Electrical Contact Performance Degradation in Electromechanical Components

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Abstract
Detailed materials evaluations have been performed for MC2969 Intent Stronglink switch monitor circuit parts returned from the field out of retired weapon systems. Evaluations of local contact resistance, surface chemical composition and surface roughness and wear have been determined as a function of component level contact loop resistance testing position. Several degradation mechanisms have been identified and correlated with the component level measurements. Operational degradation produces surface smoothing and wear with each actuation of the monitor circuit, while aging degradation is observed in the segregation of contaminant species and alloy constituent elements to the surface in the stressed wear regions.

Introduction
Electromechanical devices perform functions critical to nuclear safety and weapon system performance and are susceptible to degradation caused by materials aging. Electrical contacts in electromechanical devices need to maintain low contact loop resistance (CLR), while keeping friction coefficients within design range to insure proper operation. Electrical contacts in the devices are of sliding or rotary design, and require some form of dynamic contact wiping as a part of normal switch operation. Contamination and corrosion of exposed electrical contact surfaces can occur through outgassing of contaminants or volatile species from surrounding materials, or through loss of hermeticity of the electromechanical device. Modification of the surface layers of contacts can also occur through oxidation or segregation of alloy constituent elements. Since low CLR values are obtained by using uncoated metal surfaces, reaction with adsorbed species can readily produce surface layers that are nonconductive. If these modified surface layers can not easily be removed by the dynamic wiping action of the contacts, then the resulting CLR may be high enough to limit signal transmission through the device. On the other hand, the same dynamic wiping process utilized to clean the contacts during use also produces adhesive wear transfer buildup on the contacts and generates particulate wear debris that may introduce electrical shorts into the device. In order to make predictions for service life extension, the role of each of these processes in device performance must be understood.

Experimental
The work reported here is a part of a program evaluating materials degradation in electromechanical devices returned from the field after years of deployment. In particular, this work reports on the electrical contact degradation observed in the monitor circuits of MC2969 Intent Stronglink switches, where there are significant increases in CLR values after the stronglinks are returned from the field. A large number of stronglink switches from retired
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weapon systems have been utilized, along with comparison to “new” WR quality hardware and various other D-test and Accelerated Aging program units. The evaluation program uses a thorough examination of local contact resistance, surface chemical composition and surface roughness and wear measurements at locations that correlate to specific known test positions monitored at the component level. Local contact resistance (CR) of the piece parts has been measured using a custom designed 4-point probe and a Keithley 580 Micro-ohmmeter. Resistance measurements have been made as a function of applied load using a dry circuit test mode at 20 µV. Surface composition measurements have been made using x-ray photoelectron spectroscopy (XPS) with a PHI 3057 system. Spectra have been acquired from a 400 µm diameter spot size using Al irradiation at 15 keV and 600 W. Surface roughness and wear have been measured with a Wyko NT2000 and an analysis area of 368 µm by 240 µm. All of the local piece part measurements have been acquired within the wear tracks formed by the dynamic wiping process at each test point location.

These local materials evaluation results are then correlated to component level measurements of CLR, sampled internal component atmosphere, and component age and history to gain an understanding of the types of aging phenomenon that are occurring.

Results and Discussion
A number of degradation mechanisms have been observed in stronglink switches to date. Operational degradation occurs with every actuation of the monitor circuit mechanism, resulting in irreversible smoothing and wear with every use. Rougher surfaces are more effective at cleaning the wiper contact and trapping of the adhesive wear debris generated by contact. Consequently, a general trend of increasing contact resistance with each operation and the subsequent smoothing is observed. In fact, the observed contact smoothing correlates well with both the local contact resistance measurements made at specific test locations, as well as with the component level CLR measurements. This is illustrated in Figure 1, which shows the component

Figure 1: Component level CLR measurements as a function of the measured surface roughness at each test point location.
level CLR measured at room temperature (LA) as a function of the measured surface roughness at each test location. The expected aging trend for this type of degradation is very rapid initially, since the first wipes across the surface will eliminate many of the roughest asperities. With continued wiping, further smoothing will occur, but each pass will have less affect on the total surface roughness. Most of the use of the electrical contact circuits is completed during production and acceptance testing of the component, and little degradation is expected during component deployment, although continued wear and smoothing will occur in the normally occupied switch position as a result of day-to-day vibration and motion.

Actuation of the monitor circuit mechanism also introduces subsurface mechanical stresses and irreversible microstructural changes in the electrical contacts. These microstructural changes modify segregation paths and rates of impurities contained within the electrical contact materials and individual constituent elements in the alloys to the contact surfaces. The build up of these elements on the contact surfaces can increase electrical contact resistance substantially as a function of time, even without further actuation of the device. The concentration of a number of elements observed on the electrical contact surfaces correlates roughly with the surface roughness as a function of test location, where the measured surface roughness is believed to act as a gauge of the mechanical stresses and microstructural changes experienced in each particular test location. This is illustrated in Figure 2, which shows the concentration of Zn (an alloy constituent element) on the surface as a function of the surface roughness at each test location. The expected aging trend for this mechanism is also very rapid initially, since the segregation curve will be steepest initially. As surface concentrations build up, segregation will slow with time. However, it is currently unknown where the measured concentration levels sit on the diffusional segregation curves, since the maximum segregation concentration limits are not known.

![Figure 2: Surface concentration of Zn as a function of the measured surface roughness at each test point location.](image-url)
Continuing efforts are underway to establish an idea of the segregation induced concentration limits, rates and current positions on the segregation curves in order to be able to make predictions for service life extension for MC2969 Intent Stronglink switches and similar electromechanical components.

Conclusions
In order to make predictions for performance during extended service life applications, a thorough knowledge of the degradation and aging mechanisms taking place at a materials level is required. In an effort to gain an understanding of these issues for electrical contact performance in electromechanical components, a detailed examination of the MC2969 monitor circuit piece parts is being conducted. This circuit has been chosen because of the ready availability of tested parts at the component level, and because of significant increases in contact loop resistance measured at the component level as a function of component age. Several degradation mechanisms have been observed, including both operational and aging degradation processes. Operational degradation occurs with every use of the monitor circuit switch, with a resulting smoothing and wear of the monitor circuit parts resulting from the dynamic wiping experienced by the electrical contacts. This surface smoothing correlates well with contact loop resistance values measured at the component level, as well as with local contact resistance values measured at specific test point locations on the piece parts. In addition to surface smoothing and wear, subsurface mechanical stresses and irreversible microstructural changes also occur as a result of the dynamic contact wiping. These changes modify the adsorption, reaction and segregation rates and mechanisms for impurity and alloy constituent elements within the wear zone. These reaction/segregation changes result in aging degradation that continues as a function of time, whether or not the monitor circuit switch sees any further operational use. Surface concentration levels of a number of elements have been correlated with the measured surface roughness values. In this case, it is believed that the surface roughness serves as a monitor for the amount of subsurface stress built up during dynamic wiping. Work is continuing to quantify reaction/segregation limits and rates, in order to be able to provide materials aging predications for service life extension.

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