SAND97-2007C

CONF-970982--

SAND--97-2007C

A Hardware Review of Electrical Contact Aging and Performance in Electromechanical Stronglinks

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Abstract
Contacts from the functional switch assembly have been examined for a series of MC2969 stronglinks varying from 9 to 14 years of age. Wear tracks are apparent on the contacts as a result of oxide removal by wiping action as the switch is exercised. Typical contaminants observed on the contacts include C, O, S, Cl, F and Si, all of which vary with position on the contacts. All of the contacts show segregation of Ag into the near-surface region. Measurement of the local contact resistance on the ends of the contacts provide resistance values that are reasonable for this material, but with variation among contacts as a result of changes in the local surface chemistry.

Introduction
Electrical contacts in electromechanical devices need to maintain low contact loop resistance (CLR), while keeping friction coefficients within design range in order to insure proper operation. Electrical contacts in these devices are usually of the sliding or rotary contact design, and the contacts are usually maintained in an open or grounding position while in safe status. This leaves the electrical contacts exposed to the surrounding environment for most of their life, facilitating contamination or modification of the surface layers. Contamination and corrosion of the exposed electrical contact surfaces can occur through outgassing of contaminants, water, or volatile species (plasticizers or curing agents) from surrounding materials. Modification of the surface layers of the exposed contacts can also occur through oxidation or segregation of alloy constituents into or out of the surface layers. Since low CLR values are obtained through the use of uncoated metallic surfaces, reaction with adsorbed species can readily produce surface layers that are less conductive or even nonconductive (i.e. sulfides or oxides). If these modified surface layers can not easily be removed by the action of the electromechanical device (i.e. wiping contact), then the resulting CLR may be high enough that the limited voltage and current sources which provide the electrical signals being passed through the device may not be sufficient to ensure circuit completion and signal transmission. In addition, if any sticking occurs as a result of surface reaction or segregation effects, then the limited force or torque available for electromechanical device activation may be insufficient to break the device out of its safe position to allow signal transmission. Since electromechanical devices are primarily used as safing mechanisms, failure to transmit a signal through any of these degradation pathways could result in zero nuclear yield upon weapon detonation. An overview of the current status of electrical contacts from stronglinks that have been deployed in the field for a number of years will help to identify any potentially important degradation mechanisms that could affect electrical contact performance for stockpile life extensions.

The initial efforts of this program have been concentrated upon conducting a screening study of weapon hardware available from stockpile evaluation and field return programs, in order to assess the status of electrical contacts in electromechanical devices after years of deployment in the field. The goal is to establish whether any evidence of electrical contact performance degradation exists, based upon evaluation of the available hardware. The results presented here are from screening electrical contacts from the MC2969 Intent Stronglink, since they were available through the stronglink evaluation program.

Experimental Procedure
Where possible, we have attempted to use hardware that has been tested to establish current CLR values, or other electrical testing that addresses the current status of the electrical contacts in the functioning component, and has been gas sampled in order to assess the internal gas composition of the device. This information has been correlated with a thorough examination of the electrical contact surfaces. Individual electrical contacts have been visually and microscopically examined for any abnormalities and general appearanc, and local contact resistance values have been measured. Surface analysis has been completed for a large number of the individual electrical contacts to establish the surface composition and chemistry.

The surface chemistry has been analyzed by x-ray photoelectron spectroscopy (XPS) to determine the elemental composition of the near surface layer and the oxidation state of the chemical species present. Survey scans were used to identify the atomic species present, and detailed high resolution scans for each element were used to determine chemical state information and quantitative surface composition information. Standard sensitivity

factors were used[1] to calculate elemental compositions, assuming a homogeneous distribution of species with respect to spatial and depth distributions.

Local contact resistance of the piece parts has been measured using a specially made 4-point probe and a Keithley 193A System Digital Multimeter. The contact resistance probe has been constructed using a square orientation of fine probes covering a surface area of about 2.5 x 1.5 mm. The probe has been mounted on a 3-dimensional motion stage, with the sample holders mounted on a Denver Instruments pan balance. By adjusting the vertical axis on the contact resistance probe, a variable load can be placed on the probe tips, allowing the measurement of contact resistance as a function of applied load. Contact resistance values have been measured as a function of location on the electrical contacts and as a function of applied load.

Results and Discussion

The MC2969 stronglink contains a 14-stage switch assembly for the functional signal contacts. Each stage contains a z-shaped strip (z-bar) of Au-based alloy material (ASTM B541) isolated in a ceramic deck. The switch assembly is shown in Figure 1. Figure 2 illustrates typical z-bars contained in the switch assembly. In safe status, the switch is kept in the open-circuit position, with both ends of the z-bars fully exposed to the internal atmosphere of the stronglink. The center portion of each z-bar, nested in the ceramic deck, has much more limited exposure to the internal atmosphere and any contaminants it might contain. Upon activation, the switch assembly is rotated so that the ends of each z-bar are brought into contact with 2 parallel rows of Pd-based alloy (ASTM B540) wire. The wear tracks left by this wiping contact are readily apparent as clean and shiny grooves on the duller oxidized ends of the z-bars. In order to maximize the information obtained, XPS analysis and local contact resistance measurements are completed for both the exposed ends and the protected centers of the z-bars. Examination has been completed for the switch contacts from 9 MC2969 units of ages varying from 9 to 14 years of age, and varying environmental conditions.

XPS analysis of the z-bars shows hydrocarbons as the dominant surface species, typical of metal surfaces exposed to general atmospheric conditions. High concentrations of C on noble metal electrical contact alloy surfaces may result in the formation of frictional polymers, which can be detrimental to contact resistance.[2] Figure 3 shows representative surface compositions for the ends and centers of the z-bars of selected units. The z-bars also show significant quantities of O, S, Cl and Si contamination, especially from the older units. Typically, the center regions of the z-bars show less contamination with C, O and Cl. Some of the z-bars show sufficient oxidation to produce a sizable Cu^{2+} oxide spectrum on the exposed ends. In contrast, the center regions of the z-bars often show greater concentrations of S than the exposed ends. Sulfur is known to segregate to the surfaces of these alloys with wear or thermal cycling, especially on clean surfaces, and has been shown to cause contact resistance increases to 30 mΩ or higher with a 35 g load.[2,3] Most of the units show F and C-F species deposited on the z-bars, especially on the exposed ends. These species appear to be outgassed from the Vydax fluorocarbon lubricant used on the bearings and escapement gear assemblies within the stronglink assembly. All of the z-bars show significant segregation of Ag to the surface, with surface concentrations much larger than the base alloy composition. Depletion of surface Cu and enhancement of surface Ag have previously been attributed to acid etching of the alloy by the manufacturer during production.[3] Work is continuing to correlate surface compositions with the known ages and internal gas environments of these units.

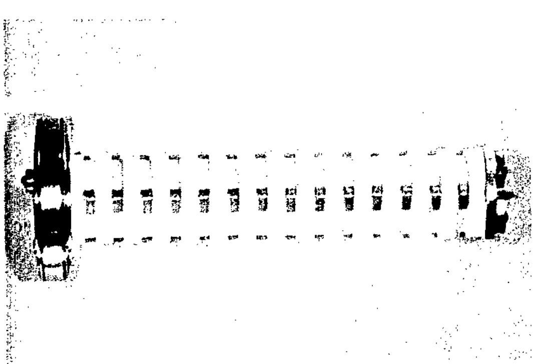

Figure 1: MC2969 14-stage functional switch assembly.

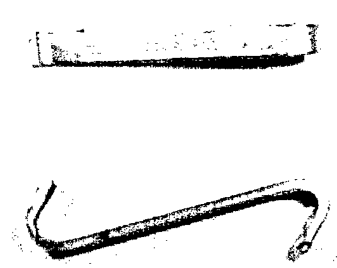

Figure 2: Z-bar contacts from the MC2969 switch assembly.

Work has begun to measure the local contact resistance at the ends and centers of the z-bars, and to correlate this data with the surface chemistry observed. Figure 4 shows a sampling of the contact resistance as a function of load for measurements on both ends of one-half of the z-bars from a typical unit. The contact resistance starts high, but quickly levels off to a base value as the load is increased. This curve is typical in shape and values for electrical contact metal alloys.[4,5] However, there is considerable scatter in the measurements from each individual z-bar in the switch assembly, representative of the changes in local surface contamination layers. Steady-state contact resistance values measured for this Au-based alloy as a function of wiping contact with the Pd-based alloy under a 35 g load range from about 5 mΩ for operation in a vacuum ambient to about 15 mΩ for operation in laboratory air.[3] Operation in a pure O_2/N_2 atmosphere, without atmospheric contaminants (especially hydrocarbons), yielded values near 10 mΩ.[3] Results will be compared for units as a function of age, stronglink internal atmosphere, surface composition and location on the z-bars.

Conclusions

The z-bar contacts from the 14-stage functional switch assembly have been examined from a series of 9 MC2969 stronglinks varying from 9 to 14 years of age. Visible wear tracks are apparent on all of the contacts as a result of oxide removal by the wiping action of the Pd-based alloy wires on the Au-based alloy z-bars as the switch is exercised. Typical contaminants observed on the surface of the z-bars include C, O, S, Cl, F and Si, most of which are more prevalent on the exposed ends of the z-bars. Only S is more prevalent on the cleaner, protected surfaces at the center of the z-bars. All of the z-bars show enhanced quantities of Ag in the near-surface region, possibly as a result of manufacturing processes for the Au-based alloy material. The surface chemistry of the z-bars is typical of that expected for these types of materials, with the concentration of contaminants generally increasing with age. Measurement of the local contact resistance on the ends of the z-bars from a typical stronglink unit provide resistance values that are quite reasonable for this contact material, but with a lot of variation from z-bar to z-bar as a result of changes in the local surface composition of the contacts.

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Acknowledgments

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-AC04-94-AL85000. The authors would like to thank Rand Garfield and Sara Doughty for assistance in development and testing of the contact resistance probe.

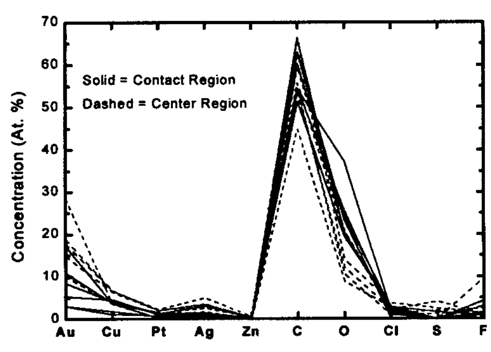

Figure 3: Atomic composition of the exposed and protected surfaces of z-bar contacts for different MC2969 units.

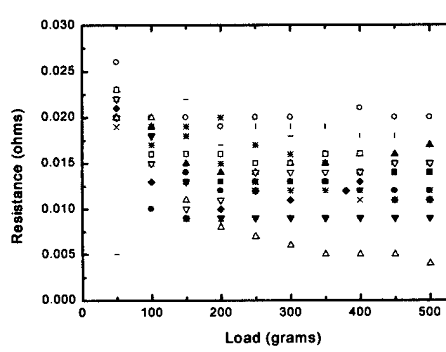

Figure 4: Contact resistance of the exposed surfaces of z-bar contacts for a D-tested MC2969, 8150-E84.

M98000198

Report Number (14) SAND--97-2007C
CONF-970982--

Publ. Date (11) 199709
Sponsor Code (18) DOE/DP, XF
UC Category (19) UC-700, DOE/ER

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