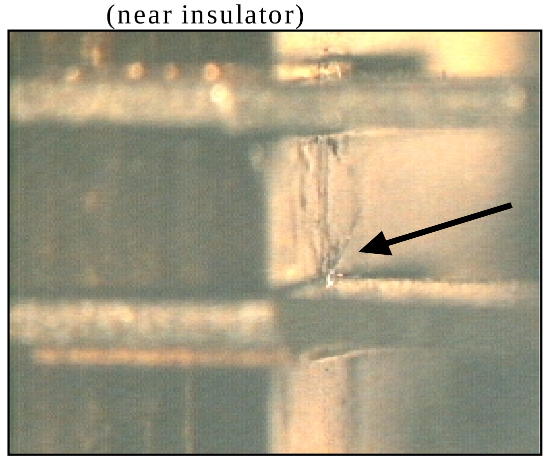




Tin Whiskers



Tin whisker on N.C. terminal (near insulator)



Upper Left, Upper Right & Lower Left Images: High magnification images of tin whiskers detected inside one insulator guide hole (*page #3 'Arrow F'*).

Lower Right Image: Depicted in this image is the area between contact support arms adjacent to the support arm insulator (*page 3 'Area D'*). Arrow in photograph points to tin whisker detected near insulator.

All whiskers were detected in areas where high mechanical stress existed.

The supplier's Staff Chemist confirmed that the plating on the contact support arm is pure tin. The utilization of pure tin plating was enacted as a cost reduction effort in 1981 when the supplier changed manufacturing sites. Production of this particular relay was discontinued in 1993 by the supplier.

Corrective Actions Implemented:

The customers typical application of this relay is such that normally no current flow appears across the contacts. When energized, the relay operates a photocoupler circuit. The suspect relays were in service for 8 years before a failure instance occurred. It can be determined that this customers application of this type of relay has some uniqueness due to the fact that no other failure instances have been reported. It was demonstrated that when switching loads capable of producing a spark across separating and closing contacts, potential shunt paths from tin-whiskers could be removed. This ounce of prevention has been confirmed by the supplier.

Due to the potential safety issues associated with the root-cause and application of the relay by both commercial and Nuclear customers, it was determined that customer notification was warranted. A relay replacement program was established. Such activity covers all relays supplied by this particular relay supplier. It is recommended that all relays utilized in applications where switching potential are not large enough to produce a spark during relay operation, be replaced with a similar relay supplied by another qualified supplier.

References:

1: Savi, John: “Reliability of Electronic Assemblies”
38th Annual Spring Reliability Symposium: Reliability and Safety, May 2001.

Biography:

Craig Stevens

- Associates of Science in Electrical Engineering.
- Employed 20 years with The Foxboro Company.
- Last 14 years within Component Technology Group – Corporate Quality Assurance Dept.
- Some Specific areas of responsibility: electrical & electro-mechanical components (including test, evaluation & failure analysis).