Environmental Stress Screening (ESS)

Titu-Marius I. BĂJENESCU[1]

[1] Prof. Eng., Doctor Honoris Causa of Military Technical Academy of Romania and of Technical University of Republic of Moldova (Chișinău); Romanian Academy „Tudor Tănăsescu" Prize Laureat

Abstract

Reliability tests are often indispensable. The material properties, needed in design, can only sometimes be found in data sheets. If they are not available, they must be obtained by testing. Also, the manufacturers of electrical components must provide the reliability data for catalogues (e.g. the failure rate and the data characterizing the influence of some factors, such as temperature or vibrations). It is also impossible to predict with 100% accuracy the properties of a complex system consisting of many parts, whose properties vary more or less around the nominal values. In all these cases, tests are often necessary to verify whether the object has the demanded properties or if it conforms to the standards. Environmental stress screening is a powerful tool for electronic-systems designers to improve electronic-design reliability.

Keywords: Bathtub curve, bathtub failure rate, infant mortality, wear out, fewer customer returns

Received: 08 October 2019

To cite this paper:
BĂJENESCU I. T.-M., "Environmental Stress Screening (ESS)", in *Electrotehnica, Electronica, Automatica (EEA)*, 2019, vol. 67, no. 4, pp. 58-63, ISSN 1582-5175.

Historic

Stress screening is a final test performed on electronic production units before being shipped to the customer. To speed up the failure rate of weak units (so to detect early defects), certain stress factors (usually the environment) are applied during the test. This test is called *Environmental Stress Screening* (ESS); he should not damage acceptable units. Uninflated units will be delivered to customers.

Stress screening is a process in which vibrations, thermal and electrical stresses are applied for sufficiently long periods of time so that parts with design defects and / or insufficient lifetime can be removed. This screening process is known as *Environmental Stress Screening* (ESS) and is mainly applied to electronic, electrical and software assemblies. ESS tests may indicate to a manufacturer the problems that exist in the design before the item is produced in series.

Environmental Stress Screening (ESS)

Testing at the design stage is performed on all units to be delivered at loads exceeding those of the in-service package. ESS does not improve inherent reliability; it simply indicates the weaknesses of the design - through early testing - and ensures the removal of non-conforming assemblies before using it at the customer. Reliability is determined by designing rather than ESS testing.

ESS is a powerful tool available to designers of electronic systems. It is an essential step in the design of electronic systems (Figure 1) and helps engineers design and develop highly reliable products that will work in different environments.

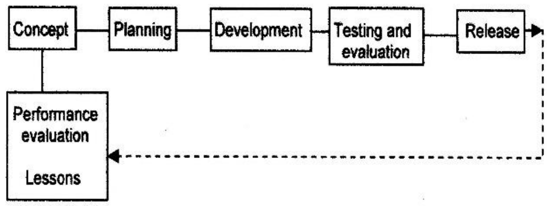

Figure 1. Stages of achieving reliability in the design process [10]

In particular, in systems whose dimensions are continually decreasing with increasing complexity, to meet the growing demand of the low-energy consumer of portable systems or high-quality gadgets. Maintaining high and operational reliability, providing fault-free operation in all types of environments, requires a careful design of the product, during which a number of factors have to be taken into account. ESS is a useful process that exposes the weaknesses of the product and allows for design corrections. Defects detected during business tests are less expensive than repairing any equipment failure at the customer.

A good application program for ESS has the following advantages:

- Less defects during the warranty period, which means greater product reliability at the customer, better customer image and lower repair costs;
- Help in planning spare parts;
- Better economy by detecting errors and

correcting them during the product development cycle;
- Help in making business decisions, such as warranty period for a product;
- Improved overall quality of the manufacturing process and product;
- Help in streamlining the processes of eliminating child mortality defects;
- Improving productivity; and
- Less product defaults to the customer.

The defects identified by ESS are divided into two categories: *(i)* labor errors; *(ii)* process defects.
- Select the stresses that probably stimulate the defect without damaging good specimens (eg cycling temperature, random vibrations, heat shock, high combustion temperatures).
- Select the appropriate level of intensity, duration, temperature range, vibrations, repetitions, etc.
- Use ESS at the lowest manufacturing level to find work and assembly faults when the ESS repeat is the least expensive.
- Select the appropriate request for the technology used; Efficiency of ESS stresses decreases when manufacturing processes are under control and the failure rate is too low to make ESS profitable.

Component screening level

If the screening is done at the component level, knowing the specific modes of failure and accelerating the stress that speeds up these modes can provide valuable information in selecting appropriate tests.

Reliability engineers have long recognized an inherent feature in many types of equipment that exhibited a downward failure rate during the early run. Intuitively, a high early failure rate that decreases over time until the levels finally stabilize can be explained by the inherent variability of any production process.

The "non-compliant" portion of identical track production is expected to fail earlier. Defects of these substandard portions are labelled "early defects." Experience shows that semiconductors prone to fail earlier will usually fail in the first 1000 hours of operation. After that, it is assumed that the failures stabilize, perhaps, for 25 years, before they begin to grow again as the components enter the wear period. These failures, called "infant mortality", can account for about 10 % in a new technology, and about 0.01 % in an experimental technology.

Selection of stress levels

Engineers must carefully select the levels to find as many defects as possible, with no false positive (non-defective) or false negative (missed defects) and minimal damage to the product. Choosing the correct levels is an iterative process. Low stress levels first apply. If he does not stimulate latent defects, he goes to a higher level. If the upper level damages the specimen, engineers may decide to lower the level or modify the design.

To select the appropriate level of random vibration screening, five methods are used. Table 1 presents the benefits and shortcomings of these five methods [2].

Table 1. Advantages and disadvantages of methods for determining the level of screening for random vibrations

Methods	Benefits	Disadvantages
Spectrally adapted response: Uses the defect trigger threshold to develop the input spectrum and detection level for detection.	The only method capable of developing spectral characteristics.	It needs spectral analysis equipment and qualified operators.
	The least susceptible to damage good hardware.	More expensive and time-consuming than the adapted general response method.
	The shortest exposure to vibration during development.	It may not be effective for the new technology.
Globally tailored response: Uses general internal response levels to develop screening levels.	Similar to the adapted, but less costly and complex spectral response method.	Can not adjust spectral characteristics.
Step-Stress Tests: Defines the level of screening between the operating level and the half of the design or tolerance limits.	Empirical method useful for existing and emerging simple technology.	A certain risk of overloading if the design boundaries are unknown.
	Defines the design boundaries of the object and makes the equipment stronger.	The design may be modified to make it stronger.
Erroneous replication tests: Increases the selection level until known defects are replicated.	Step-stress tests add-ons.	Hardware can not have repeatable failure modes; it may be difficult to select realistic hardware defects.
Inherited Screen: Deduces the level of selection from past experience.	Minimal development resources needed and therefore easier to obtain resources.	Transparent clutter can make screening inappropriate or harmful.

ESS can be used successfully if engineers carefully calculate the stress level to avoid degradation of the equipment for normal use [3]. However, the long-term effects of ESS may limit the life of a product. In this case, simulation can be used to find potential failures.

When using ESS?

ESS can be useful in the circuit of the card, the unit being tested, or the system level. Generally, the cost per failure is the lowest if ESS is used at the lowest possible level, but the detection efficiency is the best at the highest level, since interference errors as well as other types of errors can be detected. For each project it has to be decided which is the most profitable level [4].

You can achieve high operational reliability using industrial and commercial grade components by carefully designing and applying ESS techniques during the design and product development phase. Sometimes, product safety requirements that certain statutory requirements have to meet make SBS mandatory. In applications such as space electronics, automotive, defence, life-saving appliances and others where the failure of a system could have serious consequences, ESS provides the necessary controls to eliminate infant mortality failures to ensure trouble-free operation under harsh operating conditions. Products that have to adhere to international standards, such as MIL, IEC, and JSS, also have to meet different parameters testing parameters such as temperature, humidity, pressure, shock, vibration, dust, chemical atmosphere and solar radiation. In such situations, ESS tests are helpful during product design and development.

Since screening is expensive, planning is needed to get the most benefit, at the lowest cost and at the lowest risk, to get quality products [1].

Typical stress levels

There are a number of different methods to determine ESS profiles. Traditionally, these profiles were determined by guidelines published in military documents such as DOD-HDBK-344, Environmental Stress Screening of Electronic Equipment and/or guidelines published by the Institute of Environmental Sciences and Technology.

Table 2 summarizes typical ESS items used by the USAF Rome Laboratory Reliability.

Table 2. ESS Test Guideline Table

Type of request, parameters and conditions	*Printed circuit boards*	*System, equipment*
Thermal cycles		
Temperature range	-50°C...+75°C	-40°C...71°C
Time	until stabilization	until stabilization
Temp. change rate	min. 20°C/minute	min. 15°C/minute
Temperature cycles	20...40	12...20
Powered equipment	no	Yes, during heating Not during cooling
Monitorizare echipament	no	surveillance *go/no go*
Test after request	yes, at amb. temp.	yes, amb. temp.
Random vibrations		
Acceleration	6 Grms	6 Grms
Frequency	20...2000 Hz	20...2000 Hz
Stimulated axis (serial or concurrent)	3	3
Vibration duration	10 min/axis	10 min/axis
Serially stimulated axis	10 minute	10 minute
Power on/off	*off*	*on*, during heating *off*, during cooling
Equipment monitoring	no	monitoring *go/no go*

Strength of screening

In order to quantify and "refine" guidance on the starting point of screening, models have been developed to assess the impact of different levels of stress, their duration and defect detection approaches.

These models were developed by Air Force [5].

Check screening

One way to check a screening is to introduce known defects in hardware. Effective screening will find most of these flaws; inefficient screenings will not find them [1].

Cycling temperature

Cycling temperature is widely used to find defects in electronic equipment, including cards, assemblies and systems. It is used during development to find and eliminate design issues and problems during production to find and remove defective units due to process and workmanship. With cyclical temperature variation, the temperature gradually increases and then decreases gradually for a predetermined set of times. The rate of change in temperature depends on the specific heat of the unit or system under screening.

Random vibrations

Random vibrations are appropriate when the design is sufficiently mature (there are no major design problems unresolved and no major design changes are expected). Random vibration excites many modes at once and has proven to be more efficient than a single sine wave frequency. Using a device with 100 simulated faults, Northrop Grumman compared random vibration to fixed sinusoidal frequency and sinusoidal tests at different levels for different time periods. Random vibration was the most effective. She found defects that the other tests did not report. Removing these defects can prevent degradation of reliability.

Harmful vibrations may occur during the use, handling or transport of the product. To determine the susceptibility of a product to vibrations, it is subjected to random change of frequency (usually from 2 to 200 cycles per second). A critical component may resonate, may be tired and then defective. The fault is likely if the vibration interval that destroys the unit is the same as the vibration range of the truck, train or airplane carrying the specimen. If the intervals are the same, damping is needed. Examples of latent vibrations stimulated by random vibrations include welds or weak connections, inadvertently coupled or disconnected connectors and defective components.

The goal is to eliminate the sources of defects. Many companies use feedback from ESS results to improve product design and manufacturing. Impairment rates, scrap and reprocessing are lower.

Efficacy of screening

The effectiveness of a screening must be evaluated with factory and customer fault rates, adjusted accordingly. ESS results can be added to finding the root causes and corrective actions to prevent defects.

Corrective measures

After applying the corrective measures, the defects should drop to almost zero.

If the "close to zero" trend continues and the team believes that the sources of defects have been eliminated, it may decide to decrease or eliminate screening and perhaps focus on other areas with larger sources of defects.

As the traditional ESS takes several months to reproduce the existing environment at the customer, new screening machines are able to do so in just a few days, making significant cost savings. The main accelerated techniques are known as Life Highly Accelerated Life Testing (HALT) and High Accelerated Stress Screening (HASS).

Highly Accelerated Life Testing (HALT)

HALT emerged for the first time when manufacturers began to force prototypes or pre-production units to fail, in order to learn more about certain defects and design margins of the device. Test conditions for HALT were determined based on the element to be tested and its vulnerabilities in terms of its geometry of construction.

The term "acceleration" was not originally intended to be used in the context of terms of statistical reliability; it refers to the high stress level used (usually the temperature) to shorten the test time.

The environmental defects highlighted by HALT are represented in Figure 2.

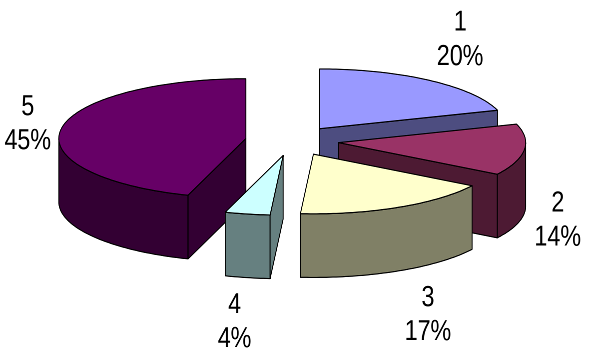

Figure 2. Failures, according to the environment, highlighted by HALT [7]. *(1)* Fast vibration thermal transitions with 6 degrees of freedom. *(2)* Extreme low temperature. *(3)* Extreme high temperature. *(4)* Fast thermal transactions. *(5)* Vibration with 6 degrees of freedom.

Highly Accelerated Stress Screening (HASS)

HASS is a stress-detection program that is performed to ensure that the final product will exceed environmental requirements. The design proved to be robust using a HALT test program. The environmental stress of a HASS program may exceed the design specifications of the product. A HASS program can only be used if a HALT program has been used during product development.

The HASS program will detect process issues that negatively affect the product's reliability. HASS is not intended to detect the problems of the ongoing process. Its purpose is to detect a change in a process that has previously been proven to be in order. HASS testing is not intended to compensate for a less productive production process.

Before HASS can be used successfully, acceptable quality procedures must be applied to the process. Trials must have the ability to measure at acceptable levels. Appropriate statistical process control SPCs should be applied. Modern test equipment allows for testing with combined media.

Problems localized by HASS tests will be corrected, and the unit is again tested. Any significant change may require a repeat of the HALT tests. Once HASS no longer detects production defects and/or defective components, the number of items tested may be reduced in accordance with the Highly Accelerated Stress Audit (HASA) criteria.

Accelerated Stress Test AST / Accelerated Life Test ALT began to be used in the US 1960s for space projects with much higher reliability requirements. Over time, technology has become increasingly advanced due to the rapidly changing market, old verification methods were too slow, and new test methods were required to meet changing market needs due to competition. So, a key issue for all national and international companies has been to find a quick and effective way to detect flaws during the design phase. This is why, HALT and HASS have become important.

Overloading testing (a process characterized by application of product stresses that exceed its design specifications) has become one of the main methods used by electronic equipment manufacturers to improve the reliability of their products in service.

Over the years, many companies have applied these techniques with phenomenal success. Some saw the rise in their market share from one of the last places in the ranking, the industry leader in a short time. Others have used the HALT, HASS and HASA techniques to increase the warranty for their products to three times the industry standard and to reduce their global warranty costs and dramatically increase the share market their products; while others have used them to win the coveted American national quality award.

HALT / HASS

Accelerated testing is an effective strategy to improve equipment reliability. The two most commonly used tests are Highly Accelerated Life Testing (HALT) and Accelerated Life Testing (ALT).

HALT is a technique that results after a few days due to the nature of the acceleration factors used; the equipment is subject to progressive stress with ever higher levels; includes temperature combined with vibrations. The key combining factor: the added stress will reveal more defects and justify the cost. HALT is an invaluable method for discovering design weaknesses and is used both at system level and at assembly level.

ALT is the tool that allows us to determine wear mechanisms or lifespan within the confidence limits. ALT is able to determine the reliability of a product over a short period of time (a few weeks or months) with accelerated environmental factors. ALT can find dominant fault mechanisms and is a valuable tool for detecting breakdowns due to wear. In addition, ALT methods can serve as criteria for qualification for the confidence limits of the prescribed lifetime. For ALT, the acceleration factor, duration of the test, number of samples, required confidence level, and test environment are known. The most common temperature acceleration factor is based on the Arrhenius model. One of the ALT's effective skill features is testing the performance of the tire at extreme environmental conditions.

To improve reliability design, use a closed-loop process (Figure 3).

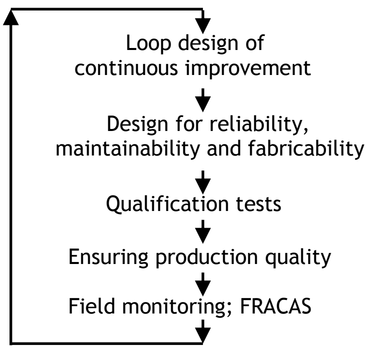

Figure 3. Reliability improvement process

Another approach to determining screening levels is to perform a Highly Accelerated Life Test (HALT) to determine the limits of operation and destruction (Figure 4).

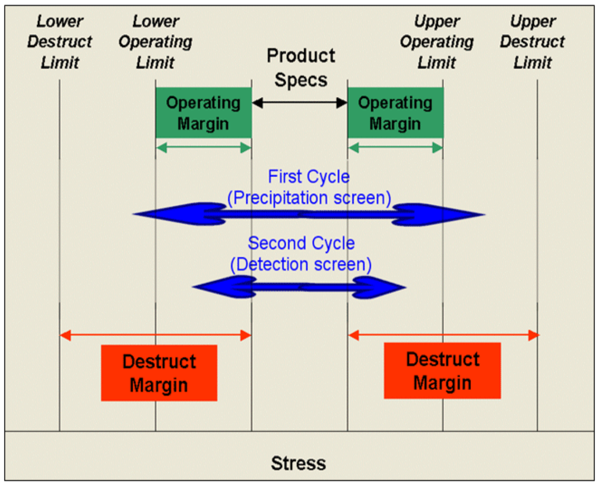

Figure 4. HALT stress thresholds

HALT is a process to evaluate a design to identify its weaknesses as well as to determine effective stress limits for Highly Accelerated Stress Screening (HASS). HALT evaluates the equipment in terms of exploitation and destruction limits by applying stresses. Typically, the test is performed on some of the first manufactured units to establish adequate limits for HASS monitoring, which will be performed on 100% of the manufactured product. HALT / HASS testing can be done at different assembly levels, from the circuit board to the system.

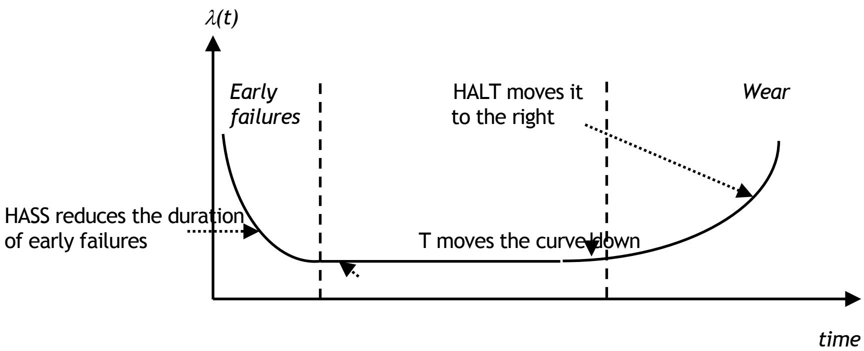

Figure 5. Influence of HALT and HASS on the bathtub curve [9]

Figure 5 illustrates the influences exerted by HALT and HASS on the bathtub curve.

Conclusion

ESS is the "custom" application adapted to electrical and environmental demands for parts, modules, units and electronic systems to identify and eliminate defective, abnormal or marginal parts as well as manufacturing defects.

Typically, ESS is made on 100 % of manufactured items. The objective of ESS is to accelerate early failures so that repair is carried out at the most cost-effective stage. Correcting defects in the manufacturer's factory is more cost-effective than repairing customer failures. ESS is a powerful tool for electronic system designers because it improves project reliability before serial production of the electronic product. The key issue for all companies was to find a quick and effective way to detect flaws during the design phase. This is why HALT and HASS have become important.

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Author' Biography

Titu I. BĂJENESCU was born in Câmpina (Romania) on April 2, 1933. He received his engineering training at the Polytechnic Institute Bucharest. He served for the first five years in the Romanian Army Research Institute, including tours on radio and telecom maintenance, and in the reliability, safety and maintainability office of the Ministry of Defence (main base ground facilities).

R&D *Experience*: design and manufacture of experimental equipments for Romanian Army Research Institute and for air defence system.

He joined Brown Boveri (today: Asea Brown Boveri) Baden (Switzerland) in 1969, as research and development engineer.

R&D *Experience*: design and manufacture of new industrial equipment for telecommunications. In 1974, he joined Hasler Limited (today: Ascom) Berne as Reliability Manager (recruitment by competitive examination).

Experience: Set up QRA and R&M teams. Developed policies, procedures and training. Managed QRA and R&M programmes. As QRA Manager monitoring and reporting on production quality and in-service reliability.

As Switzerland official, contributed to development of new ITU and IEC standards.

In 1981, he joined "Messtechnik und Optoelektronik" (Neuchâtel, Switzerland, and Haar, West Germany), a subsidiary of Messerschmitt-Bölkow-Blohm (MBB) Munich, as Quality and Reliability Manager (recruitment by competitive examination).

Experience: Product Assurance Manager of "intelligent cables". Managed applied research on reliability (electronic components, system analysis methods, test methods, etc.).

Since 1985, he has worked as an independent consultant and international expert on engineering management, telecommunications, reliability, quality and safety.

Mr. Băjenescu is the author of many technical books - published in English, French, German and Romanian.

He is emeritus university professor and has written many papers and contributions on modern telecommunications, and on quality and reliability engineering and management. He lectures as invited professor, visiting lecturer or speaker at European universities and other venues on these subjects.

Since 1991, he won many Awards and Distinctions, presented by the Romanian Academy, Romanian Society for Quality, Romanian Engineers Association, etc. for his contribution to reliability science and technology. Recently, he received the honorific titles of *Doctor Honoris Causa* from the *Romanian Military Academy* and from *Technical University of the Republic of Moldavia*. In 2013, he obtained, together with Prof. Dr. Marius Bâzu (head of reliability laboratory of Romanian Research Institute for Micro- and Nano-technologies – IMT*) the Romanian Academy "Tudor Tănăsescu" prize* for the book *Failure Analysis*, published by John Wiley & Sons.