MEOST,

a jump into the future

Given the demand for shorter development lead times, traditional methods of system and product reliability testing are too time-consuming. The Multiple Environmental Over Stress Testing (MEOST) method appears to be a very strong tool for designing and developing a robust and reliable product.

• *Jan Eite Bullema* •

Companies are often pressured by competitors and by their business environments to bring new products and new innovations to the market as quickly as possible. This rapid introduction of new products increases the risks associated with the reliability of new products. Traditional test methods used to guarantee the reliability of new products are not sufficient to reduce the time of design cycles.

The reliability of a system is often derived from testing its subsystems. Subsequently, the reliability of a subsystem is derived from the reliability of the components of that subsystem. Often these tests are guided by 'mission profiles' that are used to model the practical conditions of use. In practice, it appears to be very difficult, if not impossible, to infer a systems' reliability from the reliability behaviour shown by subsystems and components. As the renowned quality guru Edwards Deming put it, "*you cannot test a battleship*" [1].

It has been known for at least twenty years that traditional methods for arriving at reliable products take too much time and have relatively little predictive value [2]. For example, the reliability handbook of the American military, MIL-Handbook-217, has not been updated since the mid-1990s due to the limited predictive value of the traditional Mean Time Between Failure (MTBF) approach that the handbook uses. The handbook is much too conservative and hence often unrealistic when it comes to failure prediction.

New, modern quality approaches such as Six Sigma [3] offer little in the way of a reduction of the design cycle time. Despite claims that the 'Design for Six Sigma' method leads to a substantial reduction in the development lead time, the method contains no real solutions for the urgent demand for accelerated reliability testing [4].

According to Keki Bhote [4], Multiple Environmental Over Stress Testing (MEOST) is a method that may well lead to robust and reliable complex systems. The MEOST method was developed in the 1960s and successfully applied by NASA in the development of the lunar module, a complex system that placed extraordinarily high demands on reliability.

The main benefits of the MEOST method are (a) that it requires very short development cycles that enable short time-to-market developments, and (b) that the design is very robust.

Critical subsystems

Electronic printed circuit boards are often critical subsystems in mechatronic systems. Failure in a printed circuit board leads to a standstill of the total system. The Netherlands Organisation for Applied Scientific Research (TNO) has worked with the Dutch suppliers association NEVAT EMS (Electronic Manufacturing Services) in a technology transfer project on the subject of the reliability of lead-free soldering [5] [6]; see Figure 1. In particular the relationship between certain choices in the design of the lead-free printed circuit board and the impact on the reliability of the soldered printed circuit board was studied. The lead-free design work was done on a practical printed circuit board design for the production of one of the NEVAT EMS companies.

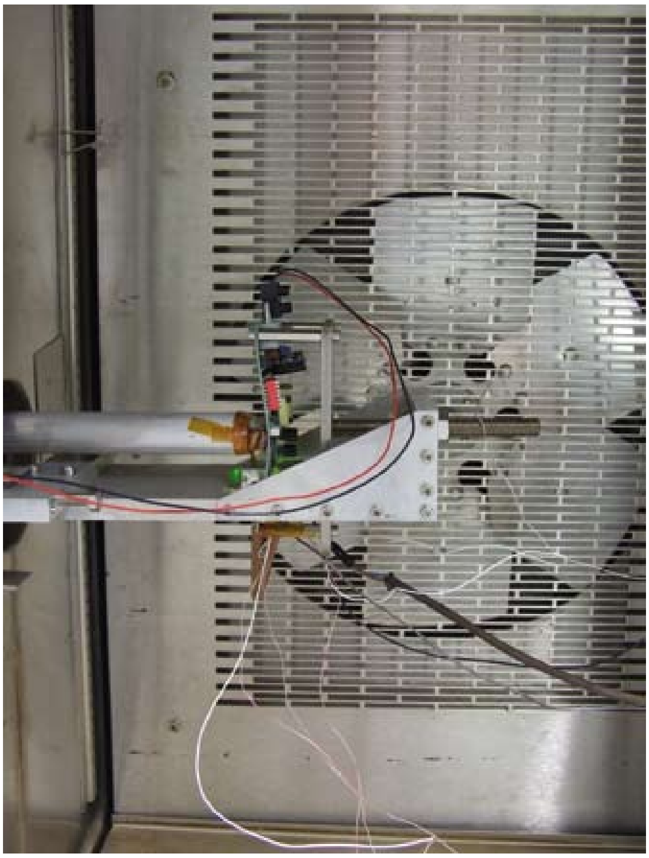

Figure 1. The experimental set-up developed by TNO to test printed circuit boards according to MEOST test plans. Simultaneous bending, heating and electrical bias are applied [6].

Failure modes

If we zoom in on electronic products, and especially on failure modes that are associated with lead-free soldering, we can identify numerous potential failure mechanisms; see Table 1 and Figure 2. These become manifest under specific stressing of a product. This is crucial for the understanding of accelerated testing. It is often very difficult to predict the user profile of specific individual users. Testing product ageing at elevated temperatures does not provide an insight into failure behaviour due to mechanical shock.

Table 1. Frequently encountered failure mechanisms in lead-free soldered electronics.

- Thermo-mechanical fatigue
- Mismatch between coefficients of thermal expansion
- Bulk solder brittleness
- Mechanical shock
- Vibration
- Low-cycle fatigue
- Electro-migration and electro-corrosion
- Warping
- Kirkendall voiding

During the transition towards lead-free soldering in the electronics industry, there have been numerous examples of companies incurring financial damage because of their ambitions to beat competitors. Well-known, in the context of lead-free soldering, are the reliability problems Microsoft encountered with the introduction of the Xbox, which led to an estimated write-off of 1.15 billion Euros in 2007 [5]. The Swiss watch company Swatch reported a loss of approximately 1 billion Euros as a result of ‘tin whiskers’ in lead-free soldered watches [7].

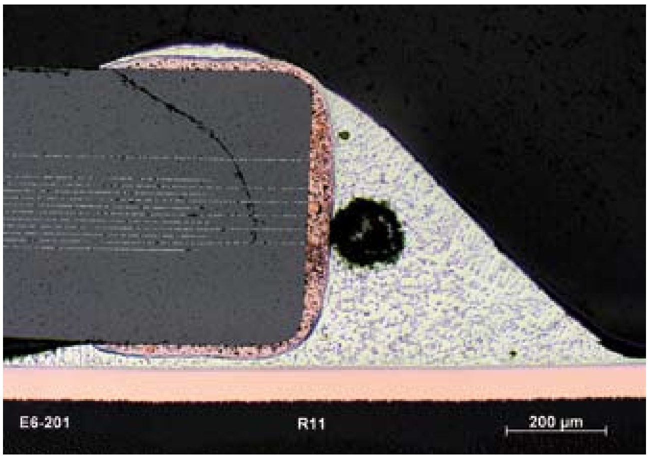

Figure 2. An electrical capacitor crack, the result of a thermal mismatch (mismatch between coefficients of thermal expansion) [5].

A thorough knowledge of material properties is required to design tests that make it possible to assess the reliability of a product. Many lead-free solder alloys are stiffer and less ductile than the traditional lead-tin solders. To be able to predict the expected useful life of a solder interconnect based on a cyclic thermal load, it is necessary to adjust the time that the interconnection is loaded at a higher temperature (i.e. dwell time) [8]. Some lead-free solders lose their ductility abruptly below a certain transition temperature, which can lead to brittle breakages at impact stresses below these temperatures [9]. Specialist knowledge of these material properties is needed to develop and design meaningful tests for lead-free soldered interconnects. This is even more the case for accelerated reliability tests.

Traditional methods

The electronics industry traditionally uses what are known as reliability handbooks for reliability prediction, one very well known one being the MIL-Handbook-217 [10], which was introduced in 1962 by the American military and used to estimate the failure rate (Failures In Time or FIT) or the Mean Time Between Failure (MTBF). This handbook was last revised (revision F) in 1994 and there have been no updates since then. The Handbook-217 is still used by many designers for estimating the reliability of an electronic design.

Arrhenius acceleration model

The most commonly used method of determining the acceleration factors in accelerated testing is based on a method developed as early as the 19th century by Svante Arrhenius [11] and used to determine the effect of increased temperature on chemical reaction rates. The Arrhenius method also can be used to predict the ageing behaviour of products. A quantitative prediction of acceleration factors can be made on the basis of measurements. In turn, these acceleration factors enable a quantitative prediction of the expected life of a specific product. Measurement data is plotted using what is known as an Arrhenius plot, in which the reciprocal absolute temperature in Kelvin is plotted against the logarithm of the reaction rate. In many cases, the plot leads to a straight line. According to the quality guru Joseph Juran, straight lines are very much appreciated by scientists and engineers.

Weibull Statistics

Waloddi Weibull formulated a statistical approach [12] that has become the standard in the field of reliability engineering. In the Weibull method, the cumulative defects are plotted on a double logarithmic scale against the logarithm of time. Again, this leads to straight lines. Depending on the statistical parameters of the Weibull distribution function, a product's life is classified in three phases:

- infant mortality, characterised by a decreasing failure rate;
- useful life phase, characterised by a constant failure rate;
- wear-out phase, characterised by an increasing failure rate.

These phases in a product life lead to the well-known bathtub curve, which graphically represents these three phases of the product life. Aspects such as reliability and expected life can be estimated using the Weibull analysis. With a knowledge of acceleration factors and specific failures, it is possible to predict reliability and expected life on the basis of accelerated testing.

HAST

As mentioned above, traditional reliability testing approaches are time-consuming and often do not correspond to the practical conditions in which the products are used. In the testing of electronic products, methods such as Highly Accelerated Stress Testing (HAST) are already being used. Here, combinations of stresses are applied to accelerate reliability testing. A disadvantage of the HAST method is that a relatively large test series is required to arrive at statistically significant conclusions.

MEOST

A method for testing reliability that differs fundamentally from existing methods for testing the reliability of products and systems is the Multiple Environment Over Stress Testing (MEOST) method developed by Dorian Shainin. This method is based on very small sample sizes and takes a subtle approach to the stressing of a product in that a well-designed combination of stresses is carefully applied. The

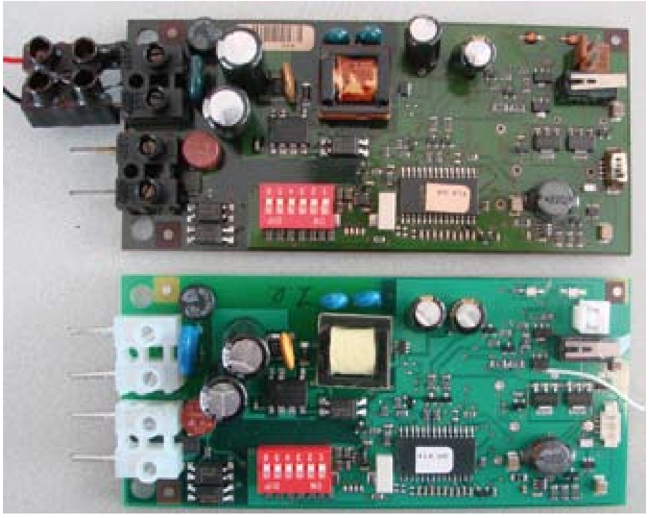

Figure 3. A printed circuit board after 0 hours (above) and after 1,800 hours (below) in the climate chamber at TNO.

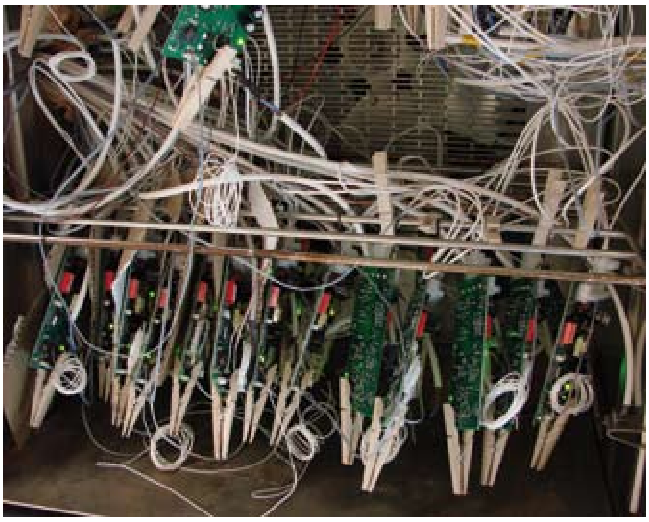

Figure 4. Printed circuit boards in the climate chamber at TNO. The clothes pegs are used for pressing a test switch.

aim is not to arrive at a sound statistical straight line but to develop a product that is robust and can withstand any stress or combination of stresses during its useful life.

The starting points that distinguish Multiple Over Stress Testing from the traditional reliability approach are:

- Failure of the product during testing is a success.
- Stresses are combined, where possible, to create interactions that lead to product failure.
- Stresses are applied preferably as far as possible above the design specifications.
- Stress levels are adjusted as rapidly as possible (steep ramp-up and ramp-down).
- Extremely small test series (three to five products in a test) suffice.

Because of the combination of stresses, an analysis of MEOST data does not lead to straight lines as we have seen in the Arrhenius and Weibull plots, which is probably why acceptance of the MEOST method has been slow.

Experimental work

In the context of the TNO and NEVAT EMS knowledge transfer project, TNO performed a series of classical MIL-STD-883 reliability tests to evaluate design changes in a lead-free soldered printed circuit board; see Figures 3 and 4. Parallel to these traditional experiments, a series of MEOST tests was performed on the same printed circuit boards to evaluate the different designs. The aim was to compare the traditional reliability test and the MEOST test.

One of the variables in the experiments was the glass transition temperature of the printed circuit board material. As lead-free soldering leads to higher soldering temperatures, the material quality of the printed circuit boards becomes more critical. It can also drive costs up.

The conclusion drawn from both experimental studies using traditional and MEOST tests was that the glass transition temperatures in the selected materials had no influence on the failure behaviour of the soldered printed circuit boards. This led to the choice of the most cost-effective material.

A MEOST test lasting ten hours enabled the same conclusion to be drawn as the traditional MIL-883 test where testing time was one thousand hours.

It is clear that successful use of the MEOST test demands a thorough knowledge of product design, material and production technology. Moreover, an understanding of lead-free soldering mentioned in the introduction is needed to design MEOST experiments and to come to meaningful interpretations.

Conclusion

The MEOST method appears to be a very strong tool for designing and developing a robust and reliable product. The MEOST method can be used to assess and improve the reliability of a technical system in very short cycles. More specifically, the MEOST method can be used to test the reliability and robustness of mechanical systems, mechatronic systems and complex software. In short, this method reduces design cycle time (a factor 100 is possible) and enables the design of more robust and more cost-effective systems.

Author's note

Jan Eite Bullema works at TNO Science and Industry in Eindhoven, the Netherlands, on the development and application of microsystems packaging. This article is based on work within the framework of a knowledge transfer project that TNO has conducted for NEVAT EMS, which investigated the reliability of an existing product.

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