

HALT Guideline

Change Record

| Rev | Originator | Description of Change |
|------------|---------------------|--|
| 3.0 | D. Rahe (QualMark) | Third draft. |
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1.0 Purpose

- 1.1. This document is intended for the use of companies as a guideline to perform the HALT process. Adherence to this guideline will assist to achieve optimal HALT test results and delivery of more robust/rugged products to the marketplace.

2.0 Scope

- 2.1. The process elements to successfully implement and perform HALT are defined in this document. It identifies technical responsibilities, facility and equipment requirements and testing practice competencies. Adherence to this document will provide the fundamental guidelines to implement and operate a successful HALT test. This guideline applies to a diversified mix of product segments, including electronic assemblies electro-mechanical assemblies, and may be applicable to certain mechanical assemblies as well.

3.0 Definitions

- 3.1. Broadband Vibration – vibration that contains energy over a broad frequency range (i.e. 20 to 10,000 Hz).
- 3.2. 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.
- 3.3. Destruct Limit (DL) – the stress level where one or more of the product's operating characteristics are no longer within specification. The product does not recover once the stresses are reduced. Also, know as a hard failure.
 - Upper Destruct Limit (UDL)
 - Lower Destruct Limit (LDL)
- 3.4. Functional Test – a test of the product that measures functionality, product operation, and critical parameters to determine if product fails to perform to specifications or degradation has occurred within the product. This test may include internal diagnostics. Functional testing is to be performed throughout the environmental stresses of HALT.
- 3.5. Grms – Vibrational G's in root mean square, where G is the acceleration due to gravity.
- 3.6. HALT (Highly Accelerated Life Test) - a process that utilizes a step stress approach in subjecting products to varied accelerated stresses to discover design limitations of the product. HALT is intended to discover the stress limits of a product and identify product weaknesses.
- 3.7. Operational Limit (OL) – the stress level prior to where one or more of the product's operating characteristics are no longer within specification. The product recovers when the stress is reduced. Also know as a soft failure.
 - Upper Operating Limit (UOL)
 - Lower Operating Limit (LOL)

- 3.8. Power Spectral Density (PSD) – a measurement of the amplitude and frequency content of a random vibration spectrum, expressed in units of g²/Hz. Also commonly referred to Acceleration Spectral Density (ASD).
- 3.9. Quasi-Random Vibration – Non-periodic vibration that possesses all frequencies within a band limit 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.
- 3.10. Repetitive Shock Vibration (RS) – a vibration originating from a repeated shock impulse excitation. Typically created from pneumatic hammers impacting a vibration table to which test samples are attached.
- 3.11. 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.
- 3.12. Six Degree of Freedom Vibration (6DOF) – vibration that has simultaneous acceleration energies in three translations and three rotations.
- 3.13. Step Stressing – An experimental process of sequentially incrementally increasing a stress level to identify product limitations.
- 3.14. Thermocouples – temperature sensors that are created when two dissimilar metals are joined, i.e. fused together. A thermoelectric current flows and creates a voltage potential proportional to temperature.

4.0 Staffing Requirements

- 4.1. The HALT team should include those individuals involved in the design and test of the product. HALT testing typically will require multiple disciplines within the facility to cooperate. These disciplines include design engineering and test engineering expertise on the product to HALT. Design engineering will assist in the development of the product 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, but must be available on an as needed basis. Other disciplines should also include reliability engineering, manufacturing engineering, and the personnel who run the HALT system, if they are not part of the aforementioned groups. Each discipline shall take responsibility for their area of expertise as HALT result issues arise.
- 4.2. A failure analysis lab (in-house or outside lab) may be required to determine root cause analysis on failures found during HALT.
- 4.3. Cross-Functional Committee Meetings: This committee should meet on a regular basis (i.e. monthly) to define HALT test requirements, review past HALT 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 product HALT.
- 4.4. Pre-HALT Meeting Agenda: The critical topics of discussion include defining the HALT test specifications, the functional test requirements, methods of fixturing the product to the table, product components and/or locations to monitor with thermocouples and accelerometers.
- 4.5. Post HALT Meeting Agenda: a review of HALT results including discussion of failures and corrective action planning.

5.0 Equipment Requirements

5.1. HALT Chamber Requirements

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

5.1.1. Vibration: Chamber technology for HALT is:

- Repetitive shock vibration that is 6 degree of freedom (3 linear and 3 rotational) multi-axis and quasi-random
- Broadband energy exists from 10 Hz up to 10,000 Hz
- 35 Grms minimum vibration table output with no load

5.1.2. Thermal: the goal is to force rapid thermal change rates on the product. It is additionally important that the chamber has sufficient air velocity to produce the desired rapid thermal rates of change as measured on the product and to maintain thermal stability.

- High rate of change (minimum air temperature average of 45°C/minute)
- Thermal range from -80°C to 170°C

5.2. Laboratory Test Equipment

Product response data is acquired during the HALT process. This data includes thermal, vibration and product functional performance.

5.2.1. The collection and storage of thermal data is required to provide credible evidence that thermal stress was applied to the product. 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.

5.2.2. The collection and storage of vibration data is required to provide credible evidence that vibration stress was applied to the product. 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.

- 5.2.3. Accelerometers for the measurement of product response from vibration. These accelerometers should be low mass type (e.g. # 4 grams), with frequency response capability of 2 Hz to 10KHz, 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 sample tested.
- 5.2.4. Thermocouples for the measurement of product thermal response. The use of thermocouple wire is required. Thermocouples used for HALT should have sufficient stability characteristics through the temperature range of the chamber (approximately -100°C to +200°C). The diameter of the thermocouple wires size should not exceed 22 gauge.
- 5.3. Test Equipment Setup Requirements
- 5.3.1. The HALT system, ancillary test equipment setup and operation is performed in accordance with manufacturer's instructions.
- 5.3.2. Verify that all test equipment to be utilized for the HALT is calibrated and operable. Document the test equipment in the test reporting documentation including equipment description, model number, serial number, and calibration status.

6.0 Test Samples

The test samples are uniquely identified by a serial number or other means of identification.

6.1. Test Sample Setup Requirements

- 6.1.1. Ensure that a thermocouple (control thermocouple) is properly attached to the test sample to provide the reference for the chamber thermal setpoint adjustment. This is the thermocouple used for HALT control systems that use a closed loop feedback thermal measurement for chamber temperature control. The product thermocouple is attached to a location that provides an accurate approximate average of the temperature of the sample. The product thermocouple should be placed on an exposed surface on the test unit, preferably in an area of relatively low thermal mass. This thermocouple should not be placed on or near a heat-generating component, nor inside a closed portion of a product
- 6.1.2. Secure the test sample(s) to the vibration table using a suitable test fixture that maximizes the thermal and vibration energy to the sample. The goal is to stimulate the product tested to accelerate fatigue damage to uncover product weaknesses. Therefore, optimization of maximum stress to the product is beneficial.
- 6.1.3. Product size and weight should be taken into account when determining feasibility of a particular chamber to properly stress the product.
- 6.1.4. Thermal transition rates on the sample may be improved by modification of the test sample chassis (i.e. remove panels/covers, create openings for air passage through the sample by drilling holes in chassis).
- 6.1.5. Product response thermocouples are attached to adequately assess the response of the sample(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 sample to provide a measure of the dwell time necessary to achieve temperature stabilization.
- 6.1.6. The goal for vibration is one-to-one transmission of table energy to the sample(s).

- 6.1.7. Product response accelerometer(s) are attached to adequately assess the response of the sample(s) to the input vibration. Suggested placement: near mounting hardware, at or near point of greatest deflection (center of PCB), near 'suspect' weak area.

7.0 Functional Testing Requirements

- 7.1. The functional test of the sample under test should provide adequate coverage to determine overall performance of the sample and the occurrence of multiple types of failure modes. The test must exercise the major functions of the product with a feedback measurement of performance of each function. The goal of the functional test is to achieve 100% test coverage, or as complete test coverage as is possible, of the sample under test.
- 7.2. Product Specific Stresses: These stresses are specific to the product tested and are performed during each step stress to enhance additional failure precipitation and detection. These stresses should include power cycling, and may include line voltage margining, line frequency margining, DC supply voltage margining, on-board oscillator margining, output loading, and any others 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 process.
- 7.3. The functional testing of the sample under test 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. Identifying how and what is tested on the product. Documentation shall also provide evidence of how the functional test objectives as defined in the pre-HALT meeting were achieved.
- 7.4. Before beginning the HALT process, the test sample(s) 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 test samples, if applicable.
- 7.5. At each level of applied stress, functional testing is performed on the sample to evaluate the operation of the sample. Documentation shall detail the occurrences of sample degradation and the conditions at which they occurred, including the operating and destruct limits of the sample and any other important comments.

8.0 Test Reporting and Documentation

8.1. Data Collection and Storage Requirements

8.1.1. 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. Product response measurements and the HALT system data including temperature data and vibration data are collected during the entire test.

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

- the identification of the person(s) who performed the HALT,
- the samples tested identified by a unique identifier (e.g. serial number) including revision level,
- deviations from the HALT procedure,
- dates of testing,
- a description of the product fixturing used during testing, including photographs to support the description,
- specific thermal and vibration data measurements (supported by tables, graphs, photographs as appropriate),
- locations of product response sensors (thermocouples and accelerometers),
- description of the functional testing performed on the samples,
- the performance of the test samples to the HALT stresses, detailing the occurrences of sample degradation and the conditions at which they occurred, including the operating and destruct limits of the sample and any other important comments,
- the root cause analysis (RCA) information and results,
- any corrective action (CA) implemented.

9.0 HALT Test Procedure

This section defines the methods or activities that are performed during the actual process of performing a HALT on a product.

9.1. Thermal Step Stress Test

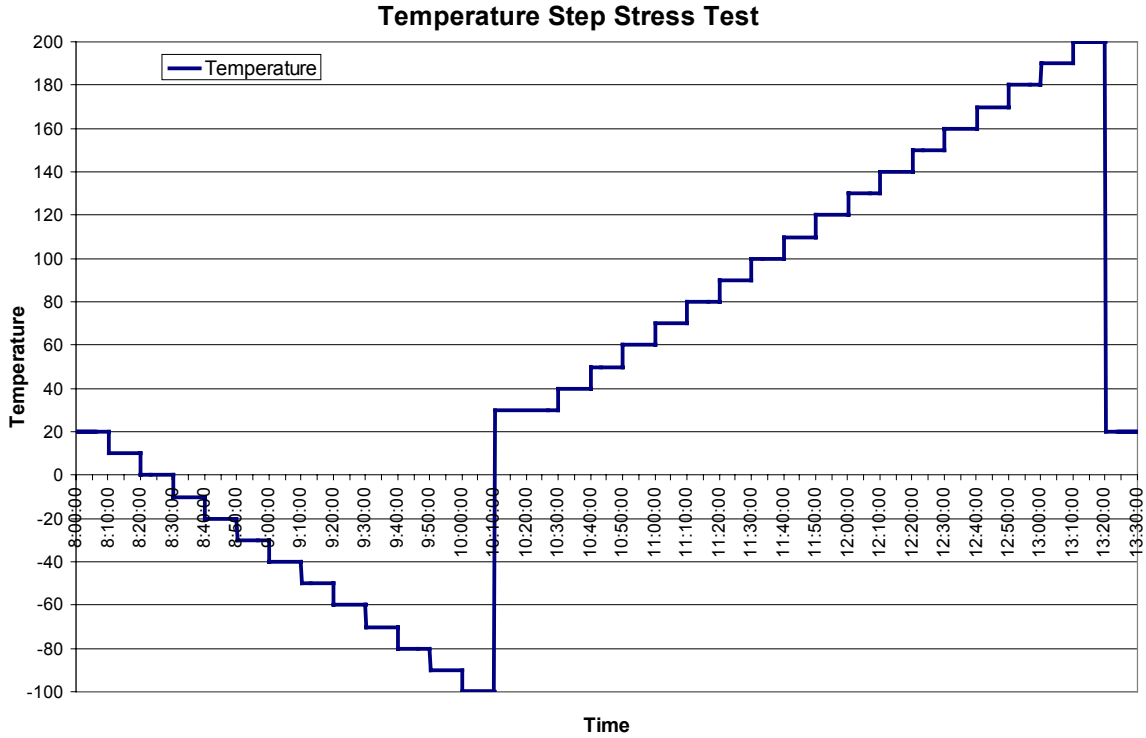
9.1.1. Thermal Step Stress shall begin at ambient (defined as 20°C to 30°C).

9.1.2. The step increments are a maximum of 10°C.

9.1.3. The dwell time is a minimum of ten (10) minutes following stabilization of the sample at the setpoint temperature as determined by the sample thermocouple response. Complete functional testing follows the dwell period and may be performed throughout this step.

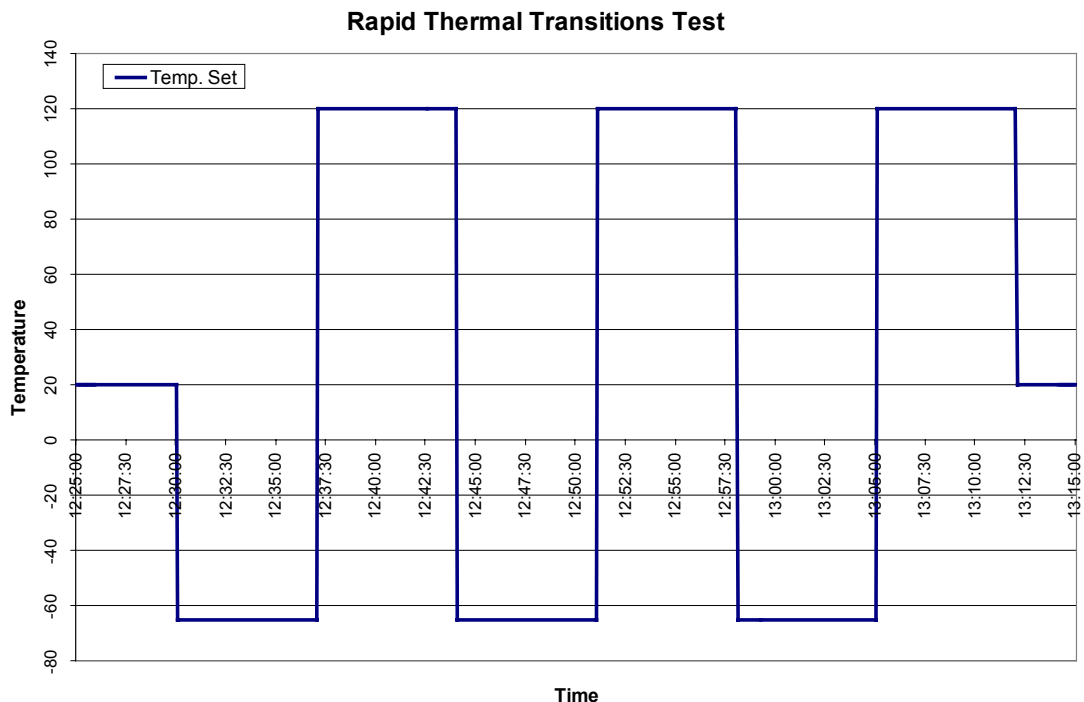
9.1.4. The thermal step stress is continued until the operational limit of the sample is determined or the chamber maximum is achieved.

9.1.5. Once the operating limits are determined, the process of incrementing the temperature stress in 10°C should continue beyond the operational limit to the destruct limit or the chamber maximum. However, since the sample may not be operational, it will become necessary to reduce the thermal stress between each dwell to determine whether the sample is still functional. I.e., return to 20°C or a temperature between 20°C and the operational limit.



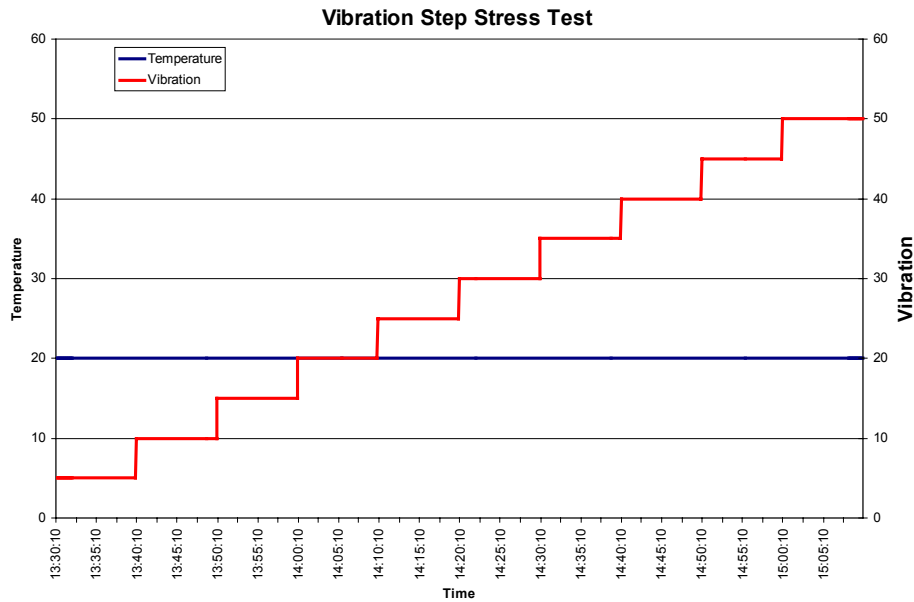
9.2. Rapid Thermal Transitions Stress Test

- 9.2.1. 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.
- 9.2.2. 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. 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.
- 9.2.3. The dwell time is a minimum of five (5) minutes following stabilization of the sample at the setpoint temperature as determined by the sample thermocouple response. The dwell time is increased to allow higher mass components to reach at least 80 percent of the thermal range.
- 9.2.4. Functional testing of the sample is conducted on a continuous basis throughout the transition (ramp) portions of the exposure, where possible, to determine whether there are thermal rate sensitive issues.



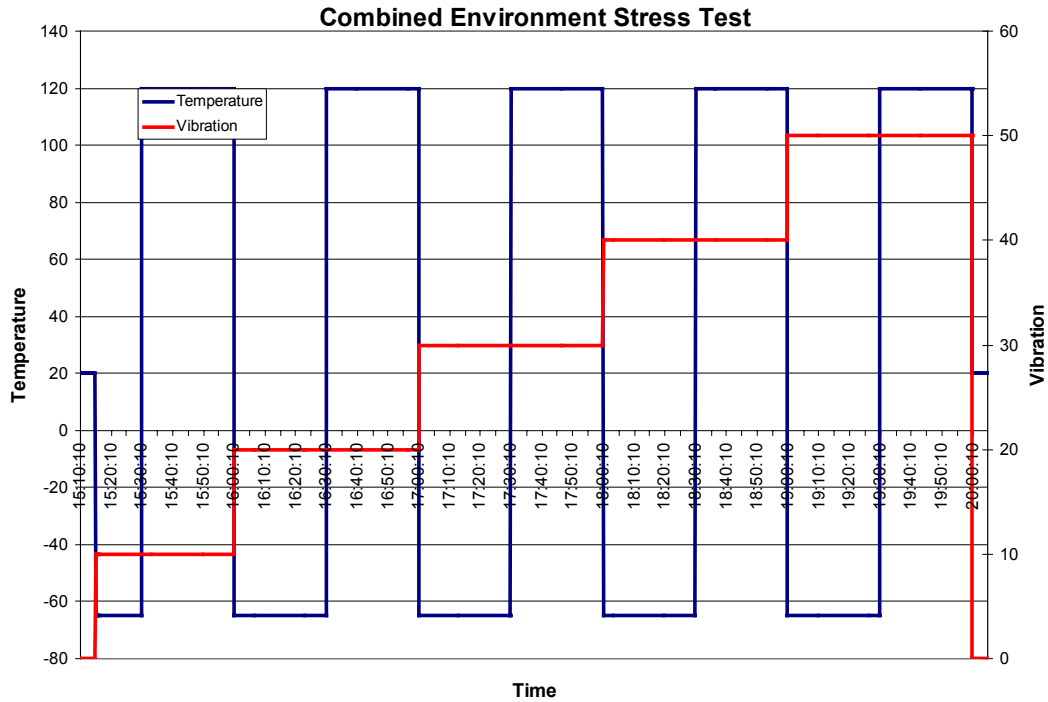
9.3. Vibration Step Stress Test

- 9.3.1. Vibration step stress begins at a chamber setpoint of 2 to 5 Grms, as measured over a 2Hz to 2000Hz or greater bandwidth (5 Grms recommended.) Then increased in 2 to 5 Grms increments (5 Grms recommended) upon completion of the dwell period and subsequent functional test.
- 9.3.2. The dwell time at each level of vibration is a minimum of ten minutes. Functional testing is performed at the conclusion of the ten minute dwell period. Thus the total dwell at each level of vibration is dictated by the length of time it takes to run one cycle of functional testing on the sample. Note that it is recommended that the functional test be performed throughout the step, however it must minimally be performed at the conclusion of the ten minute dwell.
- 9.3.3. The vibration step stress is continued until the operational limit of the sample is determined or the chamber maximum is achieved.
- 9.3.4. Once the operating limit is determined, the process of incrementing the vibration stress in the previously defined increments continues beyond the operational limit to the destruct limit or the chamber maximum. However, because the sample may not be operational, it is necessary to reduce the vibration stress between each dwell to determine whether the sample is still functional. This could include a return to 0 Grms or a level between 0 Grms and the operational limit.



9.4. Combined Environment Stress Test

- 9.4.1. A minimum of five (5) Combined Environment cycles is required unless a destructive failure is encountered prior to completion of the five cycles.
- 9.4.2. The thermal profile for the Combined Environment test is performed by cycling between the thermal operational limits. The minimum dwell period at each thermal extreme is ten minutes.
- 9.4.3. The starting vibration level for the five (5) required cycles is determined by dividing the maximum vibration level applied during Vibration Step Stress by five. The vibration level is increased by the same number during each subsequent thermal cycle. Therefore, if the sample experienced a destruct failure at 35 Grms during the Vibration Step Stress, 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 destruct limit was not determined during Vibration Step Stress, then the maximum vibration level attained is divided by five. Note that smaller starting vibration and increment levels may be used.



9.4.4. Functional testing of the sample is required following all dwell periods of the test cycle. The dwell period is extended accordingly to accommodate the length of the functional test. Note that it is recommended that the functional test be performed throughout the step, however it must minimally be performed at the conclusion of the ten minute dwell.

10.0 Post HALT Test Requirements

The HALT process continues after completion of discovering the failure modes. The next process is determining why the failure(s) occurred and deciding what should be done about them. This process is the root cause analysis and corrective action process. Engineering decisions need to be made and justified regarding the action that will be taken from the HALT results.

10.1. Root Cause Analysis: an integral part of the HALT process is the determination of the root cause of the failures identified from 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 judgement decisions must be made to assess what corrective action, if any will be performed to eliminate, minimize or live with this failure.

- The root cause analysis process must be documented with the failure mode, the exact cause of the failure or the suspected cause if uncertain. This should include the results of a failure analysis lab, if used, with pictures of damage at the flawed site.
- Tracking of the process – documentation / reporting process.
- The process is defined and 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.
- The facility shall have failure analysis capability, or may utilize an external / independent facility to perform this responsibility.
- The RCA process begins during the HALT test, as functional limitations or failures are encountered efforts are made to understand the failure mode. This can be accomplished by some limited sample ruggedization implemented during the HALT service. This is beneficial to allow the sample to be stressed at higher levels of stress in order to find additional failure modes. Another method in which further stress levels can be investigated is through component isolation (i.e. placing a weaker component external to the HALT chamber and wiring it to the sample within the chamber to maintain system functionality).

- 10.2. Corrective Action: following the understanding of the failure mode through the root cause analysis process a corrective action plan is incorporated. The company is responsible to document, report, and as necessary, implement corrective action for all design and process defects identified during the HALT.

The corrective action “fixes” are summarized with a cause and effect report for review by the appropriate decision-makers within the company. This 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 the redesign changes or to leave the product unmodified.

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.

- 10.3. Verification HALT: this HALT process 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 HALT. The goal of this HALT is to assess the impact of the corrective action changes implemented. Did they improve or eliminate the earlier discovered defects from the previous HALT, and are there any other new problems resulting from the changes.

- A documented process must exist to establish the criteria for what conditions will require verification HALT to be performed. It is recommended that this Verification HALT be performed on all but the least significant of design changes.
- The verification HALT that is performed would be most beneficial if the full HALT process were adhered to. However, a modified HALT is also acceptable. This HALT may use larger (2 X) increments for the step stress environments and more attention given to the stress levels that are of concern, i.e. the stress levels that the sample failed during the first HALT.
- HALT test report documentation is required, that identifies the results and provides data that summarizes the results. This report should be in the same format and style as the standard HALT report.

- 10.4. Product Engineering Changes: for products that are in production, changes made to the design subsequent to the last HALT on the product need to be evaluated for the possibility of product design degradation. It is recommended that when changes are made to products, that a HALT is performed to assess the effect of the change. These changes could be due to redesign or vendor changes.

A documented process (perhaps contained in the company Engineering Change Order - ECO) must exist to establish the criteria for what conditions will require verification HALT to be performed (i.e. after one or more engineering changes, after major subassembly/component change). It is recommended that this Verification HALT be performed on all but the least significant of engineering changes.

HALT 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.