WHITE PAPER

RATING POWER CONNECTORS **USING VOLTAGE DROP**

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ABSTRACT

Typically, measuring temperature rise at rated current has been used to rate power contacts in connector applications. In some cases this is done after accelerated aging tests. In this paper, it is proposed that voltage drop and change in voltage drop be used to evaluate the performance of power contacts. This method is intended to replace the standard use of thermocouples to monitor performance throughout an accelerated test series. Criterion is developed empirically from high current testing of tin plated power contacts. Moreover, data from accelerated aging tests followed by high current cycling tests are used to establish an empirical basis for change in voltage drop criteria. These results are analyzed using basic contact theory to relate loss of metallic contact to change in voltage (resistance) criteria. The ultimate goal is to develop a method using voltage drop as a performance indicator to quantify the current level at which power contacts reliably work. To this end a series of tests are conducted at various current levels to establish a relation between current level and failure rate. Subsequently, the relationship of voltage drop stability and reliability are established to provide a methodology in current rating power contacts.

Introduction

Last year the first author proposed voltage drop change be used to evaluate the performance of high current power contacts [1]. It was shown that when the voltage drop change of aged contacts crosses a threshold of 0.01 to 0.03 volts, that thermal instability ensues. This was demonstrated with plots of voltage drop change per cycle versus voltage drop change as shown in figure 1a. In addition, it was shown that voltage drop data correlates very well with temperature rise data as seen in figures 1b and 1c. While this type of data clearly shows a threshold that defines performance criteria, it does not provide a means to rate the contacts in question. Consequently, a method is needed that enables one to establish the current level at which a contact system can operate over it's expected life in the field. To this end the present paper addresses this issue by using voltage drop data from contacts subjected to accelerated aging tests. These data are analyzed statistically and used to correlate the results with subsequent failures observed during the high current cycle phase of the test sequence. Consequently, the end of life voltage drop data is used to predict high current failures and provides a basis on which the power contacts can be rated.

Moreover, the test results for voltage drop change are related to physical changes that occur at the interface. Consequently, the change in voltage drop is related to loss of metallic contact at the interface. It was seen in previous work for typical power contacts [2], as voltage drop change transitions from 0.01 to 0.03 volts, metallic contact at the interface drops by more than an order of magnitude. Consequently, the local current density increases by this factor causing excessive localized heating. These results are presented in figure 2 where an analysis of voltage drop change versus loss of contact area was conducted in reference 2. These results are for typical pin and socket contacts of the type considered in the present study.

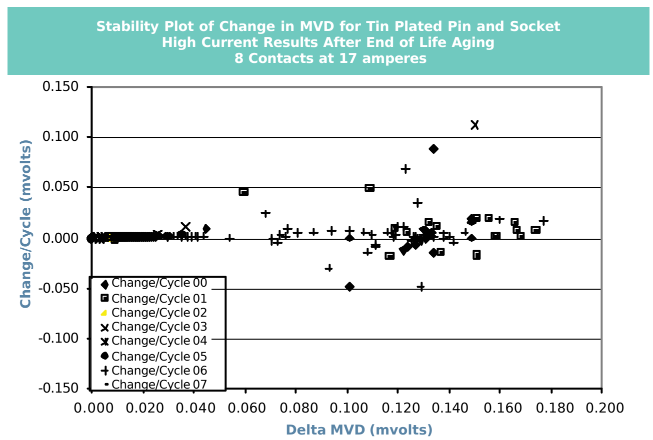

Figure 1a: see reference [1]

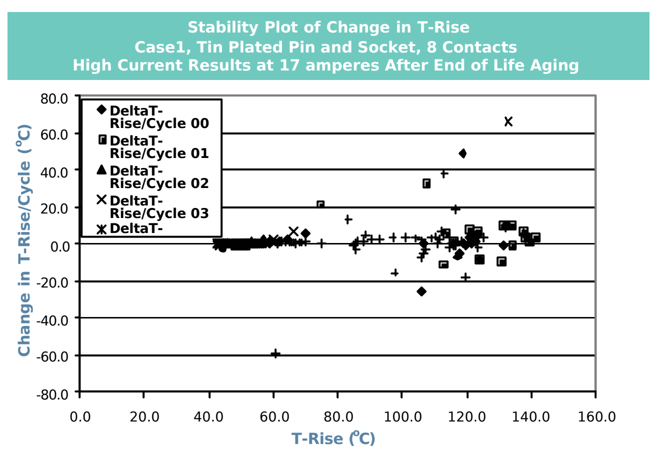

Figure 1b: Stability Plot of Case 1, see reference [2]

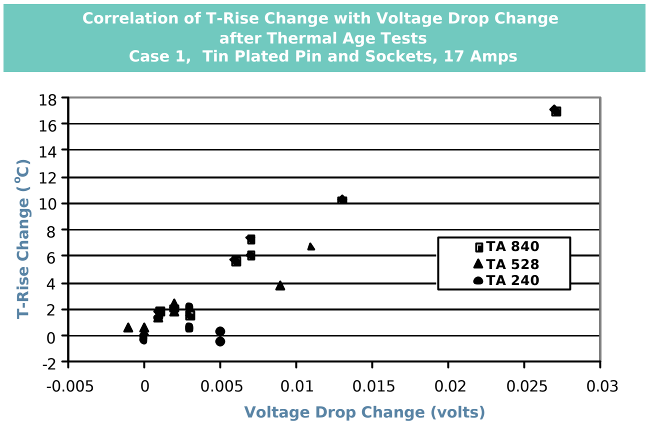

Figure 1c: Correlation of T & V Case 1, see reference [2]

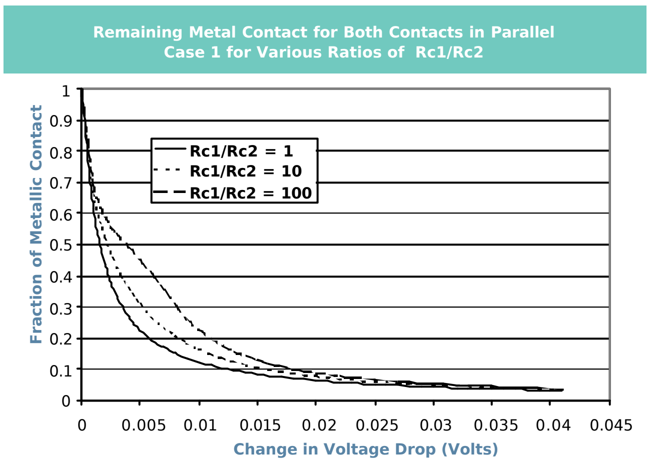

Figure 2: Two point contact Pin & Socket, see reference [2]

TEST PROGRAM

In addition to the data provided in references [1] and [2], new data were developed in the present work for similar power contact systems. These contacts were tin plated square pin and socket types where each socket makes contact to two of the faces of the square pins. Consequently, this system provides two parallel paths through the pin and socket contact. In addition, the pin and sockets were loaded into connector housings and mated for test purposes. In these cases, samples were subjected to accelerated thermal aging tests during which the voltage drop of each contact was monitored periodically at various dc current levels. Moreover, the voltage and temperature were measured on an initial set of samples to establish current levels at which subsequent current cycling tests were conducted to evaluate performance after thermal aging (TA). The latter was based on the initial temperature rise produced by these current levels. The results are provided in figure 3 where it is seen that temperature rise versus current is plotted. The dc current levels chosen for this study were 13, 16 and 19 amperes respectively. As shown in figure 3, these values produce average initial temperature rises of about 30, 45 and 60 degrees Celsius respectively. In this test program, the
samples were purposely aged beyond the end of life.

Moreover, as discussed above the currents were elevated to produce temperature rises and voltage drops that were above the rated levels for these types of power contacts. It should be noted that a 30 °C temperature rise has been used as a standard requirement for current rating connector contacts [3].

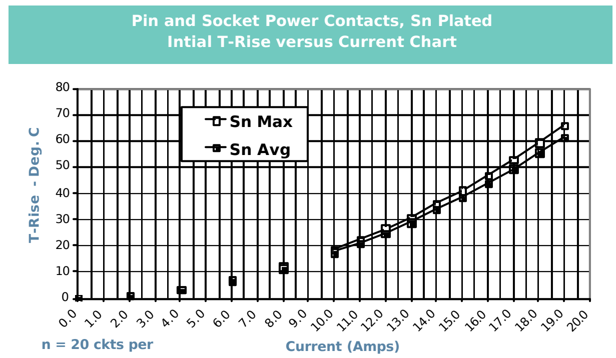

Figure 3: Initial T-Rise Measurements

The actual test program involved the following sequence.

1. Measure the initial voltage drop for each test current group
2. Expose the samples for 240 hours at 105 °C TA
3. Measure voltage drop for each test current group
4. Subject each sample group to 96 one hour current cycles
5. Measure voltage drop for each test current group
6. Expose the samples for 288 hours at 105 °C TA
7. Measure voltage drop for each test current group
8. Subject each sample group to 96 one hour current cycles

The voltage drop measurements and maximum dc current used in the current cycles were 13, 16, and 19 amperes respectively for the three test groups studied in this work. The dc current cycle had a 75% duty cycle where the maximum current was on for 45 minutes. The number of samples in each test group was 30. These contacts were randomly chosen from production runs and housed (two each) in 15 randomly chosen housings. One should note that this sequence provides aging due to thermally activated processes, such as stress relaxation, oxidation and intermetallic compound formation. It should be noted that the thermal aging steps 2 and 6 were based on data in table 8of the EIA-364-1000.01 test standard. These levels are thought to correspond to field conditions of 10 years at 65 test oC and 3 years at 85 oC respectively. Moreover, the current cycling tests have the potential to promote fretting motion due to thermal cycling. From this sequence, the change in voltage drop (from the initial value) was monitored at each stage of the test. The change in voltage drop is simply calculated by subtracting the initial value from each subsequent measurement.

Test Results

Typical results are provided in figure 4 where voltage drop change distributions are plotted for the 13 ampere test group. In this plot one sees distributions after steps 4 and 6 respectively. Clearly after step 6 (after 240h TA, 96 current cycles and 288h of TA) the 13 ampere samples exhibit values of voltage drop change in the 0.01 to 0.03 volt stability window discussed earlier. From this data one would expect to see instability in subsequent current cycle tests as shown in figure 5. Here one sees 2 out of 30 samples exhibiting voltage drop changes up to and exceeding the melting voltage of tin. These 2 cases exhibited thermal instability and are considered failures.

Sequence 4 and 5, Post TA/CC at 240 h and TA at 528 h
Sn 13 Amps Case

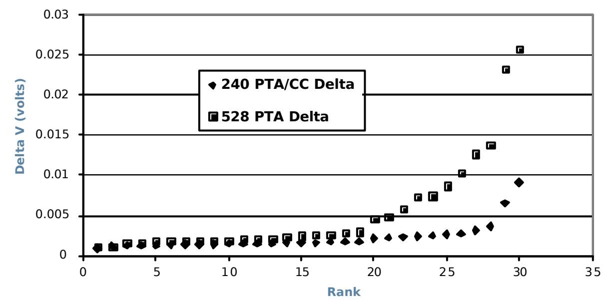

Figure 4

13A Tin, Delta V Post 528TA/CC
2 Failed Contacts out of 30 Tested

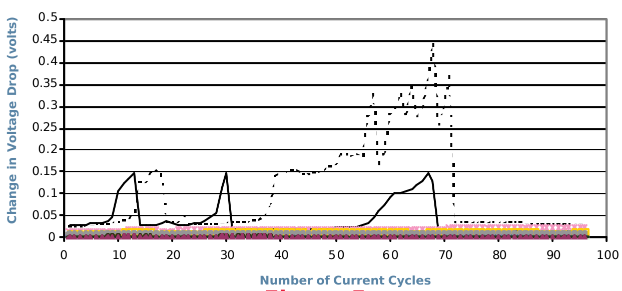

Figure 5

Sn 13 Amp Case, Post 528 TA

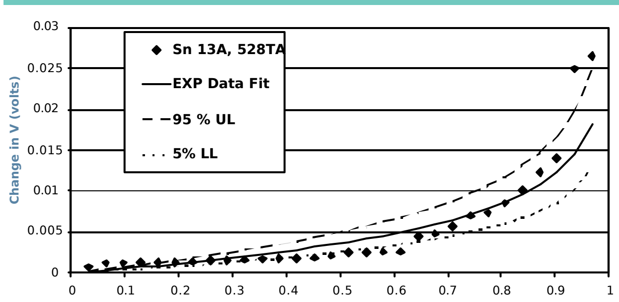

Figure 6

In addition, figure 6 provides a statistical plot of the voltage drop change after 528 hours of thermal aging (step 7). This is prior to submitting the samples to the final current cycle test (step8). As shown, an exponential fit of the data provides a reasonable estimate of the distribution. Also shown are the upper 95% and lower 5 % limits to the exponential distribution. These limits were obtained using a Chi Squared distribution for the observed mean change in voltage drop, denoted below as Λ. As given by Kapur and Lamberson [4], the statistical model used was a simple exponential distribution function as follows.

$$P(\Delta V_c > \Delta V_t) = e^{-\Delta V_t/L} \qquad (1)$$

Where $P(\Delta V_c > \Delta V_t)$ is the probability that $\Delta V_c > \Delta V_t$ and Λ is an estimate of the mean change in voltage drop as calculated from the data. Equation 1 can be used to define a limit for ΔV_t where failure is predicted. This is done by using the number of observed failures (2 in 30 for the 13 amp case) from the subsequent current cycle test as a measure of P in equation 1. For the 13 amp case, Λ was found to be 0.0053 volts and P was observed to be 2 failures in 30 samples. With these values ΔV_t, was calculated from equation 1 to be 0.0143 volts. Consequently, this level of voltage change defines the end-of-life failure criteria for the 13 amp case. A similar procedure was followed for the 16 and 19 ampere cases. Table 1 summarizes these results.

Table 1

AMPS	Λ	P	ΔVT	J/J_o
13	0.0053	2/30	0.0143	8.3-11.1
16	0.0096	8/30	0.0127	4.5-8.3
19	0.0041	5/30	0.0074	3.1-6.3

The last column in table 1 (labeled J/J_o) is an estimate of the ratio of the current density to the initial value as determined for ΔV_t from figure 2. While the range obtained from figure 2 is fairly broad, the upper value in each case shows that the end-of-life criteria (ΔV_t) reveals the current density to either exceed or approach an order of magnitude change.

As table 1 reveals, the failure criteria, ΔV_t , appears to depend on the current level the samples are cycled at. This is reasonable as one might expect higher currents produce greater stresses due to higher temperature rises and greater temperature swings. Consequently, higher stresses may well lower the threshold to failure. One should keep in mind in this case that ΔV_t , is being used as a criteria to predict the probability of failure in current cycling. With this said, the present approach provides an opportunity to develop a statistical model that can be used to estimate failure rates as a function of current. The way this can be done is to first fit a curve to the values of ΔV_t , in table 1. The results of a linear fit are provided in figure 7 where it can be seen that the upper 95% and lower 5% values have been plotted for comparison. The actual fit exhibited a correlation coefficient of greater than 0.95. Subsequently this mathematical fit can be used with equation 1 to estimate failure rates as a function of current for a specific set of data as represented by Λ. In other words, given a value of Λ from a sample group that was aged, one can use the model represented by equation 1 and the data fit for ΔV_t to calculate a current for a specific reliability criteria. This model is written mathematically as,

$$P(\Delta V_c > \Delta V_t) = e^{-((a+bI)/\Lambda)} \qquad (2)$$

Where a+bI is the linear fit for ΔV_t as a function of current I as discussed above and Λ is obtained from aging data. In this example a and b were found to be 0.0299 and –0.00115 ohms respectively.

Linear Fit of Calculated Thresholds for Various Currents

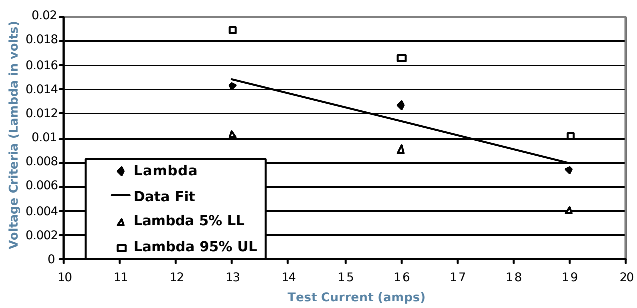

Figure 7

Estimated Upper 95% End-of Life Failure Rate
Two Aging Cases for Various Currents

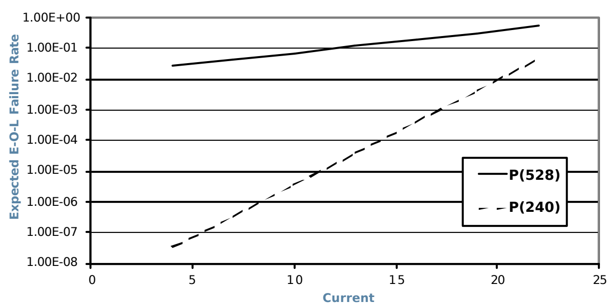

Figure 8

For example, if 240 and 528 hours of thermal aging represent the expected field aging for two applications respectively, then a current versus failure rate curve can be constructed for each case using equation 2 as shown in figure 8. As one can see the 240 hour thermal age samples exhibit significantly lower end-of-life failure rates. The way these charts are used is to pick an acceptable end-of-life failure rate and find the current level that meets that requirement. From figure 8, as an example, assume 10^{-5} at 95% confidence is acceptable. As one can see only the 240 case provides acceptable performance at about 11 amperes or lower. Consequently, one could rate this product at 11 amperes for the application represented by 240 hours of thermal aging. However, the final step in rating a system as suggested above, is to conduct a final confirmation test at the predicted current rating level. The design of this test should include accelerated aging and current cycling that represents the specific application for which the system is to be rated.

Conclusions

It was shown in this work that current rating may be accomplished using end-of-life voltage drop data in concert with an appropriate statistical model. In the present cases studied, it was found that a simple exponential distribution worked reasonably well. This method provided a way of using accelerated aging tests and voltage drop readings at various currents to rate a given product for a specific application (as represented by the aging tests). This was the goal of the present work. It should be noted that the accelerated aging tests used in this study are by no means exhaustive with regard to representing all tin alloy applications. Consequently, each application requires a set of tests that properly represent field aging. However, we believe this effort demonstrates that this approach has merit for tin (alloy) plated contacts and can be used to improve on the existing methods employed to rate power connectors.

Moreover, the method to rate power connectors as developed in this paper depends on the observation that the threshold ΔV_t , (which is used to predict end-of-life failure in current cycling) depends on the current. If this turns out to be an artifact of the analysis technique, then the method will require modification. Consequently, it is recommended that this aspect of the model be carefully studied in follow up programs to establish this feature. Finally, as this work was focused on tin plated contact systems, it would be prudent to conduct similar research for other types of plating such as gold and silver. This is likely to require other types of accelerated aging that are specific to the failure modes of these plating materials. As an ongoing study, the gold case is under consideration by the present authors.

ACKNOWLEDGMENTS

The authors would like to thank Bob Smid, from Molex product reliability laboratory, for collecting and helping format the voltage drop and temperature rise data provided in this analysis.

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Originally published in 2004/2005.

Order No. 987652-4994 USA/0K/GF/2022.03