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General linearized model use for High Power Reliability Assessment test results: Conditions, procedure and case study

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A B S T R A C T

In semiconductor manufacturing for automotive, AECQ_100 standard requires test of load drivers in continuous short circuit conditions: this test is called High Power Reliability Assessment (HPRA). It is about a robustness test in which a sample of parts is led to breakages on a cycled overload or short circuit current. The test is stopped when a sufficient number of parts to conduct a statistical analysis failed. The expected result from this statistical analysis is failure cycle modeling according to the test temperature. But this is a complex modeling that has to proceed in several steps, the final step being use of a general linearized model.

This paper presents the main features of modeling, but it shows their implementation on a real HPRA test in Load Short Circuit (LSC) condition. Modeling allows result prediction at a temperature for which a test has not been performed, but it allows also a full explanation of the phenomena: for example, it enables to estimate activation energy of acceleration factor in the test, but also the failure mechanisms at the breakage origin. This paper highlights the necessary conditions for the tests so that interpretation may be complete and significant.

1. Introduction

The AECQ-100 standard for automotive requires electronic component manufacturers to perform a High Power Reliability Assessment (HPRA) on the protection drivers. HPRA takes on the form of accelerated stress tests: components operate in a continuous short circuit condition, in an oven at monitored temperature. The overload or short-circuit current is seen continuously switched on–off. Several parts are used for a test, and the result is the number of on–off cycles that each of the parts can endure before to fail.

This paper deals with modeling of these HPRA test results when the temperature is modified from one test to the other one [1,2]. But this modeling is complex since it is about to mix several modeling conditions: in a first time, modeling focuses on modeling at one temperature, before addressing modeling the result curve on all the different temperature set-up.

There are two final purposes of this HPRA test result modeling:

- the first one is to predict HPRA result at a temperature at which the test was not already led;
- the second one is to explain the failure mechanisms that caused each of the failures: that explanation purpose is going to bring about the question of the temperature as the factor of the failure mechanism type.

Far to be only a theoretical paper, this work describes the different modeling steps in a real case study. It gives some practical recommendations to model HPRA test results, but in extension any accelerated stress test results.

2. HPRA test description

The AECQ_100 standard defines the precise requirements for the HPRA test conditions.

Devices that have the function to power supply to an external load, usually provide embedded protections against system malfunction due to short circuit of that load. The HPRA addresses these protections, testing their robustness on an on-off-cycled short-circuit or overload current. Schematic depends on the type of parts (low side or high side devices), and a specific resistance and inductance simulate the cable length between the device and the short-circuit.

The AECQ_100 describes two types of HPRA tests: it speaks about a Terminal Short Circuit (TSC) when the short-circuit occurs close to the device, and about a Load Short Circuit (LSC) when it occurs at the end of the cable. The values of the cable length simulation components depend on the device specifications.

An HPRA test is constituted by a minimum of 10 DUT, taken from 3 different lots. During the cycling, each DUT is monitored and the number of cycles that it went through before failing is recorded: the statistical analysis and modeling use this data. The final result for the component is given by a grade level, defined by the number of cycles until the first observed failing DUT, or by the total number of tested cycles, if no failure occurs with a sample during the duration of the test.

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3. Regression and modeling methodology

Let a couple of random numerical variables (X, Y). If Y and Y are not independent, knowledge of the value taken by X changes uncertainty about the realization of Y. X is called explaining variable or predictor, and Y is the explained variable or criteria.

Typically, this uncertainty decreases since conditional distribution of Y, according to a value x of X (X = x), E(Y/X), has a variance inferior in mean to the variance of Y distribution. If the random phenomena of X is assumed to be able to predict the random phenomena of Y, a prediction formula of Y by X is searched as well as prediction error estimation, measured by variance of:

$$\varepsilon = Y - (\text{prediction of } Y). \quad (1)$$

This variance $Var(\varepsilon)$ is wanted the smallest possible.

If X and Y follow a normal distribution, conditional distribution of Y, according to X, can be described by:

$$E(Y/X) = A + B\,X. \quad (2)$$

Therefore:

$$Y = A + B\,X + \varepsilon. \quad (3)$$

This last formula defines what is called linear regression.

We have now n couples (x_i, y_i), from i = 1 to n that constitute an n-sample of independent observations of (Y, Y). In that case, we have only to assume that for each observation, we have:

$$y_i = A + Bx_i + \varepsilon_i \quad (4)$$

where ε_i are independent realizations of a variable ε: ε has a null expected value and a constant variance σ^2, whatever x_i. Then, we speak about linear model rather than linear regression.

To estimate A, B and σ^2, least square mean method uses the fact that E(Y/X) = A + B X (2) is the best estimation of Y by Y in quadratic mean. We look for a straight line with the equation:

$$(\text{Predicted } y) = a + bx \quad (5)$$

such as $\Sigma[y_i - (\text{predicted } y_i)]^2$ is minimal.

We speak about the general linearized model when:

- probability distribution for Y is no longer normal: it can be a Poisson distribution, an exponential or gamma one, and so on…
- the link function g between E(Y/X) and X is not as simple as a linear form, but it is expressed by a matrix X′:

  $$g[E(Y/X)] = X'B \quad (5)$$

- the least square mean method has to be replaced by the maximum likelihood estimation (MLE).

4. HPRA test modeling

In HPRA tests, such as defined and led following the AECQ_100 requirements, temperature can be the explaining variable or predictor, and the failure cycle is the explained variable or criteria.

4.1. HPRA test modeling steps

To model HPRA test results, the first step is to model failure cycle distribution per temperature: this knowledge determines if modeling by a linear model is possible or not, as the least mean square method use.

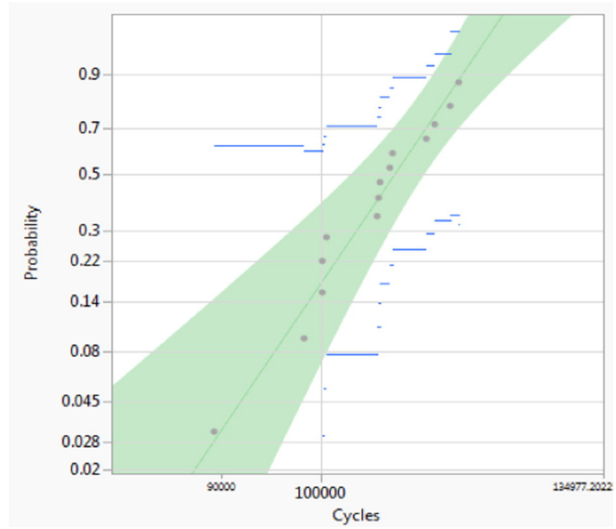

Fig. 1. Distribution probability modeled by a Weibull model.

Then, the different failure cycle distributions per temperature can be compared, and acceleration factor can be modeled from a temperature to the other one.

Finally, modeling of the link function will be possible using a general linearized model if failure cycle distribution is not normal.

4.2. Failure cycle distribution modeling per temperature

Failure cycle distribution modeling is performed on an LSC test on 16 parts at a temperature equal to 85 °C. The failure cycles are reported into a file with additional data of censoring:

- 14 parts failed during the test: their censor data is equal to 0;
- 2 parts did not fail yet when the test was stopped: censor data is equal to 1.

This is a case of type I censoring, when exact failure data is known. 2 data are right censored, since failure cycle is not known at the test end.

A modeling allowed determine that a Weibull model is the best one (see Fig. 1).

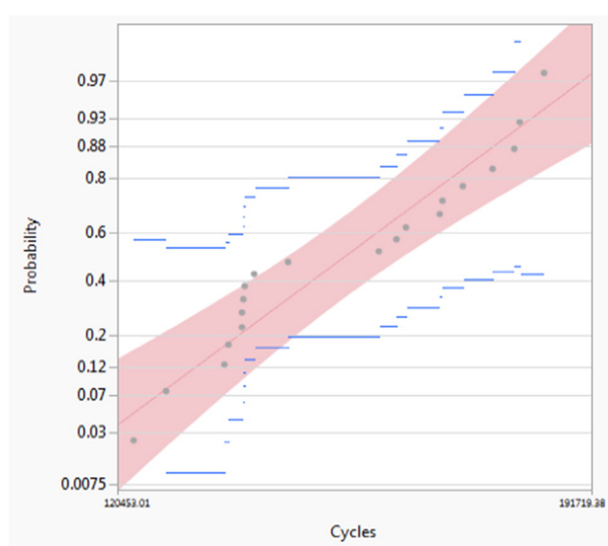

Fig. 2. Distribution probability modeled by a Lognormal model.

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