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The last edition of Tech Topics described the application of in-process scintillation testing as an output measure for process improvement. This edition describes a novel surge current test-to-failure technique. Both are designed to help the R & D engineer recognize performance improvements in highly reliable components rapidly and by testing relatively few parts.

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A Surge Step Stress Test for Tantalum Capacitors

by Jim Marshall

Introduction

Quality and reliability are essential benchmarks of a successful new capacitor design. We associate the quality of a product primarily with its ability to meet performance objectives at the beginning of its life. Quality testing is usually straightforward, with definitive, nondestructive test methods and specific criteria. In the electronics industry, quality tests are often performed on every part.

Reliability, on the other hand, is associated with the performance of a product over its useful life. Reliability testing determines how many hours, or for how many cycles, or to what load level the product can be expected to meet performance objectives without failing. By necessity, reliability testing is often inferential; we predict the useful life of a group of parts by testing a representative sample to failure.

This article describes a KEMET reliability test designed to predict the likelihood of abrupt failures. Called the Surge Step Stress test, it has proved instrumental in the development and comparison of potential new product designs.

Background

Failures generally fall into two classes: gradual or abrupt. Gradual failures occur as stress levels (time, cycles, load, heat, etc.) increase, causing performance to deteriorate. When the decline reaches an unacceptable limit, we say the part has "failed," even though it may continue to function at some level. Information about the rate of decline can often be used to predict impending failure.

Abrupt failures are not as predictable. They are much like the incandescent bulb that provides consistent light until the instant it ceases to function. Under certain stress conditions, tantalum capacitors may exhibit this failure mode.

Under normal steady-state circuit conditions, the expected life of solid tantalum capacitors can be literally millions of years. However, the increasing demand for miniaturization and fast switching has led to low impedance AC circuitry, which is much more transitory. These new circuits not only expose capacitors to higher stress levels, but also demand lower equivalent series resistance (ESR) and improved current surge robustness. To ensure that new product designs meet these requirements, new methods of predicting abrupt failure are required. The Surge Step Stress test is one method found to be useful.

Surge Step Stress Test (SSST)

In many reliability test regimes, the idea is to complete the test without incurring any failures. This is reassuring to a point, providing both producer and consumer with confidence that the product meets certain minimum requirements. But these types of tests do not provide insight regarding safety factors (how close are we to the stress at which failures are likely). In addition, when multiple groups undergo this type of testing, we learn little about the relative strengths among the groups. In many cases the sample size is limited, so that even when failures do occur there are too few to allow meaningful conclusions or comparisons. We are relying on "pass/fail" information (did the part fail?), which is very limited in value compared to parametric, or variable data (at what stress level did the part fail?).

So our objective was to design a stress-to-failure test generating parametric data and addressing the issue of component reliability under low impedance, surge current conditions. The test that emerged built on the recognized approach of sequentially testing parts under ever-increasing stress levels - "step stress testing." We replaced the commonly-used constant voltage stress with stepped voltage, and applied a series of current surges at each step via a low impedance circuit.

In the SSST, total circuit resistance is less than .3 ohms. To supply maximum instantaneous current at turn-on, an 11,000 µF capacitance bank is wired in series with each part and kept charged via the power supply. Each test step consists of five cycles, each consisting of a one-half second charge followed by a one-half second discharge. Starting with the first step at the rated working voltage of the part, voltage is increased by 10% at each step. A failure is indicated when a part does not charge to at least 95% of the applied voltage. The test is terminated when roughly two-thirds of the parts on test have failed.

Plotting and Analyzing Results

New techniques were also needed to analyze SSST data. The old method of using histograms was useful, but limited because no direct prediction could be made. Enter Weibull analysis! KEMET has found Weibull analysis* very useful in describing capacitor-related data: field failure predictions, reliability "grading" of capacitors, flexural strength of ceramic capacitors, and so on. Perhaps the beauty of Weibull mathematics is that a straight line can be fitted to a variety of different failure distributions. Reliable predic-

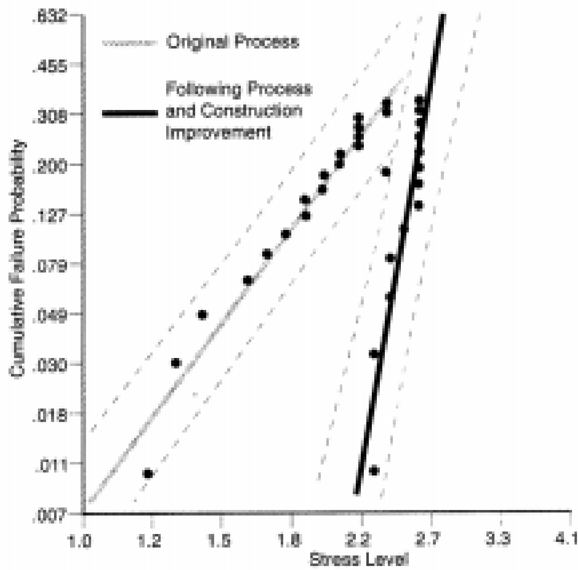
* See references at end of article.

tions can then be made.

The output data from the test include the voltage at which each failure occurs. This data is plotted on Weibull paper as follows:

1) The failure voltages are ranked in order from lowest to highest. These values are the horizontal coordinate for each plot point.
2) Vertical coordinates are calculated as (i-.5)/n, where n is the sample size and i is the rank. For example, the coordinate for the 20th ranked failure in a sample size of 50 would be (20-.5)/50, or .39.
3) Using regression analysis, a best-fitting straight line is drawn through the plotted points.

Examples of resulting graphs are shown in figures 1 and 2. Figure 1 shows SSST results for a group of 10 µF 35V



tantalum chips made by the normal process at the time of manufacture (“Original Process”). On the right side of the figure are results for a later group of parts incorporating some process and construction improvements. Here we see that failures occur at much higher test voltages over a narrower range of voltages.

In Figure 2 the primary difference between the groups is a change in the voltage conditioning procedures applied as post-assembly processes to the capacitors. Here the process improvement has shifted the mean failure voltage upward, with little change in the breadth of the distribution.

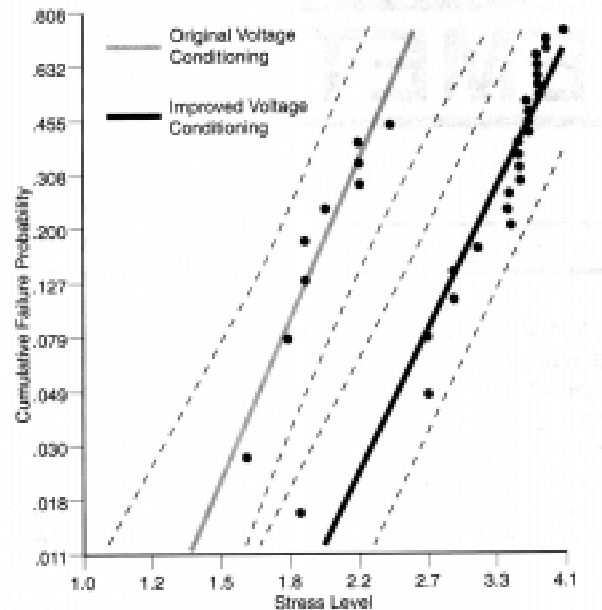
The SSST has proven useful in ranking process modifications for the development of surge-robust, low-ESR tantalum capacitors. Its advantages are that it provides rapid, comparative feedback with good batch-to-batch discrimination. Intuitively, it provides a good measure of product robustness. Decisions based on its results have so far been supported by the less discerning results of conventional tests.

Appendix

A word about Weibull. One useful way to express the Weibull distribution is:

Where ln = logarithmic function

$$\ln\ln \frac{1}{(1-p)} = \beta \ln(y) - \beta \ln(\propto)$$



p = fraction which has failed
y = the applied stress (voltage, time, cycles, etc.) at failure
$\propto$ = a constant value for the distribution corresponding to its characteristic “life" (voltage, time, cycles, etc.)
β = a constant value for the distribution corresponding to various well-known distributions:
$\beta = 5$ Normal
$\beta = 3$ Log - Normal
$\beta = 1$ Exponential

Both $\propto$ and β are determined empirically from the test data.

In Figure 1 the major difference between the two distributions is in β. In Figure 2 the major difference is in $\propto$.

Further information related to this article may be found in:

1) King, James R.; Frugal Sampling Schemes, Technical & Engineering Aids for Management, Box 25, Tamworth, New Hampshire 03886, 1980.
2) King, James R.; Probability Charts for Decision Making, Technical & Engineering Aids for Management, Box 25, Tamworth, New Hampshire 03886, 1971.
3) Nelson, Wayne; Volume 1: How to Analyze Data with Simple Plots, American Society for Quality Control, 161 West Wisconsin Avenue, Milwaukee, Wisconsin 53203, 1979.
4) Nelson, Wayne; Volume 6: How to Analyze Reliability Data, American Society for Quality Control, 230 West Wells Street, Milwaukee, Wisconsin 53203, 1983.
5) Marshall, J.C., and Moore, J.J.; “Development for the T495,” Tech Topics, KEMET Electronics Corporation, P. O. Box 5928, Greenville, South Carolina 29606, May 1994.

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