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HALT AND HASS
THE ACCEPTED QUALITY AND RELIABILITY PARADIGM

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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 stress levels. These methods are **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, that is, we want to find problems and we do everything necessary in order to do so and then to remove the weaknesses found. The old paradigm of qualification or design verification testing was one of trying to pass. In a compliance test, every attempt is made not to discover problems, so that the design phase can end and the production phase can begin. Any failure that occurred was usually declared to be unusual or due to overstress and therefore not relevant. This latter approach is called success or compliance testing by the author and is still in use today. As you can see, the two paradigms are diametrically opposed. The HALT and HASS techniques represent a paradigm shift of major proportions. Companies using these evolving techniques correctly have obtained outstanding reliability, yet most of them do not publish their results given the significant competitive advantage that these techniques provide to them.

HALT is an acronym for Highly Accelerated Life Tests that was coined by me 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[1] 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. Hence, these techniques are called Time Compression™. 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 that was also coined by me in 1988 after using the term "Enhanced ESS" for some years. These screens use the highest possible stresses (frequently well beyond the "QUAL" level) in order to attain time compression in the screens. Note that many stimuli exhibit an exponential acceleration of fatigue damage accumulation with stress level[1], and so a drastic reduction in screening equipment and manpower is obtained by the use of higher stress levels. The screens must be, and are proven to be, of acceptable fatigue damage accumulation or lifetime degradation using Safety of HASS techniques[1]. HASS is generally not possible unless a comprehensive HALT has been performed as, without HALT, fundamental design limitations will restrict the acceptable stress levels to a great degree and will prevent the large accelerations that are possible with a very robust product. It has been proven that HASS generates extremely large savings in screening costs because much less equipment (shakers, chambers, monitoring systems, power and liquid nitrogen) is necessary due to time compression in the screens. HASS, too, is discovery testing as compared to success testing.

THE PHENOMENA INVOLVED

Many phenomena are involved when screening occurs. Among these are electro migration, chemical reactions and mechanical fatigue damage. Each of these has a different mathematical description and responds to different stimuli. Only two are mentioned herein. See our web site: **www.hobbsengr.com** for our Physics of Failure seminar for an extensive coverage of the subject.

Chemical reactions and some migration effects proceed to completion according to the Arrhenius model or some derivative of it. It is noted that many misguided screening attempts assume that the Arrhenius Equation **always** applies; that is, that higher temperatures lead to higher failure rates, but this is just simply not an accurate assumption. MIL-HDBK 217 is based on these concepts and therefore is quite invalid for predicting the field reliability of the products built today. MIL-HDBK 217 is even less valid and completely misleading when used as a reverse engineering tool to improve reliability. It will lead one to make changes such as cooling that may well reduce reliability due to the introduction of new failure modes in the cooling system or due to the cooling system; e.g., vibration induced when cooling fans load up with lint and generate vibration. In an actual case in which the author was involved and found a fix, application of MIL-HDBK-217 thinking called for more cooling fans which led to more vibration which led to more failures which led to more cooling fans and so on. The fix suggested by the author was to go back to one fan and clean it occasionally. The fix worked even though it was completely counter to the MIL-HDBK-217 thinking!

The fatigue damage done by mechanical stresses due to temperature, rate of change of temperature, vibration, or some combination of them can be modeled in many ways, the least complex of which is the Miner's Criterion. This criterion states that fatigue damage is cumulative, is non-reversible, and accumulates on a simple linear basis which, in words, is "the damage accumulated under each stress condition taken as a percentage of the total life expended can be summed over all stress conditions. When the sum reaches unity, the end of fatigue life has been reached and failure occurs". The data for percentage of life expended is obtained from S-N (number of cycles to fail versus stress level) diagrams for the material in question. A general relationship based on the Miner's Criteria follows:

$D \approx n\sigma^{\beta}$, where:
D is the fatigue damage accumulated,
n is the number of cycles of stress,
σ is the mechanical stress (in pounds per square inch, for example), and
ß is an exponent derived from the S-N diagram for the material. ß ranges from 8 up to 12 for most materials in high cycle fatigue (low stress and many cycles to failure).

The flaws (design or process) that will cause field failures usually, if not always, cause a much higher than normal stress to exist at the flaw than at a position without the flaw. For illustrative purposes, let us assume that there is a stress that is twice as high at a particular spot that is flawed due to an inclusion or void in a solder joint. According to the equation above, the fatigue damage would accumulate about 1,000 times as fast at the position with the flaw as it would at a non-flawed position. This means that we can fatigue and break the flawed area and still leave 99.9% of the life in the non-flawed areas. Our goal in environmental stress screening is to do fatigue damage to the point of failure at the flawed areas of the structure. With the proper application of HALT, the design will have several, if not many, of the required lifetimes built into it and so an inconsequential portion of of the life would be removed in a HASS. This would, of course, be verified in Safety of HASS. Note that the relevant question is "How much life is left after HASS?" not "How much did we remove in HASS?" Also note that **all screens remove life from the product.** This is a fundamental fact that is frequently not understood by those unfamiliar with the correct underlying concepts of screening and damage.

EQUIPMENT REQUIRED

The application of the techniques mentioned generally is very much enhanced by, if not impossible without, the use of environmental equipment of the latest design; such as, all axis broadband random vibration systems capable of 150 GRMS or more and very high rate thermal chambers (120°C/min. or more **product** rate of change). Both of these techniques, HALT and HASS, have been in use by me and by most of my consulting clients for four decades, using the early all axis shakers for about 10 years and the more modern and more effective systems in later years. The pneumatically driven shakers create fatigue damage much more rapidly at the same GRMS level than do "classical" shakers which usually are set to clip acceleration peaks at 3 sigma (standard deviations from the mean) and therefore prevent cost effective screening. The repeated impact shakers available today have a peak to RMS ratio of about 10 (for the standard vibrators, higher for the high performance vibrators) whereas the classical electrodynamic shakers have a ratio of about 3 (when set to clip at 3 sigma so as to pass the test).

We are trying to do fatigue damage in a screen; and the more rapidly we do it, the sooner we can stop and the less equipment and consumables we need to do the job. It is not unusual to reduce equipment costs by orders of magnitude by using the correct stresses and accelerated techniques combined with the best equipment. This comment applies to all environmental stimulation and not just to vibration. An example given in my seminar shows a decrease in cost from $22 million to $50 thousand on thermal/vibration chambers alone (not counting power requirements, monitoring equipment and personnel) by simply increasing the rate of change of temperature from 5°C/min to 40°C/min! Another example shows that increasing the RMS vibration level by a factor of 2 times would decrease the vibration system cost from $100 million to only $100 thousand for the same throughput of product. The use of an all axis shaker would further reduce the cost ratio. With these examples, it becomes clear that HALT and HASS, when combined with modern stressing equipment, provide quantum leaps in cost effectiveness, which is precisely why most of the leaders in HALT and HASS techniques are not publishing! Watch out for the misuse of the names HALT and HASS as they abound in significant numbers! In some cases, the methods used are less than worthless, that is, they cause the field reliability to decrease and cost money as well!

Some typical results of these screening techniques applied to product design and manufacturing are as follows:

1. An electro-mechanical product's MTBF was increased approximately 1000 times when HALT was applied. A total of 340 design and process problems were identified in the several HALTs that were run, and all of these identified problems were removed from the product before production began, resulting in an **initial production system** MTBF of 55 years on a product that wore out in 5 years! This means that most products never had even one failure before wear out. This happened in 1983.

2. **HALT** found, using only four units in just a few weeks, 97% of the problems which were later found in an extended life test lasting 16 weeks and involving 12 units run 24 hours per day under normal conditions. The one problem not found in HALT was missed due to a

technician reapplying grease to a lead screw every evening without my knowledge! No corrections were made to the product until after the standard life tests as the designers refused to believe that failures caused by HALT were relevant until these same failures were found under normal operational conditions and only after an extended period. This reluctance to address identified problems because they were found by "over spec" stresses is a typical tendency of those unfamiliar with the modern methods, and why a paradigm change through education is necessary for the methods to be effectively applied.

3. In 1991, **HALT**, in a three hour demonstration associated with a seminar, detected and allowed solutions to three real design problems in three different pieces of equipment which had been fielded and also tested for 3-5 years and which had had many field failures, two mission critical (safety of flight, that is “hull loss” in airplane talk) and the other one disabling (grounding the aircraft, forcing a landing or resulting in hull loss). This represents one major problem found per hour! The manufacturer had not been able to duplicate the field failures, although extensive classical testing had been done for several years, and therefore could not understand the failure mode and conceive the corresponding fix. All three failure modes were found "over spec", two in temperature slightly beyond spec and one in six axis vibration in ten minutes at four times the "spec" GRMS! The total HALT time was only three hours. The fix was easy once the failure mode and mechanism were understood.

4. In 1993, Storage Technology Corporation reported “savings of hundreds of millions of dollars” in the first 2½ years of HALT and HASS. This was without the benefit of Precipitation and Detection Screens and before Modulated Excitation was introduced. These advanced techniques have added several orders of magnitude to the effectiveness of HALT and HASS.

5. A large farm equipment manufacturer put a new product into their normal 125 hour verification tests. About 75% of the way to completion, a failure occurred. A fix was implemented and the test started over. After about 75% of the test, another failure occurred. A second fix was implemented and the test again started over. Again, after about 75% of the test, a third failure occurred. At about this time, the company was introduced to the HALT and HASS techniques. They then took an original model of the equipment, without fixes, and ran HALT on it. Within hours, all of the weaknesses plus one additional one that had been discovered in days of DVT were found. After fixes were in place for the four weaknesses, the DVT ran to completion (and was repeated) without any failures. HALT would have prevented the long DVTs and saved huge amounts of money if it had been done during the design phases.

6. Thermo King, a manufacturer of air conditioning for trucks carrying perishables, compared a program with HALT to one without. The program without HALT took twice as long to enter production, had many more field failures and cost approximately twice as much in terms of engineering development and field failures. This paper is available upon request from Hobbs Engineering.

PRECIPITATION AND DETECTION SCREENS

Correctly done stress screening is a closed loop six step process consisting of at least: Precipitation, Detection, Failure Analysis, Corrective Action, Corrective Action Verification and Database Maintenance.

Precipitation here means changing some flaw in the product from latent (undeveloped or dormant and usually undetectable) to patent (evident or detectable). An example would be to break a nicked lead on a component or to fracture a defective bond or solder joint.

Detection here means to observe in some manner that an abnormality exists, either electrically, visually or by any other means. In the cases illustrated above, we could visually or electrically detect that a lead had broken or a bond or joint had broken. An abnormality may be intermittent in nature and may only be observable under particular conditions such as low temperature and/or low-level impact vibration. **Proven** high coverage in the test system is mandatory.

Failure Analysis here means to determine the origin or root cause of the flaw. In the illustrations above, we would determine where in the production process and why the lead had been nicked, why the bond had been improperly done or why the solder joint had not been properly done.

Corrective Action here means to implement a change intended to eliminate the source of the flaw in future production. The nicked lead might be prevented by using a correct forming die, the bond might be corrected by using a different pressure or perhaps better cleaning and the solder joint might be corrected by using a different solder or a different temperature.

Corrective Action Verification means to verify that the corrective action taken did indeed solve the problem. Verification is done by repeating the conditions that caused the problem to be exposed before as well as any other appropriate conditions or tests and verifying that the flaw no longer is present.

Database Maintenance means to collect all of the data from the HALTs in terms of what the weaknesses were and what the corrections were. This last step is extremely important. Without it, the same mistakes will continue to occur over the years. With the knowledge gained by several HALTs, a company can design products that sail right through HALT with no relevant failures, that is, with no weaknesses that would cause field failures or cause a more expensive HASS process. The later point is very important and frequently missed. More ruggedization can sometimes actually decrease production costs by allowing more time compression in the screens.

Each of these steps in conjunction with the others is necessary for a comprehensive screening program. Any less than all six will not suffice to provide a truly successful screening program with the entire attendant benefits that all six rigorously done would provide. Specifically, just breaking and then fixing the bad ones, while maybe being better than doing nothing, is just the first step in a comprehensive screening program. Unfortunately, many efforts at screening stop here and therefore attain only small gains in quality, **but entail the majority of the costs.** It must be borne in mind that screening is quite expensive; and while very cost effective if done correctly, the costs are mostly there even if done incorrectly. In all cases, the obsolete techniques of using single axis vibration instead of all axis vibration and using slow thermal cycling with many cycles required instead of very high rate with only a few cycles required will be much more expensive than the more effective modern approaches. Safety of Screen must be correctly accomplished or early field wear out failures may be induced by the screens.

There is a great difference between precipitation and detection screens, yet almost nothing is found in the literature regarding the difference.[1]

PRECIPITATION SCREENS

A precipitation screen is intended to convert a relevant defect from latent to patent. Precipitation screens tend to be more stressful than detection screens. An example of a precipitation screen would be high level all axis vibration. This stress accumulates fatigue damage extremely rapidly, particularly in areas at a relevant flaw, where stress concentrations usually exist. High rate, broad range thermal cycling, which is intended to create low cycle fatigue in the most highly stressed areas, which, fortunately, are usually found (if the design is proper) at a flaw and finally is combined. And finally, we combine power on-off switching, which is intended to generate electro migration at areas of very high current density, usually at a flaw. In using HASS correctly, one uses the highest possible stresses that will leave non-defective hardware with a comfortable margin of fatigue life above that fatigue damage which would be done by remaining screens and the shipping and in use environments. This approach demands the application of HALT techniques and design ruggedization in order to be able to rapidly and effectively precipitate flaws. Without using these techniques, the application of HASS is usually not possible due to weaknesses that will not allow the high stresses which would therefore reduce costs.

Precipitation screens may well be run at above an upper design operating limit (or below a lower design operating limit) where the system cannot perform normally and therefore cannot be tested during stimulation. In this case, more than 90% of the defects could be expected to be missed when tested under quiescent conditions; i.e., without any stimulation at all. This is where the detection screen comes in and (where classical ESS fails).

DETECTION SCREENS

Detection screens are usually less stressful than precipitation screens and are aimed at making the patent defects detectable. It has been found that many patent defects are not observable under full screening levels of excitation even when the screen is within the operational limits of the equipment. What is required is **Modulated Excitation**™[1], which subjects the article under test to a search pattern in temperature and all axis vibration looking for the conditions under which the product will exhibit intermittents. Modulated Excitation and how to design, prove and tune screens is covered in the HALT & HASS seminar. Screen Optimization results in a minimum cost screen regimen that is safe and effective.

For example, it has been found on several products that plated through-hole solder joint cracks could only be detected by a Modulated Excitation. In an experiment utilizing 13 samples, all 13 exhibited intermittents at some (all different) combination of stresses but at no others. This implies that no defects at all would have been found if Modulated Excitation were not used.

Detection screens should be used on equipment returned from the field as defective, as we **must** assume that a patent defect is present or the equipment would not have been returned. It is noted in passing that non-defectives are frequently returned from the field for various reasons caused usually by the press of time to "get it running ASAP!" Field repair people are inclined to replace whole sets of boards or boxes, when maybe only one of the set truly has a problem. A full blown precipitation screen may not be necessary on field returns as the patent defect(s) present may be exposed by a much more gentle detection screen. If the detection screens do not suffice, then a precipitation screen followed by a detection screen could be in order.

In the case of field returns, it may be prudent to **simulate** the field conditions under which the failure occurred if these could be ascertained. These conditions might include temperature, vibration, voltage, frequency, humidity and any other relevant conditions. The military, airlines, auto manufacturers and others, too, would be well advised to follow this course of action as No Defects Found account for about 50% of field returns in these industries. Stimulation is not necessarily called for in this case, as simulation and/or detection screens are probably the more effective approach on field returns. See reference 2 for elimination of the no defects found problem.

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. It is repeatedly demonstrated that almost all defects observed in Modulated Excitation[TM,1] are not observable when the stimuli are changed or removed entirely. Several cases have been observed where companies tried to use the methods with incomplete or incorrect training and the results were that essentially all of their mission critical hardware failed very early in field service due to damage done during screens or due to major design defects missed by an improperly performed HALT. Consistently, completely and correctly used HALT and HASS **always** work 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 paper is a synopsis of the methods taught in the seminar **HALT & HASS + Workshop** and it is intended to be an introduction to the concepts and to allow one to determine if the seminar or the book, ***HALT and HASS, Accelerated Reliability Engineering***, would be useful.

References:

1. ***HALT and HASS, Accelerated Reliability Engineering***, available from: Hobbs Engineering Corporation, 4300 W 100th Avenue, Westminster, CO 80031-2481, Phone: 303-465-5988, e-mail: learn@hobbsengr.com. web: www.hobbsengr.com

2. **"Elimination of No Defects Found"** is a short paper available through Hobbs Engineering Corporation.