TECHNICAL BRIEF

ACCELERATED TESTS

Descriptions and Applications

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Foreword

A primary goal of the ASN(RD&A) Strategic Plan is to reduce cost and cycle time for delivering equipment and services. One key objective of this goal is to acquire, interpret and share technical information and provide expert consultation to continuously improve acquisition practices. To implement this objective, the ASN (RD&A) Acquisition and Business Management Directorate will periodically issue technical briefs.

The subject of this technical brief is "Accelerated Tests," a topic selected because it is viewed by many as a primary method for saving test time and costs. However, misunderstandings may exist about accelerated testing methods and equipment usage, which could result in increased product development costs.

This technical brief is a joint effort between senior technical experts within the Navy and industry. The Navy would like to recognize the contributions of the following individuals and organizations to this technical brief: Hank Caruso, G's and Degrees; Wayne Tustin, Equipment Reliability Institute; Paul Myer, Boeing TacAir St. Louis; Roger Abbott/Morris Milam, Raytheon Missile Systems, Boeing Seattle; and the Naval Warfare Assessment Station (QA 22).

I solicit your input for technical issues that you, the user, would like to see addressed in future technical briefs. You can submit your comments on the ABM homepage at www.abm.rda.hq.navy.mil

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Table of Contents

INTRODUCTION

The increasing emphasis by the Department of Defense (DoD) on reducing costs by adopting commercial business practices has led to growing interest in the use of accelerated test methods. Accelerated testing is being used by industry to get products to market sooner, improve product reliability and performance, reduce warranty costs and increase customer satisfaction. These test methods, quite different from development, qualification, and production testing, are becoming recognized as powerful tools and as such require careful attention to their understanding and use.

PURPOSE

The purpose of this Technical Brief is to provide:

- A basic description of accelerated test methods and differences between these methods.
- A comparison of strengths and weaknesses associated with each method.
- Information on test equipment usage and associated costs.
- Selected lessons learned expressed as Watch-Out-Fors.

ACCELERATED TEST METHODS

Accelerated testing is an approach used to obtain more information during a given test time than normally would be possible. Tests are performed using stresses beyond normal life cycle or usage conditions. Accelerated tests are performed primarily to (1) identify or confirm marginal design or manufacturing areas or (2) estimate product life. Accelerated testing is not a substitute for a disciplined, up-front systems engineering process nor does it replace a sound design approach using disciplined engineering analyses or compensate for a poor design. Prior to initiating accelerated testing, weak links should be investigated and potential failure modes eliminated. In addition to a disciplined design engineering process, field failure data for similar hardware should be reviewed and appropriate design improvements made as part of the design process. Table 1 describes these tests and their corresponding strengths and weaknesses.

Table 1. Accelerated Test Methods - Strengths and Weaknesses

Description	Strengths	Weaknesses
Accelerated Life Testing is the means by which normal life can be determined through the use of commonly accepted accelerated test models. The primary focus is on estimating the life of an item under normal operating conditions, based on data obtained under conditions or stresses beyond *(continued on next page)*	• Identification of potentially detrimental product characteristics that are least understood. • Reduction in total engineering test times and costs. • Rapid design and manufacturing process maturation.	• Will not provide documented evidence to prove that the product meets performance specifications. • Test environments are not directly related to mission/life cycle profiles and may become controversial. • Decision to implement

Description	Strengths	Weaknesses
normal life cycle or usage levels.		corrective action for failures caused by the highest stress levels sometimes requires subjective engineering judgement. • It is very difficult to properly model the acceleration for complex assemblies and equipment and hence to quantitatively predict the item life under normal usage conditions.
Step Stress Test units are subjected to a given level of stress for a preset period of time, then subjected to a higher level of stress for a subsequent period of time. The process continues at ever-increasing levels of stress until either all units fail, or the time period at the maximum stress level ends.	• Step-stress testing, which involves short term failure mechanisms, can identify load/stress limit conditions that determine basic design margins. • Causes failures to occur earlier for analysis.	• Step-stress test results cannot be extrapolated to long-term fatigue life. • It is very difficult to properly model the acceleration for complex assemblies and equipment and hence to quantitatively predict unit life under normal usage conditions. • Time dependent failure modes may not be exposed.
Highly Accelerated Life Test (HALT) is a term coined by Hobbs Engineering. It is a modified form of step stress testing used during development. *(continued on next page)*	• Typically used to identify design weaknesses and manufacturing process problems. • Increases the design strength margins.	• Will not predict quantitative life or reliability of the product. • It is very difficult to properly model the acceleration for complex assemblies and equipment and hence to quantitatively predict the item life under normal usage conditions. • Time dependent failure modes may not be exposed.

Description	Strengths	Weaknesses
Accelerated Stress Screening, also known as Environmental Stress Screening (ESS). It is a process to precipitate latent, intermittent, or incipient defects or flaws introduced during the manufacturing process to hard failures. The stresses may be applied in combination or in sequence on an accelerated basis but within product design limits. For a further description of the ESS process, please refer to DoD Tri-Service Technical Brief 002-93-08 (July 1993), which is available online in the Defense Acquisition Deskbook at www.deskbook.osd.mil or Institute of Environmental Sciences and Technology publication IEST-PR-PR001.1, "*Management and Technical Guidelines for the ESS Process,*" 1999.	• Reduces the possibility of manufacturing flaws being introduced into the use environment. • Through corrective action, improves yield rates and the maturity of the manufacturing process.	• Possibility of reducing useful product life if over-stressed. • Difficult to optimize the effectiveness of the screen.
Highly Accelerated Stress Screening (HASS) is a term coined by Hobbs Engineering and is a form of environmental stress screening. In most cases, it requires the performance of HALT to establish HASS limits.	• See Accelerated Stress Screening.	• See Accelerated Stress Screening. • Engineering subjectivity in establishing limits makes it difficult to optimize the effectiveness of the screen. • Possibility of reducing useful product life if overstressed.

CHOOSING ACCELERATED TEST STRESSES

The basic concept of step stress testing and accelerated stress screening can be implemented using many different stresses and stress profiles. However, the stresses most often used are thermal extremes, rapid thermal rates of change, vibration and the combination of thermal and vibration. Other stresses, such as voltage margining, frequency margining, power supply loading, power cycling, and product unique stresses (e.g., clock frequency) can also be applied, resulting in additional failure modes being exposed. The stresses are specifically designed to quickly bring out failure modes. This affects the choice of test chamber used to apply the stresses as well as the type of vibration fixturing used and the routing of the airflow through the product. Given that extreme stresses are to be applied in order to quickly bring out failure modes, the chamber must be capable of causing the unit being tested to rapidly reach both hot and cold thermal extremes, execute very fast thermal ramps and provide high vibration energy.

Step stress testing is most effective when performed at the lowest level possible, usually at the part or circuit card assembly levels, where environments can be closely monitored and the effects understood. This approach usually begins with the lowest stress levels and continues to the highest stress levels. The step stress process continues, for all of the stimuli, until either the units fail, or the time period at the maximum required stress level ends. To provide adequate design margins and to compensate for variability in the margins of fielded products, stress levels are selected to eventually exceed the environmental and operating stresses required by performance specifications.

The terms upper and lower operating limits are often used to define these margins. The operating limit is usually the level of applied stimuli at which the product ceases to function properly. When the stimuli is reduced below this operating limit, the product functions within the specified performance parameters indicating that the unit experienced an intermittent or "soft" failure. Some operating limits are determined by the known capability of a piece-part or assembly as specified by the manufacturer. In some cases, the operating limit may be difficult to determine or evaluate because of specific design features of a product, such as shock isolators, that would shift the application of vibration stimuli to other components of the product. The step stress process continues, for all of the stimuli, until the upper and lower operating limits are found or at least understood. Understood means that although the limits may not be precisely determined, they are verified to be well beyond the limits which may be used in future accelerated stress screening and beyond the worst case field environments. Throughout the process, continuous evaluation is performed to determine how to make the unit able to withstand the increasing stresses. After design fixes for identified problems have been implemented, a second series of step stresses are run to verify the fixes, assure that the fixes themselves have not introduced new problems and look for additional problems which may have been missed. To assure adequate design margins, operating limits are required to be higher by some percentage than the specified product environmental performance limits (values of 20% to 50% have been observed).

HALT testing uses the additional term destruct limits. Destruct limits, as the name implies, are those where the product experiences a "hard" or catastrophic failure such that it is essentially destroyed or non-useable. High value or limited numbers of test articles may make the determination of destruct limits undesirable. According to the HALT philosophy, there are several reasons for ascertaining both the operating limits and the destruct limits. Knowledge of the operating limits is necessary in order to assess whether suitable design margins exist and how large the margins are likely to be across the product population. It is also necessary for the formulation of failure detection tests. These detection tests, run during future accelerated stress screening or HASS, are performed to establish high detectability of precipitated defects. Knowledge of the destruct limits is used in determining the design margins in a product's nonoperating environments and to assure that any future accelerated stress screening environments are well below the destruct limits. An in-depth discussion of accelerated stress screening may be found in the DoD Tri-Service Technical Brief 002-93-08 (July 1993), which is available online in the Defense Acquisition Deskbook at www.deskbook.osd.mil or the Institute of Environmental Sciences and Technology publication IEST-PR-PR001.1, "Management and Technical Guidelines for the ESS Process," 1999.

TEST EQUIPMENT

The equipment available for performing step stress testing has changed significantly during the past ten to fifteen years. Equipment that provides multiple environments is readily available. Selection of the equipment to be used should be made based on a trade-off analysis of costs versus advantages and disadvantages. Some of the more significant items that should be considered are:

- Size and weight of the items to be tested.
- Different types and quantities of items to be produced.
- Cost of new equipment (or modification to existing equipment) to meet test needs.
- Cost of utilities, such as electrical power.
- Test engineering support requirements.
- Fixturing.

Table 2 provides considerations for commonly used vibration and thermal test equipment.

Table 2. Representative Vibration and Thermal Test Equipment

Equipment	Considerations
Pneumatic Shaker *(continued on next page)*	• Low cost vibration system alternative to Electrodynamic/Electrohydraulic (ED/EH) systems. • May not be adequately controllable over all the required frequency ranges in order to investigate dynamic vibration modes, replicate actual vibration conditions, apply sine or narrowband vibration separately or combined with broadband random vibration, and differentiate between fixture and Unit Under Test (UUT) responses. • Good for engineering development testing, debris removal, or informal process control operations. • Can be as effective as ED/EH shakers if modified for selected equipment or applications. • Difficult to evenly excite heavy or large structures (above 60 pounds or one foot in any dimension). • Very effective at uncovering defects at the Circuit Card Assembly (CCA) level, particularly if the CCA can be either hard-mounted to the vibration table or installed in a properly designed fixture to avoid excessive transmissibility losses.

Equipment	Considerations
	• A single axis pneumatic shaker can behave as a multiple axis shaker if test fixtures are configured to provide an input force vector at an angle to the UUT. • Limited displacement.
Electrodynamic /Electrohydraulic (ED/EH)Shaker	• More expensive than pneumatic shakers. • Capable of shaping input spectrum and emphasizing desired vibration modes. • May compensate for transfer function losses at the assembly level. • May be used with non-ruggedized product. This benefit is due to the ability of the ED shakers to notch the input spectrum and levels around critical frequencies/frequency bands. However, whereas notching can preclude damage to good product, it can also decrease the effectiveness of the screen at those notched frequencies (frequency bands). • Capable of doing large loads with uniformity across the mounting surface. • Instrumentation requirements are more complex requiring better trained staff to operate the system.
Liquid Nitrogen/Carbon Dioxide Chambers	• Lower total ownership cost compared to other options. • Provides a capacity for very rapid thermal cycling resulting in greater thermal stresses and providing an ability to shorten test times. With liquid nitrogen/carbon dioxide systems, temperature rates of change for circuit cards can exceed 30^{o}C per minute. • May not be necessary if the hardware thermal response cannot keep up with temperature changes. Generally, the larger the item, the greater the thermal lag. • For solder connections, slow temperature cycles may be more damaging than rapid temperature cycles. • Rapid temperature change rates beyond a certain point may be more damaging due to differing thermal coefficients of expansion of the various materials in the UUT.
Compressor Based Refrigeration Systems *(continued on next page)*	• Higher total ownership cost compared to other options. • Not capable of high thermal changes. • Efficient for slow thermal changes, which are more effective for precipitating certain defects such as in solder joints. • Effective for demonstrating specification requirements, such as qualification testing.

COST

Table 3 provides representative cost information for outsourcing step stress test services and for purchasing step stress test equipment for in-plant use.

Table 3. Representative Step Stress Test Cost

	Cost Information	**Other Considerations**
Outsourced Test Labs	Lab # 1. $1700/day plus $500 fixturing fee. Includes thermal chamber and shaker. Lab # 2. $5000 analysis fee and $2000 /day. Includes ED/EH shaker. Lab # 3. $2500/day plus $350 for overtime hours. Includes ED/EH shaker.	• Process can range from a few days to several weeks. • Prices may or may not include analysis fee in daily fees. • Personnel travel as well as transportation costs of hardware and materials. • Does not require a significant investment in facilities, personnel, equipment, or training.
In House Equipment	Manufacturer #1. $150K for a multi-axis repetitive shock vibration system (approx. 48"x 48") and Nitrogen Chamber (approx. 50"x50"x50"). Manufacturer #2. 30"x30" table - $130,000. 48"x48 table – 180,000. Manufacturer #3. 38"x38" table - $120,00. 44"x44" table - $175,00.	• Does not include facility modification costs. • Requires training to acquire in-house expertise. • Cost variation correlates with the size of the unit.

“WATCH-OUT-FORS”

The following provides selected lessons learned expressed as “Watch Out Fors” that can become traps if not considered in the planning and performance of accelerated tests.

General

Attempting accelerated testing without an understanding of the principles and techniques. This is an extremely complex process to implement, and experienced engineers are required to conduct testing.

Not monitoring the product during test. Continuous monitoring of the UUT at each stress level is necessary to assure detection of intermittent flaws or defects.

Use of a standard accelerated test. Tests should be tailored to the specific application or product type.

Use of accelerated test results to predict reliability and life for complex systems and equipment. There are no generally accepted mathematical or analytical models for these items that correlate the test results to the UUT under normal life cycle stresses.

Assessment of accelerated test results without performing failure analysis to understand the failure mechanisms and their relationship to those expected under normal equipment usage.

Application of Cumulative Fatigue Damage models (e.g., Minor’s Rule) for non-metallic materials (e.g., plastics, composites) without supporting data.

Insufficient emphasis on failure analysis. Detailed failure analysis and corrective action to prevent recurrence is critical.

Insufficient management support from all organizations. An accelerated test process requires involvement of development, manufacturing, quality, and reliability engineering.

Not performing accelerated testing after design or production changes. Accelerated test and stress screening verification and optimization may be negated if significant design or production changes are not examined by re-running appropriate portions of previously successful accelerated testing.

Not performing accelerated stress screening verification test. Once the screening parameters have been established, a verification test must be performed to ensure that the accelerated screening levels precipitate latent defects without damaging the product or appreciably reducing the product life.

Equipment

Accelerometer brackets designed with resonances less than 3 times the natural frequency of the highest forcing/input frequency. This provides a reasonable margin to minimize bracket resonances causing invalid test results from accelerometer errors.

Accelerometer/sensor mountings that do not provide buffering or compensation for sensitivity to temperature changes. Temperature sensitive accelerometers/sensors require frequent calibration unless protected from these changes.

Assumption that all accelerometers/sensors are the same. Variability in accelerometers require individual calibration.

Assumption that multi-axis vibration equipment is more cost effective than single axis test equipment. The time and cost required to separately test each axis are relatively insignificant compared to the potential cost of multi-axis equipment when long term testing is required.

Assumptions that pneumatic shakers are inadequate for production stress screening. The characteristics of these shakers generally can adequately provide the UUT vibration responses to precipitate manufacturing defects.

APPENDIX A

Case Study Summaries

Case Study #1. Step Stress Accelerated Development Testing for a Major Navy Missile Program

Table 1 illustrates a three-step, tailored, Step Stress Accelerated Development Testing program implemented on a major Navy missile program. This testing program was performed on selected electrical/electronic/electromechanical assemblies and equipment.

The term Endurance Limits was used, rather than Destruct Limits, because the tests were not planned to be performed to the levels that would destroy the Unit Under Test (UUT). Rather, the UUT operating design margins were determined by the Endurance Limits. This enables the limited number of high value test assets to be repairable for other selected uses.

Testing on some assemblies/equipments (Commercial-Off-The-Shelf items that were not designed for these environments and some newly designed and manufacturing equipment) were stopped after Step 2, based on test results and failure analyses indicating that endurance limits were being approached. The test results are being used for developing accelerated stress screening criteria for production units.

Table 1. Step Stress Accelerated Development Testing Program

TEST SEQUENCE	TEST TYPE	TEST DESCRIPTION
Step 1. Determine Baseline UUT Operating Limits		
1	HI TEMP ($+77^oC$)	Functional test at ambient, then increase temperature as fast as possible in 10^oC stabilization steps to $+77^oC$ holding for 5 minutes at each setting after stabilization has been reached. Functional test, then back to ambient in 10^oC increments while monitoring functions. Functional test at end of test.
2	LO TEMP (-46^oC)	Functional test at ambient, then decrease temperature as fast as possible in 10^oC stabilization steps to -46^oC holding for 5 minutes at each setting after stabilization has been reached. Functional test, then back to ambient in 10^oC increments while monitoring functions. Functional test at end of test.
3	TEMP CYCLING WITH VARIOUS VOLTAGES ($+77^o$ to -46^oC)	Functional test at ambient, then as fast as possible ambient to $+77^oC$ stabilized, then to -46^oC stabilized, then to ambient; one cycle at nominal input voltage, one cycle at lower limit input voltage while monitoring functions. Functional test at end of test.
4	RANDOM 6 DEGREE OF FREEDOM OF VIBRATION	Functional test, then vibrate at 4 grms then increasing 2 grms every 5 minutes to a maximum of 10 grms with functional test at each level. Functional test at end of test.
5	TEMP CYCLING WITH PERIODIC	Functional test at ambient, then Step 1 temperature cycle profile with 5 grms vibration of 15 second duration at or near the middle

	VIBRATION (+77° to –46°C)	of each half cycle, and after temperature stabilization at both high and low temperature extremes for one cycle, with functional monitoring and functional test at each stabilized temperature. Functional test at ambient, then Step 1 temperature cycle profile with 10 grms vibration of 15 second duration at or near the middle of each half cycle and after temperature stabilization at both high and low temperature extremes for one cycle with functional monitoring and functional test at each stabilized temperature. Functional test at end of test.
Step 2. Determine Baseline UUT Endurance Limits		
6	HI TEMP (+99°C)	Functional test at ambient, then monitor functions during increase to +77°C at a rate of 2 °C, hold for 5 minutes after the temperature has stabilized. Functional test, then increase temperature as fast as possible in 10°C stabilization steps to +99°C holding for 5 minutes at each setting after stabilization has been reached. Functional test, then back to ambient in 10°C increments while monitoring functions. Functional test at end of test.
7	LO TEMP (-62°C)	Functional test at ambient, then monitor functions during decrease to –46°C at 2°C per minute, hold for 5 minutes after the temperature has stabilized. Functional test, then decrease as fast as possible to –57°C, hold for 5 minutes after the temperature has stabilized. Functional test, then decrease as fast as possible to –62°C, hold for 5 minutes after the temperature has stabilized. Functional test and increase to ambient in 10°C steps while monitoring functions. Functional test at end of test.
8	TEMP CYCLING WITH VARIOUS VOLTAGES (+99° to –62°C)	Functional test at ambient, then as fast as possible ambient to +99°C, stabilized to -62°C, stabilized to ambient; one cycle at upper limit input voltage, one cycle at 10% lower than lower limit input voltage while monitoring functions
9	RANDOM 6 DOF VIBRATION	Functional test at ambient, then vibrate at 12 grms and increasing 2 grms every 5 minutes to a maximum of 20 grms with functional test at each level. Functional test at end of test.
10	TEMP CYCLING WITH PERIODIC VIBRATION (+99° to –62°F)	Functional test at ambient, then Step 2 temperature cycle profile with 15 grms vibration of 15 second duration at or near the middle of each half cycle, and after temperature stabilization at both high and low temperature extremes for one cycle, with functional monitoring and functional test at each stabilized temperature. Functional test at ambient, then Step 2 temperature cycle profile with 20 grms vibration of 15 second duration at or near the middle of each half cycle, and after temperature

		stabilization at both high and low temperature extremes for one cycle, with functional monitoring and functional test at each stabilized temperature. Functional test at end of test.
Step 3. Determine UUT Operating and Endurance Limits		
11	TEMP CYCLING WITH PERIODIC VIBRATION (+110 to -79^{o}C)	Functional test at ambient, then Step 3 temperature cycle profile with 25 grms vibration of 15 second duration at or near the middle of each half cycle, and after temperature stabilization at both high and low temperature extremes for one cycle, with functional monitoring and functional test at each stabilized temperature. Functional test at ambient, then repeat the Step 3 temperature cycle profile, increasing the vibration 3 grms each cycle until a level of 44 grms is reached, with functional monitoring and functional test at each stabilized temperature. Functional test at end of test.
12	TEMP CYCLING WITH VARIOUS VOLTAGES (+110 to -79^{o}C)	Functional test, then as fast as possible ambient to +110^{o}C stabilized, to -79^{o}C stabilized, to ambient; one cycle at 10% higher than upper limit input voltage, one cycle at nominal input voltage while monitoring functions. Functional test at end of test.
13	RANDOM 6 DOF VIBRATION	Functional test, then vibrate at 23 grms and increasing 3 grms every 3 minutes to a maximum of 44 grms with functional test at each level. Functional test at end of test.
14	HI TEMP (110^{o}C)	Functional test at ambient, then monitor functions during increase to +99^{o}C at a rate of 2 ^{o}C, hold for 5 minutes after the temperature has stabilized. Functional test, then increase temperature as fast as possible to +110^{o}C, holding for 5 minutes after stabilization has been reached. Functional test, then back to ambient in 10^{o}C increments while monitoring functions. Functional test at end of test.
15	LO TEMP (-79^{o}C)	Functional test at ambient, then monitor functions during decrease to –62^{o}C at 2^{o}C per minute, hold for 5 minutes after the temperature has stabilized. Functional test, then decrease as fast as possible to –73^{o}C, hold for 5 minutes after the temperature has stabilized. Functional test, then decrease as fast as possible to –79^{o}C, hold for 5 minutes after the temperature has stabilized. Functional test and increase to ambient in 10^{o}C steps while monitoring functions. Functional test at end of test.

Case Study #2. Generic Enhanced Step Stress Testing Outline

Equipment to Be Tested
Two to six units should be available to support the test process. All units should have successfully completed all acceptance tests. If a long-term repair is required as a result of the test process, having additional units available will allow testing to continue. Step stress testing is most effective when performed at the lowest level possible, usually at the Circuit Card Assembly (CCA) level, where environments can be closely monitored and the effects understood.

Pre-Test Surveys
Thermal and vibration surveys should be conducted to verify thermal and vibration analyses and for optimization of the test setup. This should ensure optimum thermal response of the unit being tested and provide an assessment of vibration transmissibility through the fixture to the unit being tested.

Test Setup
Thermocouples and accelerometers should be attached to the item being tested at locations identified by thermal and vibration surveys. Support equipment used for functional testing is normally located outside the test chamber. The item being tested should be fully operational and continuously monitored during the test process.

Test Sequence
Stresses are applied starting with the least demanding and going to the most severe. For thermal stresses, cold step stressing should be performed first, then hot, then rapid thermal extremes. This should be followed by vibration stresses and then a final combined thermal/vibration stress environment.

Test Procedures

Electrical Step Stress
The input voltage should be stepped from the nominal to both the lower and upper operating limits while the unit is continuously monitored. The lower limit is 0 volts while the upper limit should be limited to just short of the value at which non-resetable internal protective devices, such as transorbs, activate.

- Desired operating margin: 20% beyond specified upper and lower limits.
- Voltage steps: 5 volts for 115 VAC input and 2 volts for 28 VDC input.
- A Short Circuit Test should be conducted for all outputs that are specified to withstand a short circuit.

Temperature Step Stress
The item being tested should be powered and continuously monitored.

- Temperature steps are normally in 5 to 10°C increments, starting with cold step stressing, dwelling 10 minutes at each step (after stabilization is confirmed by thermocouple data) to verify test unit functionality and to establish operational design margins. At each dwell, the input voltage should be set at the lowest and highest specified limits and test

unit functionality verified.
- Desired operational design margins:
  - Minimum required specification operating temperature minus 20°C.
  - Maximum required specification operating temperature plus 20°C.
- Transient operational failures (i.e., those that go away when the thermal stress is reduced) should have a worst case circuit analysis performed as part of the failure analysis process.

If operational design margins have not been demonstrated, modifications should be made as failures are encountered to increase these limits and ruggedize the product. After failures are corrected, testing should resume at one step less severe than the step at which the failure occurred.

Rapid Temperature Transitions

- The item being tested should be powered and continuously monitored during the cold to hot transition and off during the hot to cold transition.
- Temperature endpoints, based on the operating limits determined during cold and hot step stress, should be ramped as fast as the chamber will allow to assure maximum response in the item being tested; 20 to 30°C per minute is desired.
- After operating limits are confirmed by thermocouple data, functionality should be verified at lower and upper endpoints.
- Five cycles of cold and hot ramps should be applied to the item being tested.
- After a failure is corrected, testing should resume at one cycle less than the cycle at which the failure occurred.

Vibration Step Stress

- During vibration step stress, chamber temperature should be held at approximately +20°C and the item being tested should be powered and continuously monitored.
- The vibration test can also be accomplished on a stand-alone vibration fixture and can be tri-axial, omni-axial, separate axes, skewed axis or the worst case axis. The preferred approach is an omni-axial repetitive shock machine.
- Vibration should be adjusted in discrete steps until operating limits are determined. Finding the true operating limit when using a repetitive shock machine requires monitoring of each internal assembly response in real time. If the resonant frequencies of the internal assemblies, determined by the vibration survey, are not being adequately stimulated by the machine, the shaker or the location of the item being tested should be adjusted to raise the input level at these critical frequencies.
- The dwell time is 2 to 10 minutes based on the time required to verify UUT operation.
- Vibration starting levels are 3 to 5 grms.
- Vibration step sizes are 2 to 5 grms.
- Vibration desired operating limit confidence margin is 20%. If the operating limit confidence margin has not been demonstrated, modifications should be made as failures are encountered to increase these limits and ruggedize the product. After the failure is corrected, testing should resume at one step less severe than the step at which the failure occurred.

Combined Environment

- During combined environment step stress, the item being tested should be powered and continuously monitored during the cold to hot transition and off during the hot to cold transition.
- The item being tested should be subjected to a combined environment of vibration and thermal stress with rapid temperature transitions.
- The input voltage should be cycled between the low limit at cold to the high limit at hot.
- The number of vibration steps performed determines the number of cycles.
- Temperature endpoints, based on the operating limits determined during cold and hot step stress, should be ramped as fast as the chamber will allow to assure maximum response in the item being tested.
- Five minutes after operating limits are confirmed by thermocouple data, functionality should be verified.
- Vibration stress (starting levels defined under Vibration Step Stress above) should be applied for five minutes during the cold to hot transition and functionality should again be verified.
- Vibration should be incremented (step size defined under Vibration Step Stress above) after each subsequent thermal cycle of the combined environment.
- If the operating limit confidence margin has not been demonstrated, modifications should be made as failures are encountered to increase these limits and ruggedize the product. After the failure is corrected, testing should resume at one step less severe than the step at which the failure occurred.

Failure Definition

Failure is defined as functional performance that does not meet specified limits under specified conditions. Failure includes structural breakage, fracture, or other damage that causes the item being tested to be non-operational. Failures should also be differentiated between those caused by design or process deficiencies and those caused by workmanship or part failure. Design or process failures require corrective action before the stress testing can continue, whereas a workmanship or part failure can simply be repaired and the stress testing continued, with corrective actions developed later.

Failure Verification

Any test step that indicates a failure should be repeated to verify that the failure indication is repeatable. If failure indication recurs, the event should be logged and tracked as a failure. Otherwise, the event should be logged and tracked as an anomaly. If a Built In Test (BIT) anomaly occurs within specification limits, it should be considered a BIT false alarm and require corrective action. All failures should be documented and tracked to closure.

Failure Analysis

All failures should be analyzed to determine and categorize the basic failure mechanism: design related, part related, manufacturing process related, externally induced, or unknown. Analyses may include worst-case circuit analysis, internal part analysis, or manufacturing process review, as appropriate.

APPENDIX B

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