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Improving Product Reliability through HALT and HASS Testing of Electronics and PCB's

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Abstract: HALT & HASS technology uses a combination of accelerated stresses to expose product flaws early in the design and manufacturing stages (often at board level), improving product reliability and customer confidence. HALT & HASS will be defined and compared to traditional compliance testing to a pre-written test standard. We will discuss why companies are using HALT & HASS and finding success. The basic steps of HALT & HASS testing will be covered along with some examples of types of defects that can be precipitated and detected during HALT testing.

HALT & HASS is used to uncover many of the weak links inherent to the design and fabrication process of a new product as well as during the production phase to find manufacturing defects that could cause product failures in the field. The types of HALT & HASS chambers available in the market along with the equipment capabilities will be reviewed along with how they used for detection of flaws in design, making the product more rugged and reliable. These capabilities are key to precipitation and detection of product defects.

Introduction: HALT (Highly Accelerated Life Tests) is a method aimed at discovering and then improving weak links in the product in the design phase. HASS (Highly Accelerated Stress Screens) is a means of finding and fixing process flaws during production. Both techniques use stresses far beyond the normal operating condition. The process uses discovery testing in which problems are found by testing to failure using accelerated stress conditions. HALT is a discovery test as opposed to a compliance test. The goal is to find problems, remove them and improve the product making it more robust.

HALT is an acronym for Highly Accelerated Life Tests that was coined Dr. Gregg Hobbs in 1988 after having used the term "Design Ruggedization" for 18 years. In these tests, every stimulus of potential value is used to find the weak links in the design and fabrication processes of a product during the design phase. These stimuli may include vibration, thermal cycling, burn-in, voltage, humidity, and whatever else will expose relevant weaknesses (including stresses that will not occur in the real world if they generate real world failure modes). The stresses are not meant to simulate the field environments at all but to find the weak links in the design and processes using only a few units and in a very short period of time. The stresses are stepped up to well beyond the expected field environment in order to obtain time compression in finding design weaknesses. HALT has, on many occasions, provided substantial (5 to 1000 times) MTBF gains. Even when used without production screening it has reduced the time to market substantially and also reduced the total development costs.

HASS is an acronym for Highly Accelerated Stress Screens. HASS uses accelerated stresses (beyond product specifications and as determined appropriate by earlier HALT testing) in order to detect product defects in manufacturing production screens. The accelerated stresses of the HASS program shorten the time to failure of defective units and therefore shorten the corrective action time and the number of units built with similar flaws. Many issues caused by process changes after HALT screening were previously seen only as early life failures in the field. With an appropriate HASS implementation, these defects can now be detected and corrected prior to shipment.

HASS is generally not recommended unless a comprehensive HALT has been performed, since without HALT, fundamental design limitations and flaws will restrict stress levels that can be applied in the HASS process. HASS can generate significant savings in screening costs as less equipment (shakers, chambers, monitoring systems, power and liquid nitrogen) is necessary due to time compression in the screening process. As with HALT, HASS is discovery testing as compared to compliance testing.

The HALT Process:
In HALT, every stimulus of potential value (temperature, all-axis vibration, humidity, UV, radiation, etc.) can be used under accelerated test conditions during the development phase of a product to find the weak links in the design and fabrication processes. Accelerated stresses in combination (e.g. high-temperature ramp rates and all-axis vibration levels together) are necessary to compress or minimize the time to failure. Once again this method is aimed at discovering and then improving weak links in a product during the design phase. This is a discovery test with the goal to find problems.

The chart below shows where design flaws were discovered during the HALT process and why all-axis vibration is important.*

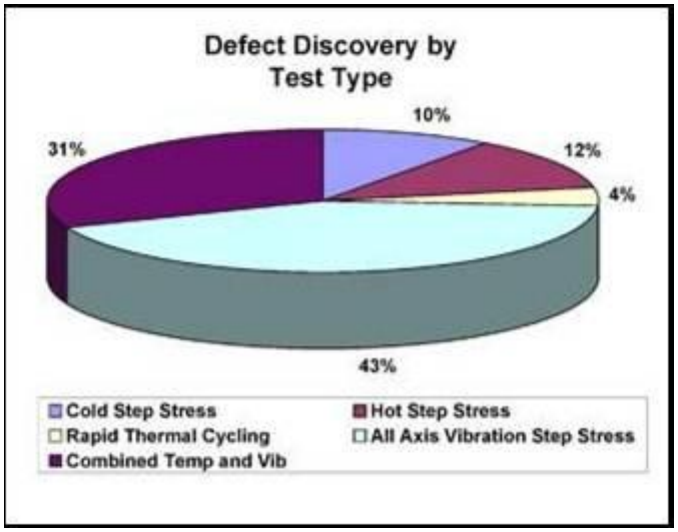

Figure 1. Defect by Test Type
* Chuck Laurenson, Parker Hannifin

Therefore, 74% of the flaws would have been missed without simultaneous, all axis vibration

By stressing the product beyond its design specification, operational and destruct limits can be determined, and decisions can be made on how to increase these margins. Each weak link provides an opportunity to improve the design or the processes, which will lead to reduced design time, increased reliability, and decreased costs. Used properly, HALT compresses this design cycle while providing a significantly more reliable and mature product at introduction. Studies have shown that a six-month advantage in product introduction can result in a lifetime profit increase of up to 50% for the market mover.[1]

Basis Steps in HALT/HASS Detection Process:

Precipitation means to change a defect which is latent or undetectable to one that is patent or detectable. A poor solder joint is such an example. When latent, it is probably not detectable electrically unless it is extremely poor. The process of precipitation will transpose the flaw to one that is detectable, that is, cracked. The stresses used for the transformation may be vibration combined with thermal cycling and perhaps electrical overstress. Precipitation is usually accomplished in HALT or in a precipitation screen.

Detection means to determine that a fault exists. After precipitation by whatever means, it may become patent, that is, detectable. Just because it is patent does not mean that it will actually be detected as it must first be put into a detectable state. Assuming that we actually put the fault into a detectable state and that the built-in test or external test setup can detect the fault, we can then proceed to the most difficult step, which is failure analysis.

Failure analysis means to determine why the failure occurred. In the case of the solder joint, we need to determine why the joint failed. If doing HALT, the failed joint could be due to a design flaw; that is, an extreme stress at the joint due to vibration or possibly due to a poor match of thermal expansion coefficients. When doing HASS, the design is assumed to be satisfactory (which may not be true if changes have occurred) and in that case, the solder joint was probably defective. In what manner it was defective and why it was defective needs to be determined in sufficient detail to perform the next step, which is corrective action.

Corrective action means to change the design or processes as appropriate so that the failure will not occur again. This step is absolutely essential for success. In fact, corrective action is the main purpose of performing HALT or HASS. One of the major mistakes happening in the industry is that manufacturers “do HALT” and discover weaknesses and then dismiss them as due to overstress conditions. It is true that the failures occurred sooner than they would in the field, due to the overstress conditions, but they would have eventually occurred in the field at lower stress levels.

Verification of corrective action needs to be accomplished to determine that the product is really fixed and that the flaw that caused the problem is no longer present. The fix could be ineffective or there could be other problems causing the anomaly that are not yet fixed. Additionally, another fault could be induced by operations on the product, and this necessitates a repeat of the conditions that prompted the fault to be evident. One method of testing a fix during the HALT stage is to perform HALT again and determine that the product is at least as robust as it was before and it should be somewhat better. If in the HASS stage, performing HASS again on the product is in order. If the flaw is correctly fixed, then the same failure should not occur again.

The last step of the six is to put the lesson learned into a **database** from which one can extract valuable knowledge whenever a similar event occurs again. Companies that practice correct HALT and utilize a well- kept database soon become very adept at designing and building very robust products with the commensurate high reliability. [1]

Comparing HALT and HASS chambers:

Figure 2. HALT/HASS Chamber

Figure 3. HALT Testing

There are many factors that need to be considered when evaluating a HALT chamber purchase. One of the first obvious criteria is to look at a size which will handle the size of your DUT. Other factors to consider are the high and low vibration limits of the chamber, and the characterization of the table (how well is the vibration distributed). A safety door interlock system should be in place to prevent the door from being open when liquid nitrogen is flowing into the chamber. It would also be useful to have multiple cable ports for any connections you need to make to your DUT, and front and rear doors on the larger size units. You will also want to check out the nitrogen and compressed air usage along with their sound levels.

With liquid nitrogen being the cooling media predominantly used in HALT testing, you need to consider how many tests you will be running per day, per month, to try to get a handle on the amount of Liquid nitrogen that will be required (you do not want to run out during the middle of a test.). You can then contact a local gas supplier to find out what is the most cost effective solution to choose. If you currently have a source of liquid nitrogen in your facility, you will need to find out where it is located and where you plan to locate your chamber. Running the vacuum jacketed connection lines from the source to the chamber is very expensive (estimates at approximately $200/running foot). It is also a good idea to put an oxygen sensor in your lab, in the event that too much nitrogen is escaping into the lab.

An ideal situation is to be able to run your DUT on a chamber before you make a purchase decision. Many chamber manufactures will have a chamber available for your use and I would suggest that you take them up on their offer. This will also give you an opportunity to determine what fixtures will be necessary. They can also guide you through the first steps in setting up your HALT test.

Using fixturing that does not transmit the stress to the product under test can be a problem because sufficient levels of stress never reach the product. Three examples are:

1. Using a vibration fixture that will not transmit the frequencies associated with critical modes of vibration of the product under test or isolates the mid-and high-ranges.
2. Using a thermal fixture that does not transmit the conditioned air to the product such that the product can be rapidly changed in temperature over a broad range.
3. Using electrical overstress and having some circuitry such as the lightning arrestor circuitry bleed off the high voltage before it gets to the internal circuits.

If the stress does not get to the product, then nothing has been accomplished. [2]

The basic steps of HALT

Determination of operational and destruct limits for temperature and vibration is an important part of HALT. Some companies do not test to destruction due to the high costs of test units (like aerospace products). Some engineers incorrectly think that HALT only consists of determining operational and destruct limits. However operation margins are important indicators of product robustness, and therefore reliability. The figure below shows the operating and destruct levels relative to the product specification.

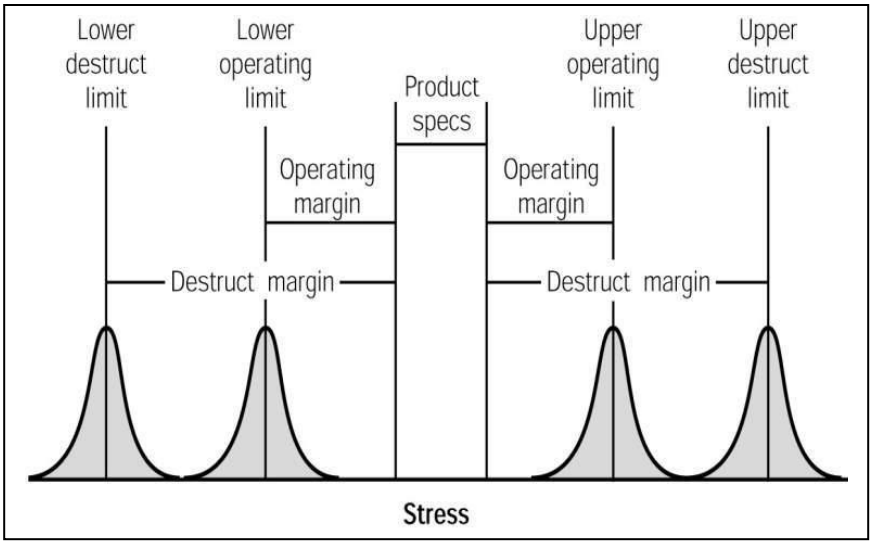

Figure 4. Operating & Destruct Limits

Usually the starting point for HALT testing is to begin with each stress being applied separately, in a step-like fashion and then in combination. IPC-9592A Requirements for Power Conversion Devices for the Computer and Telecommunication Industries makes the same recommendation. A typical progression of HALT would be:

- Cold Thermal Step Stress (see chart below from IPC-9592A)
- Hot Thermal Step Stress
- Rapid Thermal Shock Stress
- Vibration Step Stress
- Combined Thermal and Vibration Stress

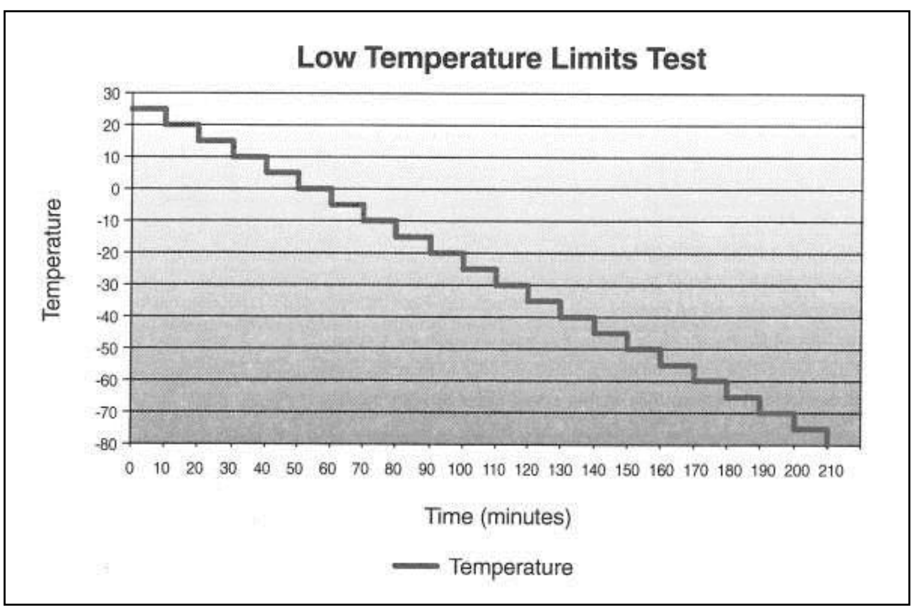

Figure 5. Low Temp Test Graph

You may also uncover some intermittent failures that the traditional HALT method may not uncover. Experience has shown that modulated six-axis vibration combined with slow temperature changes have exposed many flaws that could not be found any other way. Modern HALT and HASS equipment will easily do the modulation and it increases detection efficiency by at least a factor of ten or more in many cases. It has been repeatedly demonstrated that patent defects could not be found until the Modulated Excitation was done. Many times, 100% of the patent defects cannot be found without it. This is especially true for cracked plated through-hole solder joints and cracked surface mount solder joints. Very low vibration levels are important if not essential**.**[2]

Since HALT and HASS may identify failure modes using “unrepresentative” stress conditions, it is easy for engineers to ignore important product improvement opportunities. Corrective action should also be verified, which may require a re-HALT to verify that a problem has indeed been solved (and that new problems were not introduced).[3]

Summary: Every weakness found in HALT offers an opportunity for improvement. Large margins translate into high reliability and that can result in improved profit margins. Today, HALT is required on an ever-increasing number of commercial and military programs. Many of the leading companies are using HALT and HASS techniques successfully; however, most of the leaders are being quiet about it because of the phenomenal improvements in reliability and vast cost savings attained. The basic philosophy is, "find the weak spots however we can and then make them more robust."

Correct application of the techniques is essential to success and there are many incorrect sources of information on the techniques today. Consistently, completely and correctly used HALT and HASS **always** works to the benefit of the manufacturer and to the benefit of the end user. A typical return on investment for the techniques was 1,000:1 some 20 years ago and, with the improved techniques and much better equipment available today, we can do much better. This is why the real leaders do not publish. [1]

[1]G.K. Hobbs, Accelerated Reliability Engineering: HALT & HASS, Hobbs Engineering, 2005
[2]G.K. Hobbs, “Pitfalls to avoid in HALT and HASS”, 2007
[3]A. Barnard, “The Ten things You Should Know about HALT & HASS, 2012 IEEE
-IPC-9592A Requirements for Power Conversion Devices for the Computer and Telecommunications Industries, 2010