Qualmark HALT Testing Guidelines

Revision History

Rev	Originator	Description of Change
9/1998	D. Rahe (Qualmark)	Original Issue
4/2003	C. Drake (Qualmark)	Updated body of text.
7/2007	C. Drake (Qualmark)	Update text as needed
04	N. Doertenbach (Qualmark)	Released: ECO #3007; 9/13/2010 Placed in Document Control. Reorganized sections, updating text as needed; added acronym table

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Qualmark HALT Testing Guidelines

1. Purpose

1.1. The HALT test process helps product designers create a more robust and reliable product, thus improving field reliability and reducing warranty costs. When successfully applied, HALT testing rapidly exposes product weaknesses and gives the designer the opportunity to provide a more mature product at new product launch. The purpose of this guideline is to provide a consistent, efficient and effective description of the HALT process.

2. Scope

2.1. This document defines the process elements necessary to successfully implement a HALT test program. It identifies technical responsibilities, facility and equipment requirements, and testing practice competencies. This guideline applies to a diversified mix of product types, including electronic assemblies and electro-mechanical assemblies, and certain mechanical assemblies as well.

2.2. This document also defines modifications and variations on standard HALT testing that can be considered in limited circumstances, and discusses the effects of these changes on the outcomes of the test.

3. Definitions (Also see Acronym Table, Table 1)

3.1. Accelerometer: A transducer that measures acceleration. Typically based on piezo-electronic technology, the device provides a voltage output proportional to the acceleration at the location and in the defined direction of the device. Typically several are attached to the UUT and are used to monitor the UUT response to the vibration input from the table.

3.2. Air Control Thermocouple: A thermocouple that provides air temperature feedback to the chamber thermal control system. Depending on the control system settings, the air control thermocouple can act as a temperature safety limit controller, or as the control thermocouple for the system.

3.3. Alternating Low Level Vibration: Also referenced as “Tickle Vibration”[1]: A vibration test procedure that is typically introduced in HALT Vibration Step Stressing at input levels of 30 gRMS and higher. At the end of each vibration dwell and functional test, the vibration level is reduced to 5 gRMS and a complete functional test is conducted, without waiting for a dwell at that level. Then, the vibration level is increased to the next step level. Alternating low level vibration will help detect a failure mode that is precipitated at a higher gRMS level, but is not detectable at that level, and is also not detectable when the UUT is at rest. Low levels of vibration, however, can make the failure mode detectable. Certain types of cracked solder joints, including through-hole solder issues, can be identified this way.

3.4. Broadband Vibration: Vibration that contains energy over a broad frequency range (i.e. 10 Hz to 5 kHz or greater).

3.5. Corrective Action (CA): A change implemented in a design or process to eliminate a product weakness or flaw. Corrective actions may include changes in parts or material sources, product design, and production process changes.

3.6. Destruct Limit (DL): The stress level where a failure is identified and UUT functionality is not recovered when the stress is reduced. This type of failure is also known as a hard failure. Vibration step stressing will reveal the Vibration Destruct Limit (VDL), while cold thermal step stressing will reveal the Lower Destruct Limit (LDL) and hot thermal step stressing will reveal the Upper Destruct Limit (UDL).

3.7. ED (Electrodynamic) shaker: A vibration system consisting of a table structure that is connected to a ferrous armature surrounded by a coil. This coil is separated by an air gap from a second coil in the body of the shaker system. Controlled current is passed through the coils to create an electromagnetic force between them that moves the table in a single axis. The UUT is mounted to the table structure. The spectral and real time content of the driving force is specifically controlled to meet a desired vibration profile.

3.8. Fast Fourier Transform (FFT): An algorithm for describing a real time signal in terms of its component frequencies. Used in vibration analysis to provide magnitude and frequency information about the frequency components of an acceleration signal.

3.9. Functional Test: A test of the UUT that measures functionality, UUT operation, and critical parameters to determine if UUT fails to perform to specifications or degradation has occurred within the UUT. This test may include internal diagnostics. Functional testing is to be performed throughout the thermal and vibration stresses of a HALT test.

3.10. gRMS: The RMS (Root Mean Square) level of an acceleration signal, normalized to the value of acceleration due to gravity.[2] gRMS is measured across a specified frequency range, depending on the cutoff frequency of the filter on the acceleration level. gRMS can be measured both in the time domain, using analog RMS converter circuitry, and through sampling and FFT analysis, then calculating the square root of the area under the Power Spectral Density curve, cut off at the desired frequency (Figure 1). gRMS is typically used as a measurement of the vibration energy present in a random vibration signal. For vibration from an RS machine, the frequency cutoff used is typically 5 kHz.

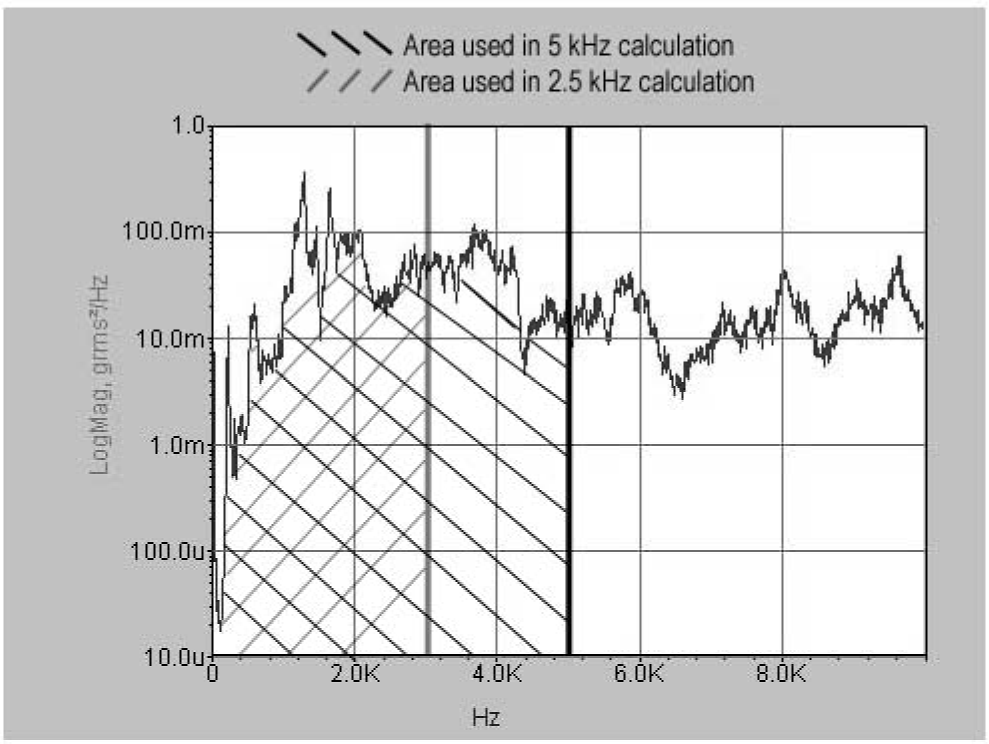

Figure 1: Example of gRMS calculations at two different cutoff frequencies using PSD

3.11. HALT (Highly Accelerated Life Test), also referenced as "HALT test": A process that utilizes a step stress approach to subject a UUT to thermal and vibration stresses of types and levels beyond what it may see in actual use, but which will rapidly induce failure modes, allowing them to be detected and corrected. The stresses applied include thermal extremes, extreme thermal ramp rates, 6DoF RS vibration and combinations of these stresses.

3.12. Hard Failure: A non-recoverable failure mode. A hard failure will not go away when the stress that induced the failure is reduced or removed. A hard failure will define the Destruct Limit of a UUT.

3.13. Isolation; thermal and vibration: Techniques used to protect portions of a UUT from the stresses of the HALT test system in order to debug failure modes or to work around a known issue and continue testing the rest of the UUT.

3.14. Operational Limit (OL): Also referenced as "Operating Limit". The stress level prior to where a failure is identified but UUT functionality is recovered when the stress is reduced. This type of failure is also known as a soft failure. Vibration step stressing will reveal the Vibration Operational Limit (VOL), while cold thermal step stressing will reveal the Lower Operational Limit (LOL) and hot thermal step stressing will reveal the Upper Operational Limit (UOL).

3.15. Picket Fencing: A description of the shape of the PSD of an RS vibration system with actuators that are all striking at the same frequency but at slightly different times. Such a system will result in a table spectrum with high vibration levels at the actuator strike frequency and its harmonics, with little energy between those harmonics. The resulting PSD resembles a 'picket fence'.

3.16. Power Spectral Density (PSD)[3]: A measurement of the amplitude and frequency content of a random vibration spectrum, expressed in units of g_{rms}^2/Hz. Also commonly referred to as the Acceleration Spectral Density (ASD). The shape of the PSD graph provides a visual representation of the relative levels of vibration across the frequency range of interest, allowing analysis of the effectiveness of vibration fixturing and insight into the UUT's transmissive and absorptive characteristics (Figure 2).

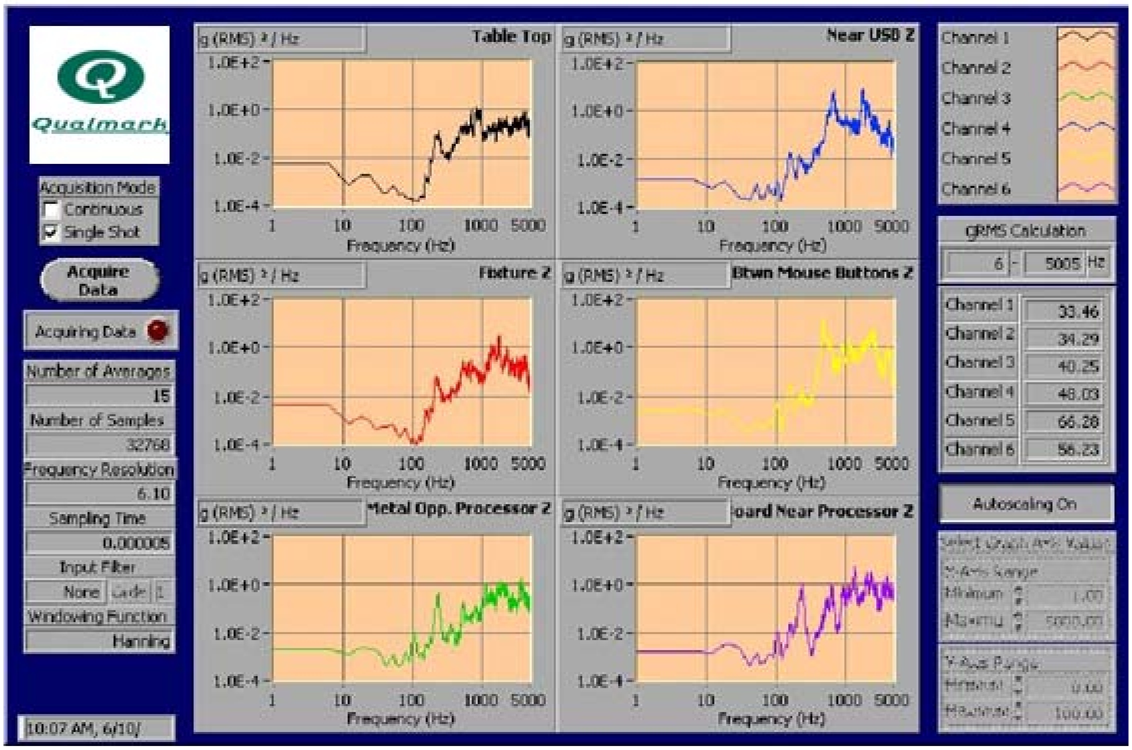

Figure 2: Typical PSD graphs from multiple accelerometers in a HALT test

3.17. Product Control Thermocouple: A thermocouple that provides product temperature information to the chamber thermal control system. Typically the chamber control system is set to use the temperature level of this thermocouple to control the thermal system, although control from the air temperature thermocouple is also possible.

3.18. Product Control Accelerometer: An accelerometer that provides table vibration level information to the chamber vibration control system. The chamber control system uses the vibration level of this accelerometer to control the vibration system.

3.19. Quasi-Random Vibration: Non-periodic vibration that possesses all frequencies within a band and having a continuously varying amplitude and phase that is specified as a probability that it will exceed a given value during a time interval.

3.20. Return on Investment (ROI): A calculation used to determine the value of a proposed investment. It is calculated as the ratio of the amount gained (taken as positive), or lost (taken as negative), relative to the amount invested. When considered specifically for HALT testing, it is the ratio of the amount of money saved by discovering and correcting faults by using HALT testing relative to the cost of doing the HALT test, including capital equipment, infrastructure, personnel, etc.

3.21. Repetitive Shock (RS) Vibration: Vibration originating from a repeated shock impulse excitation to a rigid or semi-rigid table supported by springs. Typically created from pneumatic actuators impacting a vibration table to which UUTs are attached.

3.22. Root Cause Analysis (RCA): Identifying the true cause of a weakness or flaw; fully understanding what failed and why. This process may require use of failure analysis tools like scanning electron microscopes.

3.23. Six Degree of Freedom Vibration (6DoF): Vibration that has simultaneous acceleration energies in three axes (X, Y and Z) and the three rotations (roll, pitch and yaw) around those axes.

3.24. Soft Failure: A recoverable failure mode. A soft failure will go away when the stress that induced the failure is reduced or removed. A soft failure will define the Operational Limit of a product.

3.25. Step Stressing: A stress testing process where a stress level is incrementally increased to identify UUT weaknesses and limitations.

3.26. Thermocouples: Temperature sensors that are created when two dissimilar metals are fused, creating a thermoelectric current flow and a resultant voltage potential proportional to temperature.

3.27. Thermal Ramp Rate: The rate of change of temperature in a system. When used as a thermal system specification, it is the fastest change rate the system can achieve. The measurement point is typically in the air at a centrally located point in the chamber, near the location of a UUT. It can also be specified and measured on specific areas or components on a UUT as desired. It can be used to evaluate chamber thermal performance as well as the effectiveness of the transmission of thermal energy to the UUT. Higher ramp rates result in more stress on the UUT and hence a more effective test.

3.28. Triaxial Accelerometer: Three accelerometers mounted in a single package with three outputs, to monitor x, y and z axes simultaneously.

3.29. Unit Under Test (UUT): The device being HALT tested.

4. Basic HALT Test Concepts

4.1. The goal of a HALT test is to use thermal, vibration and other product-specific stresses, typically at levels beyond the product's specifications or intended use environment, to force latent defects in the product's design or construction to become patent, allowing them to be corrected before product release. The stresses are incremented during the test to force the weakest links in the UUT to fail first. The test is successful when failure modes are identified, corrective action taken, and the effectiveness of the correction has been verified. [4,5]

4.2. While HALT testing is typically considered as a tool for evaluating new designs, it can also be very valuable for evaluating component and process changes[6], changes to an existing design or evaluating field failures that are returned with no defect found.

4.3. Whenever possible, the results from a HALT test should be compared with the results from a previous HALT test on a similar product. This will provide information that can help with failure analysis, corrective action and decisions on the need for in depth failure mode evaluations. When a HALT test is conducted for the first time, it may not be possible to do this comparison. In this case, a similar, legacy product should be tested alongside the new product to provide baseline data.

4.4. Before introducing HALT testing in a facility or product line, it is advisable to do a rough estimate of the Return on Investment (ROI) that can be expected. By reviewing the costs of correcting design defects found during design verification testing or after release of past products, as well as the potential value of releasing new products more quickly, versus the costs of HALT testing implementation, including infrastructure, staffing, training and HALT system requirements, intelligent decisions can be made on procuring equipment vs. testing at a lab, justification of staffing, etc.

5. Staffing Requirements

5.1. Training in HALT test methods and philosophy is important for all personnel involved in HALT testing, whether they are implementing the test itself, performing failure analysis, or implementing corrective action. HALT is not a 'cookbook' or 'check the box' test method. It requires good judgment and decision making throughout the test based on results found, product characteristics, business considerations and other factors. These decisions can only be made correctly if the personnel involved fully understand and agree with the goals of HALT testing. Similarly, retraining is important as personnel change.

5.2. The HALT test team should include those individuals involved in the design and test of the product. HALT testing requires cooperation among multiple disciplines within the facility. Design engineering will assist in the development of the UUT functional test. This includes identifying additional stresses that may help to precipitate defects. They will also provide support during the HALT test, and the failure analysis process (e.g. troubleshooting defects). These individuals need not be present during the entire HALT test, but must be available on an as needed basis. Test Engineering will assist in the definition of functional test protocols and test hardware design and creation. Other disciplines include reliability engineering, manufacturing engineering, and the personnel who run the HALT test system. Supply Chain Management should also be involved to help identify and correct design issues related to vendor selection as well as to oversee HALT test results and corrective action requirements throughout the supply chain. Each discipline shall take responsibility for their area of expertise as HALT test result issues arise (Figure 3).[7]

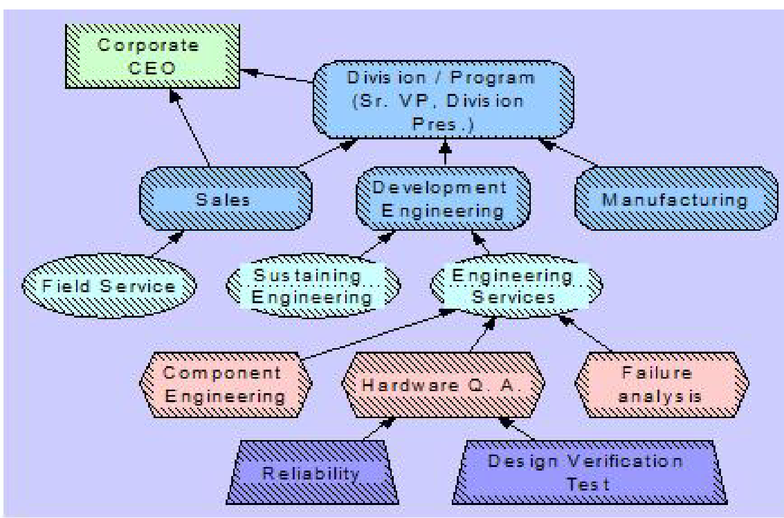

Figure 3: Disciplines Required For HALT Testing[8]

5.3. A failure analysis lab (in-house or outside lab) may be required to determine root cause analysis on failures found during HALT testing.

5.4. A cross-functional committee should be defined. This committee should meet on a regular basis (i.e. monthly) to define HALT test requirements, review past HALT test results and develop test plans for future testing. Records shall be maintained on the outcome decisions of the meetings. These meetings shall occur prior to and after the HALT test.

5.4.1. The pre-HALT test meeting agenda should define the HALT test specifications, the functional test requirements, methods of fixturing the UUT to the table, and UUT components and/or locations to monitor with thermocouples and accelerometers.

5.4.2. The post HALT test meeting agenda should include a review of HALT test results including discussion of failures and corrective action planning. It should also include the definition and implementation of a closed loop process that documents the failure modes found, confirms and records the corrective actions taken, and record these failure modes and corrective actions in a database so that similar mistakes will not be repeated.

6. HALT Test Equipment Requirements

6.1. HALT Test Chamber Requirements

6.1.1. The system required to perform HALT testing must be a single chamber capable of providing both thermal and vibration energy stresses as defined below. The equipment must create these stresses independently and in a combined environment within the same chamber at the same time.

6.1.1.1. The goal of the vibration system is to provide enough vibration stress to the UUT to induce failures. This vibration stress level will vary depending on the product being tested and the fixturing used. The vibration system used should be capable of delivering at least 50 gRMS (measured from 10 Hz to 5 kHz) into an empty vibration table. It should use repetitive shock vibration to provide 6DoF quasi-random vibration, with broadband energy from 10 Hz up to 5 kHz or higher. The actuators used in the vibration system should impact at differing frequencies in order to avoid picket fencing in the

PSD and loss of vibration energy in specific low frequency (<200 Hz) bands.

6.1.1.2. The goal of the thermal system is to force rapid thermal change rates on the UUT. It is additionally important that the chamber has sufficient air velocity to produce the desired rapid thermal rates of change as measured on the UUT and to maintain thermal stability. For an effective test, the chamber must be able to thermally stress the UUT sufficiently above the design specifications to uncover defects. The thermal system must be capable of minimum air temperature change rates of 60°C/minute, hot and cold, when changing temperature at its maximum possible rate, and must have a minimum thermal range of -100°C to +200°C.

6.1.1.3. If the product is designed and specified for extreme high temperature environments, the required upper thermal limit of the chamber will be higher.

6.2. Laboratory Test Equipment

6.2.1. UUT response data is acquired during the HALT test process. This data includes thermal, vibration and UUT functional performance.

6.2.1.1. The collection and storage of thermal data is required to provide credible evidence that thermal stress was applied to the UUT. This may be achieved by utilizing available thermocouple monitoring channels of the HALT test system or the use of a data acquisition instrument capable of multiple channel measurements.

6.2.1.2. The collection and storage of vibration data is required to provide credible evidence that vibration stress was applied to the UUT. This may be achieved by utilizing available accelerometer monitoring channels of the HALT test system or the use of a spectrum analyzer instrument capable of measuring sensors (e.g. accelerometers) and displaying the data.

6.2.1.3. The measurement of acceleration levels at various points on the UUT and fixturing is necessary to understand vibration input and response. Accelerometers are used for these measurements.

These accelerometers should be low mass type (e.g. # 4 grams), with frequency response capability of 10 Hz to 5 kHz or higher, and a measurement range of ± 500 g's. The accelerometers should be small enough to be mounted in the desired location and light enough that their mass does not significantly impact or alter the vibration dynamic characteristics of the UUT.

6.2.1.4. Thermocouples for the measurement of UUT thermal response. The use of thermocouple wire is required. Thermocouples used for HALT testing should have sufficient stability characteristics through the temperature range of the chamber (approximately -100°C to +200°C).

6.2.2. Test Equipment Setup Requirements

6.2.2.1. The HALT test system, ancillary test equipment setup, and operation is performed in accordance with manufacturer's instructions.

6.2.2.2. Verify that all test equipment to be utilized for the HALT test is calibrated and operable. Document the test equipment in the test report including equipment description, model number, serial number, and calibration status.

7. Test Samples

7.1. The UUTs are uniquely identified by a serial number or other means of identification.

7.2. Ideally a total of at least four UUTs should be tested.[9] Simultaneous testing of the four samples may reduce the total test time. However, this makes the vibration fixturing and functional testing more complex, and may make failure mode detection, analysis, and isolation more difficult. Also, limitations on availability of samples may make this approach impossible. Whenever possible, spare subassemblies should be on hand to replace failed units when failures occur.

7.3. Test Sample Setup Requirements

7.3.1. Thermal control of the HALT test system is achieved through feedback from the air and product control thermocouples. They must be properly placed on the UUT(s) to ensure effective control of the UUT temperature. The system can be configured to use either the air or product thermocouples as the control feedback to the system control loop. Monitoring of the thermal response of the UUT is accomplished using thermocouples attached at desired locations in/on the UUT, with the readings recorded with a data logger.

7.3.1.1. When operating under product thermocouple control, the product thermocouple is used for temperature control - the control system drives the chamber air temperature as needed to achieve the desired temperature setpoint as measured at the product thermocouple. The chamber air temperature will typically exceed setpoint as necessary to achieve the desired setpoint. When operating under product thermocouple control, the product thermocouple should be attached to a location that provides an accurate approximate average of the temperature of the UUT. The product thermocouple should be placed on an exposed surface on the UUT, preferably in an area of relatively low thermal mass. This thermocouple should not be placed on or near a heat-generating component, or inside a closed portion of a UUT. The air thermocouple is used as an air temperature limit control, keeping the air temperature from reaching preset levels chosen to prevent damage to the UUT. The air temperature thermocouple should be located in the air near any area on the UUT where temperature limits are of particular concern.

7.3.1.1.1. If an appropriate location for the product control thermocouple cannot be identified, the product thermocouple can be placed on a dummy load. Typically, a washer or other small mass, located near the center of the chamber and in the air flow, is used for this.

7.3.1.2. If the air temperature thermocouple is used for temperature control, the control system will maintain the air temperature at the desired setpoint. In this case, the air temperature thermocouple should be located near the UUT, in the air where the airstream is unobstructed. Air control can be used when the UUT is sensitive to temperature extremes, and close control of the air temperature is desired. It will result in slower ramp rates on the UUT itself. In this case, the location of the product temperature thermocouple is not important. It can be used as an additional thermocouple to monitor UUT temperature where desired.

7.3.1.3. Product response thermocouples are attached to adequately assess the response of the UUT(s) to the thermal environment. Suggested placement includes components that generate significant heat, components that would be sensitive to thermal transitions, components designed to respond to temperature, and on a high mass portion of the UUT to provide a measure of the dwell time necessary to achieve temperature stabilization.

7.3.1.4. Thermal transition rates on the UUT and subassemblies within the UUT may be improved by modification of the UUT chassis such as removing panels or covers or drilling holes in the cover to allow air flow through the UUT. If cable lengths and UUT functionality permit, consider removing subassemblies from the UUT and fixturing them separately to the table to maximize both thermal and vibration stresses on the subassemblies.

7.3.2. Vibration control of the HALT test system is achieved through feedback from the product control accelerometer. This accelerometer is typically located near the center of the vibration table, on the underside of the table. Unlike thermal control elements, the product control accelerometer should never be placed on the actual UUT or fixturing. Not only is there a risk of damage to the control accelerometer due to the thermal extremes of the upper part of the test system, there is a risk of loss of vibration control if the UUT breaks or fixturing loosens in such a way that the accelerometer is no longer monitoring the actual table acceleration. It is never necessary to change the location of the control accelerometer.

7.3.3. Secure the test UUT(s) to the vibration table using a suitable test fixture that maximizes the thermal and vibration energy transfer to the UUT. The goal is to stimulate the UUT tested to accelerate fatigue damage to uncover product weaknesses. Therefore, optimization of maximum stress to the UUT is beneficial. If subassemblies within the UUT do not receive adequate vibration levels to induce failures, it may be necessary to remove them and fixture them separately, or perform a separate HALT test on the subassemblies. Redesign the fixture if the vibration levels on the UUT or subassemblies are too low to stress the UUT adequately.

7.3.3.1. HALT test fixturing is very different from those used in traditional ED vibration testing. The rigid, heavy plates typically used in ED fixturing can dampen the vibration in an RS table, dramatically reducing the effectiveness of the vibration. HALT test fixturing should be flexible, to allow the table to move in its natural resonant modes.

7.3.4. In some cases, subassemblies of the UUT will be unable to tolerate HALT test stresses due to specific limitations of the subassembly. These subassemblies might include hard drives, batteries, etc. In this case, these subassemblies should be removed from the chamber using extension cables to retain functionality while protecting these sensitive devices. If cable length tolerances or other issues make it impossible to do this, thermal and vibration isolation techniques may be used to provide low stress environments within the chamber.

7.3.5. UUT size and weight should be taken into account when determining feasibility of a particular chamber to properly stress the UUT.

7.3.6. If multiple UUT's are being tested, they should be fixtured so that their locations are symmetric with respect to the table quadrants. This will help maintain uniform vibration on the UUTs.

8. Functional Testing Requirements

8.1. Functional testing of the UUT while under stress is a critical component of HALT testing. Transient failures that occur only under stress but are not detectable at ambient conditions will be identified during the functional test. Since the goal of HALT testing is to find and correct failure modes, a failure mode that goes undetected due to insufficient functional testing defeats the purpose of the test. Functional testing should be sufficient to determine the overall performance of the UUT and detect the occurrence of multiple types of failure modes. The test must exercise the major functions of the UUT with a feedback measurement of performance of each function. The goal of the functional test is to achieve as complete test coverage of the UUT as is possible.

8.2. In addition to the thermal and vibration stresses provided by the HALT test system, the product should be subjected to any product-specific stresses that may enhance failure precipitation and detection. Product-specific stresses may include power cycling, line voltage margining, line frequency margining, DC supply voltage margining, on-board oscillator margining, output loading, and any other stresses that are applicable. These product-specific stresses are incorporated into the functional testing and should be performed at each level of stress throughout the HALT test process.[10]

8.3. The functional testing of the UUT must be documented. The documentation shall provide definition of the amount of test coverage, in percentage, and include a detailed description of the test performed. Test documentation shall also provide evidence of how the functional test objectives as defined in the pre-HALT test meeting were achieved

8.4. Before beginning the HALT test process, the UUT is subjected to one or more cycles of functional testing to verify the integrity of the test setup and obtain baseline performance information for the UUT(s).

9. Test Reporting and Documentation

9.1. The test documentation must be able to achieve two key purposes; 1) it will provide information to help in failure analysis and corrective action, including detailed descriptions of the failure modes found, and the specific stresses under which they occurred, and 2) provide the detailed information needed to reproduce the test, including thermocouple and accelerometer placements, functional test method, equipment, software revisions, and any other necessary information.

9.2. It is recommended that a defined, controlled test procedure and data collection template be established for HALT testing.[11] This will help ensure that the process does not change with personnel or facility changes, keeping HALT test results repeatable and consistent.

9.3. The data is compiled and stored in sufficient detail and quantity that the flow of the process can be easily followed and the test sequence reproduced if required. UUT response measurements and the HALT test system data including temperature data and vibration data are collected during the entire test.

9.4. It is important to collect and understand response data from the UUT itself in addition to the input and control parameters of the chamber. While the control parameters (vibration setpoint and table response, temperature setpoint and control thermocouple response) provide the necessary metrics for chamber control, the actual response of the UUT is the true indicator of the UUT stresses. The thermal and vibration response on the UUT and key subassemblies within the UUT must be monitored and recorded in order to understand the true conditions when a failure mode is discovered.

9.5. The documentation shall accurately and clearly present the test results and other test related relevant information. The documentation shall contain:

9.5.1. The identification of the person(s) who performed the HALT test.

9.5.2. UUTs are identified by a unique identifier (e.g. serial number) including revision level.

9.5.3. Deviations from the HALT test procedure.

9.5.4. Dates of testing.

9.5.5. A description of the UUT fixturing used during testing, including photographs to support the description.

9.5.6. Specific thermal and vibration data measurements (supported by tables, graphs, photographs as appropriate).

9.5.7. Locations of UUT response sensors (thermocouples and accelerometers). This is particularly important, as slight changes in these locations when a test is repeated can have significant effects on the readings, making comparisons of thermal and vibration levels between tests invalid.

9.5.8. Description of the functional testing performed on the UUTs.

9.5.9. At each level of applied stress, functional testing is performed on the UUT to evaluate the operation of the UUT. Documentation shall detail failure modes and the conditions at which they occurred as well as the operating and destruct limits of the sample and any other important comments.

9.5.10. The root cause analysis (RCA) information and results.

9.5.11. Any corrective action (CA) implemented.

10. HALT Test Procedure

10.1. Thermal Step Stress Test

10.1.1. During Thermal Step Stress testing, the goal is to identify failure modes that are due to temperature extremes. In Thermal Step Stress testing, the temperature is increased (or decreased) in steps of a defined increment followed by a temperature dwell of a defined length.

10.1.2. Thermal Step Stress testing shall begin at ambient (defined as 20°C to 30°C).

10.1.3. The thermal step increments are typically 10°C.

10.1.4. The dwell time is a minimum of ten (10) minutes following stabilization of the UUT at the setpoint temperature as determined by the UUT thermocouple response. Ideally the full functional test or a subset of the functional test should be performed throughout the dwell to monitor basic UUT functionality. At a minimum, the full functional test is performed at the end of the dwell. Any product-specific stresses that are being used should be applied in a similar fashion. At the end of the dwell, the thermal stress is incremented and the dwell is repeated (Figure 4).

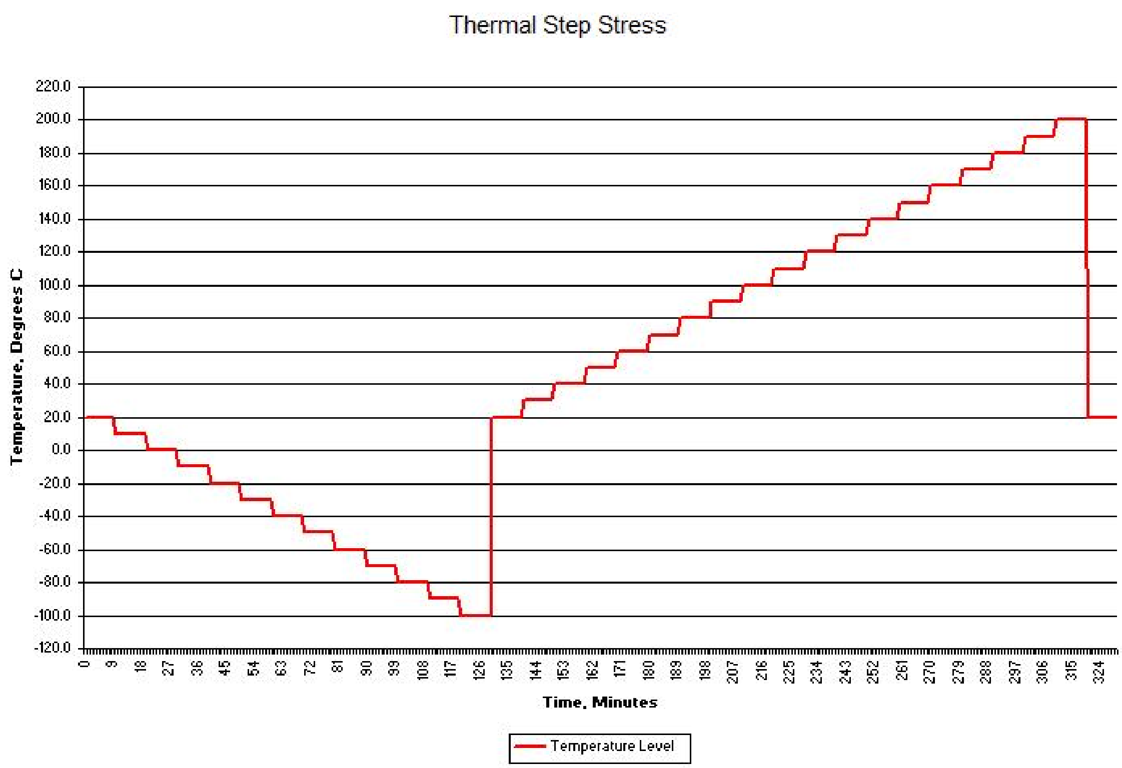

Figure 4: Sample Thermal Step Stress Graph

10.1.5. Thermal Step Stress testing is continued until a failure is identified or the limits of the chamber have been reached. When a failure is identified, it is handled as described in “Handling Failures in HALT Testing” below and step stressing is continued. If possible, continue until the operational and destruct limits for the product have been identified.

10.2. Rapid Thermal Transitions Stress Test

10.2.1. During Rapid Thermal Transition Stress testing, the goal is to identify failure modes that result from rapid thermal changes. Consequently, the thermal limits are reduced from the operational limits found in

Thermal Step Stress testing to avoid finding failure modes already identified in Thermal Step Stress testing.

10.2.2. A minimum of five (5) thermal cycles are performed unless a destructive failure is encountered prior to completion. The thermal transitions are performed at the maximum attainable rate of change.

10.2.3. The minimum thermal cycle temperature range is within 10°C of both the lower thermal operating limit and the upper thermal operating limit as discovered during Thermal Step Stress testing. Example: if the LOL was determined to be -50°C and the UOL determined to be 100°C, the thermal transition range would be -40°C to +90°C.

10.2.4. The dwell time is a minimum of five (5) minutes following stabilization of the UUT at the setpoint temperature as determined by the UUT thermocouple response. The dwell time is increased to allow higher mass components to reach at least 80 percent of the thermal range.

10.2.5. The full functional test is performed at the end of the dwell. If possible, the full functional test or a subset of the functional test should be performed throughout the ramp to monitor basic UUT functionality. Any product-specific stresses should be applied in a similar fashion. At the end of the dwell, the thermal stress is ramped to the next thermal extreme and the dwell is repeated (Figure 5).

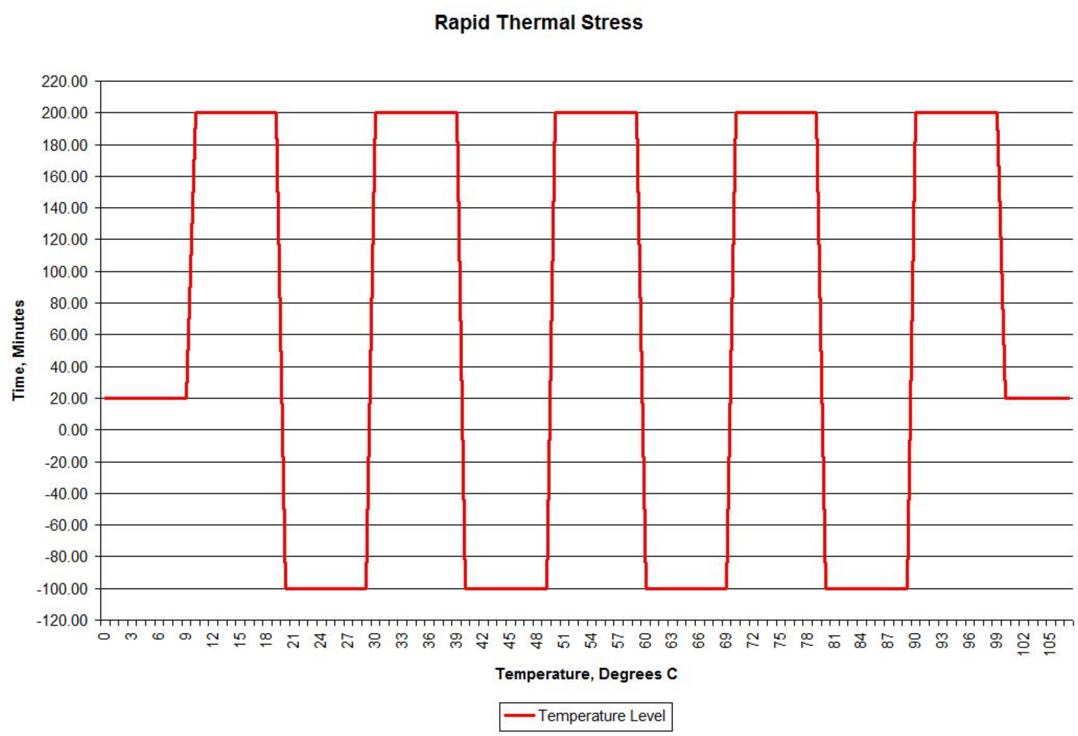

Figure 5: Sample Rapid Thermal Stress Test Graph

10.3. Vibration Step Stress Test

10.3.1. During Vibration Step Stress testing, the goal is to find vibration related failures, and to mechanically fatigue the UUT so that the weakest portions of the UUT will fail quickly.

10.3.2. During Vibration Step Stress testing, accelerometers are affixed to the UUT to monitor the UUT's response to the table input. Accelerometers should be placed on major assemblies and subassemblies in the UUT to evaluate overall transmission of vibration into these areas, as well as on massive components or components likely to have significant resonances.

10.3.3. Since the RS vibration table provides energy in all three axes, monitoring of vibration in multiple axes is recommended, particularly when inner boards or subassemblies are mounted in perpendicular axes to each other. Triaxial accelerometers are useful for this purpose.

10.3.4. Vibration Step Stress testing begins at a chamber setpoint of 5 gRMS, as measured over a 10 Hz to 5 kHz bandwidth. The vibration level is increased in steps of a defined increment followed by a vibration dwell of a defined length Then increased in 5 gRMS (recommended) increments upon completion of the dwell period and subsequent functional test.

10.3.5. The vibration step increments are typically 5 gRMS.

10.3.6. The dwell time at each level of vibration is a minimum of ten (10) minutes. The full functional test is performed at the end of the dwell. If possible, the full functional test or a subset of the functional test should be performed throughout the step to monitor basic UUT functionality. Any product-specific stresses should be applied in a similar fashion. At the end of the dwell, the vibration stress is incremented and the dwell is repeated (Figure 6).

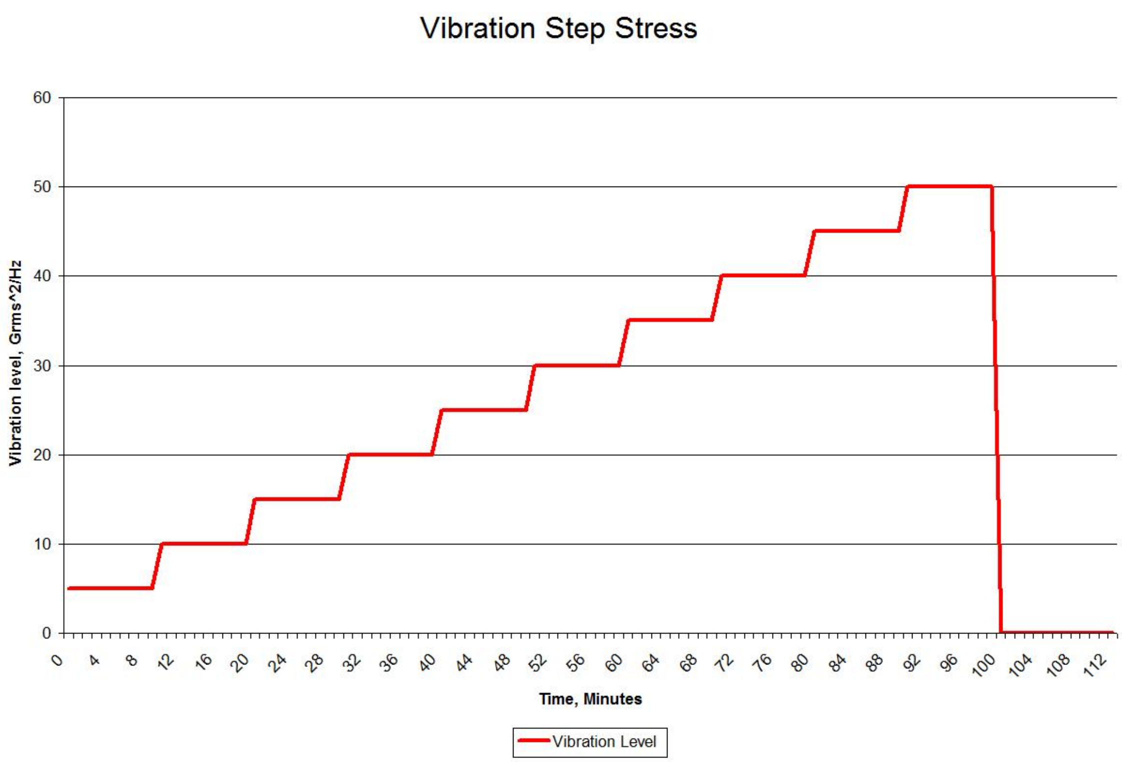

Figure 6: Sample Vibration Step Stress Test Graph

10.3.7. Vibration Step Stress testing is continued until a failure is identified or the limits of the chamber have been reached. When a failure is identified, it is handled as described in "Handling Failures in HALT Testing" below and step stressing is continued. If possible, continue until the operational and destruct limits for the product have been identified.

10.3.8. At input vibration levels of 30 gRMS and higher, alternating low level vibration should be introduced. At the end of each vibration dwell and functional test, the vibration level is reduced to 5 gRMS and a complete functional test is conducted, without waiting for a dwell at that level. Then the vibration level is increased to the next step level. Alternating low level vibration will help detect a failure mode that is precipitated at a higher gRMS level, but is not detectable at that level, and is also not detectable when the UUT is at rest. Low levels of vibration, however, can make the failure mode detectable.

10.3.9. Once the operating limit is determined, vibration step stressing continues beyond the operational limit to the destruct limit or the chamber maximum. However, because the UUT may not be operational, it is necessary to reduce the vibration stress between each dwell to determine whether the UUT is still functional. This could include a return to 0 gRMS or a level between 0 gRMS and the operational limit.

10.4. Combined Environment Stress Test

10.4.1. During Combined Environment Stress testing, all of the stresses used previously in the HALT test are combined and applied simultaneously. The goal is to drive out any failures that require this combination of stresses to be made patent.

10.4.2. The accelerometers used during Vibration Step Stress testing should be removed before beginning combined environment stress testing. Accelerometers can be damaged by the temperature extremes used in the combined environment.

10.4.3. A minimum of five (5) combined environment cycles are required unless a destructive failure forces the early termination of the stressing. Each combined environment cycle will consist of one thermal cycle that is conducted while the vibration is held at a single setpoint. For each of the five combined environment cycles the vibration level is incremented and held at the next setpoint while a thermal cycle is conducted.

10.4.4. The minimum thermal cycle temperature range is within 10°C of both the lower thermal operating limit and the upper thermal operating limit as discovered during Thermal Step Stress testing. Example: if the LOL was determined to be -50°C and the UOL determined to be 100°C, the thermal transition range would be -40°C to +90°C.

10.4.5. The dwell time at each temperature extreme is a minimum of ten (10) minutes following stabilization of the UUT at the setpoint temperature as determined by the UUT thermocouple response. The dwell time is increased to allow higher mass components to reach at least 80 percent of the thermal range.

10.4.6. The full functional test is performed at the end of the temperature dwell. If possible, the full functional test or a subset of the functional test should be performed throughout the thermal ramps to monitor basic UUT functionality. Any product-specific stresses should be applied in a similar fashion. At the end of the dwell, the thermal stress is ramped to the next thermal extreme and the dwell is repeated (Figure 7).

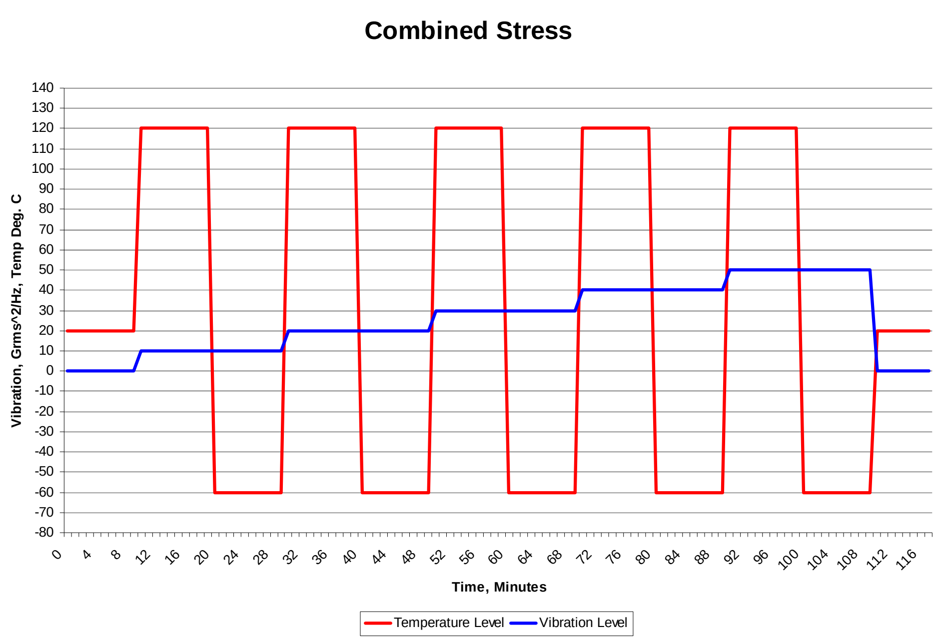

Figure 7: Sample Combined Stress Test Graph

10.4.7. The vibration is maintained at the dwell setpoint until one complete thermal cycle is finished. At the end of one complete thermal cycle the vibration level is incremented and the thermal cycle is repeated.

10.4.8. The starting vibration level for the five (5) required cycles is determined by dividing the Vibration Destruct Limit by five. The vibration level is increased by the same number during each subsequent thermal cycle. Therefore, if the UUT has a Vibration Destruct Limit of 35, the initial test cycle would be conducted at a vibration level of 7 gRMS. The vibration level would be increased by 7 gRMS after each complete thermal cycle - Cycle 1: 7 gRMS, Cycle 2: 14 gRMS, Cycle 3: 21 gRMS, Cycle 4: 28 gRMS, Cycle 5: 35 gRMS. If a Vibration Destruct Limit was not determined during step stress testing, then the Vibration Operating Limit is divided by five. Note that smaller starting vibration and increment levels may be used if the UUT is particularly sensitive to vibration stresses.

10.5. Handling Failures in HALT Testing

10.5.1. During the HALT test process, failure modes will be exposed. The first step when a failure mode is detected is to carefully document all available details about the failure and the associated stresses in the test report. Then investigation is done to determine if the failure is a soft failure (operational limit) or a hard failure (destruct limit). This is achieved by first reducing the stress, dwelling at the reduced stress, and functionally testing the UUT. During this investigation process, power cycling or UUT resets can be used as well. If necessary, the UUT is brought back to ambient and tested at ambient to determine if a failure is hard or soft. At that point, decisions must be made to replace components and continue testing, implement thermal or vibration isolation to work past the identified failure mode, continue testing and ignore the failure mode, or define the failure as an operational or destruct limit and continue with the next stress. If an operating limit is determined, the process of incrementing the stress should continue beyond the operational limit to the destruct limit or the chamber maximum. However, since the UUT may not be operational, it will become necessary to reduce the stress between each dwell and functionally test at a stress level below the operational limit to determine whether the UUT is still functional.

10.5.2. In all cases, the primary goal of HALT testing must be kept in mind – do all that is necessary to push stresses further and find as many failure modes as possible.

11. Post HALT Test Requirements

11.1. The next step in the HALT test is to determine why failure(s) occurred and deciding what should be done about them. Engineering decisions need to be made and justified regarding the response to the HALT test results. This includes root cause failure analysis, corrective action, and Verification HALT testing.

11.2. Root Cause Failure Analysis

11.2.1. An integral part of the HALT test process is the determination of the root cause of the failures identified in the test. This process may involve the need for a failure analysis lab, whether in-house or external. Attributing a root cause to a specific failure requires a full understanding of the problem. When the cause is understood, the appropriate corrective action is implemented. Engineering judgment decisions must be made to assess what corrective action, if any, will be performed.

11.2.1.1. A defined process is followed for all root cause analysis investigations. This should include a procedure and a reporting structure for review and decision making authority to assess completeness and accuracy of the analysis.

11.2.1.2. The root cause analysis process and results for each failure mode must be thoroughly documented, including any applicable pictures or other details that will facilitate understanding of the failure mode..

11.2.1.3. Root cause analysis will include a review of the HALT test documentation of the failure modes found and any changes made to the UUT to work around failure modes during the test. Thermal or vibration isolation techniques can be used during HALT to facilitate the root cause analysis..

11.3. Corrective Action

11.3.1. When root cause analysis is complete, corrective action is implemented. Corrective action for each failure mode found during HALT testing must be thoroughly documented.

11.3.1.1. Corrective actions are summarized in a cause and effect report for review by the appropriate decision-makers within the company. The report shall include a cost estimate/justification of the redesign and estimated product design margin improvement. Based on this assessment a decision is made to implement changes or to leave the product unmodified.

11.3.1.2. The engineering redesign decision process is defined and followed for all corrective actions. This should include a procedure and a reporting structure for review and decision-making authority to assess completeness and accuracy of the information reported.

11.4. Verification HALT Testing

11.4.1. A Verification HALT test is performed after the corrective action process when a product is redesigned. The design or process changes to the product are incorporated in the product samples subjected to this test. The goal of this test is to assess the impact of the corrective action changes. Did they improve or eliminate the earlier discovered defects from the previous test, and are there any other new problems resulting from the changes?

11.4.1.1. A documented process must exist that defines when a Verification HALT test needs to be be performed. It is recommended that a Verification HALT test be performed on all but the least significant of design changes.

11.4.2. Verification HALT test report documentation is required, and should be in the same format, style and detail as the standard HALT test report.

11.4.3. For products in production, changes made to the design subsequent to the last HALT test on the product need to be evaluated for the possibility of product design degradation. It is recommended that when changes are made to products, a Verification HALT test is performed to assess the effect of the change. These changes could be due to redesign or vendor changes.

11.4.3.1. A documented process must exist that defines which engineering or process changes will require a Verification HALT test (i.e. after one or more engineering changes, after major subassembly/component change). It is recommended that this Verification HALT test be performed on all but the least significant of engineering changes.

11.4.4. HALT testing should be performed periodically, typically every 3 to 9 months on production products. This may not be necessary for products that are submitted to a HASS production process.

12. Possible Modifications to a HALT Test

12.1. While the definition of HALT is rigidly defined as random repetitive shock vibration combined with rapid thermal stresses, the steps used to drive the UUT to failure may vary based upon the product type, the experience of the test engineer, the needs of the company, and other factors. At many points engineering judgment is used to determine if corrective action is necessary, when to stop incrementing a stress, how best to troubleshoot a failure mode, etc. In some cases changes to the process are made. If these changes are carefully thought out, and are in agreement with the basic philosophies of HALT, then it may be reasonable to modify the procedure. It is important that the risk of compromising the effectiveness of the HALT test is fully understood. That understanding requires a thorough knowledge of HALT philosophy and purpose. The following are possible modifications to the HALT process and the factors to take into account when considering such modifications.

12.2. Changing a HALT Test to Decrease Test Time

12.2.1. In some cases, the product's thermal tolerances across a limited range are well understood before HALT testing begins. In these cases, it may be feasible to skip the first few thermal steps, both hot and cold, perhaps even stepping directly to the highest known functional limit for the product. This will reduce the test time by reducing the total number of dwells necessary in the test. Some of the risks associated with this approach are that failures related to the accumulated fatigue of moving through the elevated thermal stresses, or failures due to transient conditions that only occur at specific thermal levels, may be missed.

12.2.2. Similarly, the elimination of the first few vibration steps may be considered. There is more risk associated with this change, as the accumulated fatigue during vibration can be an important factor in the final failure level, and skipping steps reduces that accumulated fatigue. Increasing the vibration dwell at the higher gRMS levels may help offset that risk.

12.2.3. Moving directly to a combined environment rather than performing separate stress testing is often considered. This is not recommended for three key reasons. First, there is a decrease in the accumulated vibration stress as described above. Second, without doing the thermal and vibration step stresses, the limits used in the combined environment are not known. In this case, the limits would have to be estimated somehow, introducing a possibly significant source of error. Third, it is more difficult to debug failures found in a combined environment because the stress that induced the failure is not known.

12.2.4. In general, reduction in dwell times, particularly thermal dwell times, may be considered if the product has very low mass and good thermal transition rates, such as a circuit card mounted on standoffs.

12.3. Testing Expensive Products or Limited Samples of Products.

12.3.1. If a test sample is expensive relative to the expected revenue stream of the product, the cost of four samples for HALT testing may have a negative impact on the ROI for the testing. In this case, an experienced HALT test manager can apply changes to the test procedure accordingly. The primary difference is, before testing begins, the engineers involved must determine the thermal or vibration levels at which there is a high likelihood of hard failures occurring. To avoid these hard failures, stresses are not increased to those levels. Instead, stress testing is stopped before those levels are reached, or earlier if failure modes are found that indicate the possibility of imminent hard failure modes. At the conclusion of the testing, the unit can then be tested to failure in the combined environment, or using the stress determined to be the most valuable based on earlier test results. The obvious risk with such changes is that hard failure modes may not be identified.

12.4. When a Verification HALT test is done to verify corrective actions, an Abbreviated Verification HALT test may be considered. This decision is based on the significance of the changes made, the likelihood of the changes inducing new failure modes, and the necessity of full HALT test stresses to confirm that the changes were effective. This HALT test may use larger (2 X) increments for the step stress environments and more attention given to the stress levels that induced failures during the first HALT test.

13. Table 1: Acronyms

ASD: Acceleration Spectral Density
CA: Corrective Action
DL: Destruct Limit
DoF: Degrees of Freedom
ED: Electrodynamic
FFT: Fast Fourier Transform
HALT: Highly Accelerated Life Test
HASS: Highly Accelerated Stress Screen
LDL: Lower Destruct Limit
LOL: Lower Operating Limit
OL: Operating Limit
PSD: Power Spectral Density
RCA: Root Cause Analysis
RMS: Root Mean Square
ROI: Return on Investment
RS: Repetitive Shock
UDL: Upper Destruct Limit
UOL: Upper Operating Limit
UUT: Unit Under Test
VDL: Vibration Destruct Limit
VOL: Vibration Operational Limit

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