Assessing Product Reliability

So far we have introduced the idea of failure rate, and illustrated the facts that component or product life depends on the conditions, varies with time, and can be dramatically affected by the inclusion of defects. Now we need to address the question of whether a product is intrinsically sufficiently reliable, and in testing for this find out enough about the actual failure modes to be able to devise screens to prevent potential defects reaching the customer.

Accelerating reliability tests

Unfortunately, time constraints dictate that we cannot duplicate intended life, but typically have to compress the test time to a reasonable value. Most reliability testing therefore applies more rigorous conditions to the device under test in order to accelerate failure, making it possible to get meaningful results within a short time. This gives both economic savings and quick turn-around during the development of new products or of mature products subjected to manufacturing and workmanship change.

The results from the tests are then extrapolated to give an estimate of the life for the product. The *assumption* made is that tests can be carried out under conditions of higher than usual stress ('accelerated' stress), and the effects of this stress can be represented by an acceleration factor A, where:

[life in use] = A × [life at accelerated condition]

Of course, this is only valid if:

- the failure mechanism that applies during accelerated test is the same as that which occurs during normal operation

- the laboratory specimens replicate manufacturing defects and field environmental factors.

The degree of acceleration may vary significantly, and some workers in this field define two types of test:

- ‘Low acceleration’ tests that closely mimic expected field conditions and produce a MTTF of the units under test perhaps 10–20 times less than actual life in the field
- ‘High acceleration’ tests aim at producing an MTTF that is 100–500 times less, but are much less representative of field performance.

The danger is that high levels of stress may induce failure mechanisms that are not present in normal use.

In designing and interpreting accelerated tests, it is necessary to understand which stresses accelerate which failure mechanisms, and how varying the magnitude or rate of application of the stress influences product life. Table 1 suggests some of the links between mechanisms and

Table 1: Some examples of wear-out mechanisms and acceleration stresses	
wear-out failure mechanisms	**acceleration stresses**
fatigue crack initiation	mechanical stress or strain range, cyclic temperature range, frequency of cyclic stress
fatigue crack propagation	mechanical stress range, cyclic temperature range, frequency of cyclic stress

creep	mechanical stress, temperature
diffusion	temperature, concentration gradient
corrosion	temperature, relative humidity, contaminants
electromigration	current density, temperature, temperature gradient
dendritic growth	voltage differential, temperature
radiation ageing	intensity of radiation
stress corrosion	mechanical stress, temperature, relative humidity, contaminants
wear	contact force, relative sliding velocity

Several types of stress may be used to accelerate failure, and accelerated tests should only be used when the correlation between test and field conditions is clearly understood:

- A stress may accelerate multiple failure mechanisms with differing sensitivities. For example, temperature can accelerate failure due to electromigration, corrosion, or ionic contamination, but at different rates. One of these may be the dominant failure mechanism during accelerated test, but not under field conditions.
- Failure through a particular mechanism can be induced by different acceleration stresses. For example, corrosion can be accelerated by both temperature and humidity.

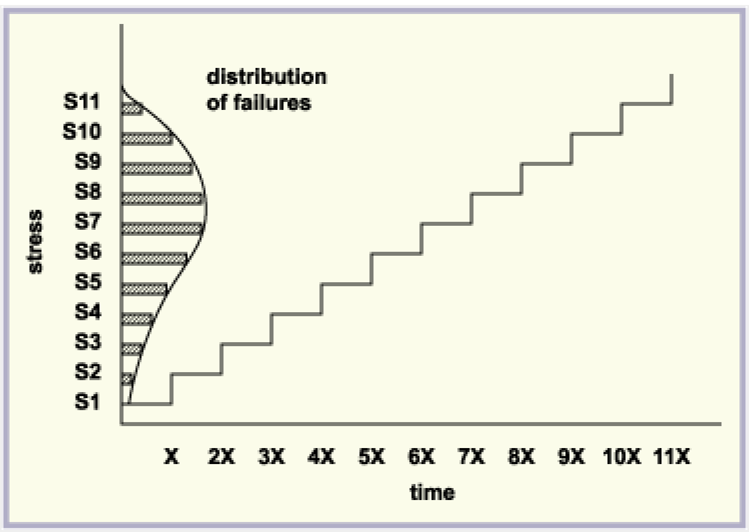
Extrapolating data

The procedure for accelerated testing consists of:

- selecting the appropriate stress parameters to be accelerated
- determining the magnitude to which the stress parameter(s) should be accelerated
- designing the test procedure, such as step-stress acceleration
- extrapolating the test data using physical failure models.

The constants in a model are typically derived by testing sample populations at several stress levels and extrapolating these values to typical operational environmental conditions, as shown in Figure 1. The more sensitive the item under test is to the imposed stresses, the greater will be the slope of the projected line, and the more uncertain the projection for field life

Figure 1: Acceleration life test concept



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The validity of extrapolation depends on how accurately the model predicts acceleration. The mechanisms are different for temperature, humidity and mechanical stress, and not necessarily known with certainty. This shows a number of different models that attempt to link failure under high stress to failure under normal working conditions. Typically, the lower the acceleration level, the closer the fit between prediction and actual results.

Even if you don't have time to read the whole of the linked document, you need to be aware of the Arrhenius formula, as this is a common way of relating the rates of physical and chemical processes to temperature. Originally based on observations relating to biological models, in the past it has been a surprisingly good fit to electronic information. However, as we will see later, it must now be viewed with some scepticism.

Types of accelerated test

Accelerated tests can be roughly broken into two types:

- '**Elephant tests**', where stress is applied once only, but at a severe level. These may be used to demonstrate product reliability or expose failure modes/mechanisms
- **Accelerated life tests** estimate reliability by carrying out extended tests at increased levels of stress. A model of the stress-life relationship is built by taking data from different stress levels, and the likely equipment life under operational conditions then extrapolated from this.

In the most general case, these accelerated tests can be carried out in three ways:

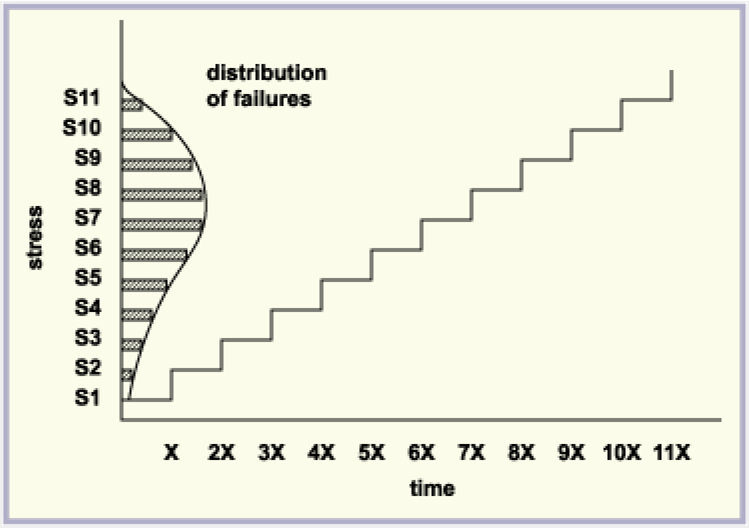
- by testing at an increased level of use (for example, running continuously instead of an intended 1 hour/day)
- by changing the size, geometry or finish of the product
- by testing at a stress level higher than the operational stress.

The last of these is common practice for electronic equipment, but there are variations in how the stress is applied:

- **Constant stress**
- **Cyclic stress**, where the product is subjected to cyclic stress at high levels, if this is the type of stress on the equipment at the usage conditions
- **Step-stress** testing, where equipment is subjected to successively higher levels of stress for specified periods of time. This is similar to **progressive stress** testing, which uses continuously-increasing stress levels
- **Random rate stress** testing subjects the equipment to randomly changing levels of stress. This type of test is often used for vibration stresses.

In **step-stress** tests, progressively increasing stresses are applied to the same sample for constant time intervals until all samples have failed. Figure 2 is a schematic presentation of typical results. The embedded assumption is that the failure probability during each time interval is *independent* of previous history, but, because the effects of exposure at high temperatures are cumulative, the gap between temperatures has in practice to be kept equal and relatively large.

Figure 2: Distribution of failures in step-stress test



Step-stress tests generate data on product reliability more quickly than constant stress tests, but are more difficult to evaluate. Constant stress testing is therefore the most common procedure, with step-stress used mostly for quick comparison tests.

Failure mechanisms that are not apparent under normal conditions may become significant under accelerated stress, a phenomenon called **failure mechanism shifting**.

Because of inevitable process and material variations, there will be statistical distributions of time-to-fail results for each stress level. Combining these with the stress-life model, a statistical estimate can be made of time-to-failure under operating conditions.

Source : http://www.ami.ac.uk/courses/topics/0187_apr/index.html