Reliability Improvement of Measuring Instruments using HALT

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[Summary] Anritsu has introduced the Highly Accelerated Life Test (HALT) to improve the reliability of electronic measuring instruments. HALT finds potential weaknesses quickly by applying high level stress to the Device Under Test (DUT). It can determine design-margin operating and destruct limits. Furthermore, it improves product reliability and stable manufacturing by expanding margins and reducing costs. This article describes the introduction of HALT by Anritsu, some HALT examples and improvements, and the validity of HALT.

1 Introduction

Electronic measuring instruments are traditionally seen as precision equipment requiring gentle handling in a relatively protected environment. However, test instruments used on electronic equipment production lines must have high reliability supporting 24-hour continuous operation without breakdown because a faulty test instrument impacts line downtime directly.

Recent economic growth in the newly industrializing economies (NIEs) has driven the movement of production lines for electronics to the NIEs and there is an urgent need for test equipment with high reliability even under severe environmental conditions.

Anritsu introduced the Highly Accelerated Life Test (HALT) to assure its ability to build high-reliability measuring instruments meeting these market demands.

This article explains how Anritsu uses HALT to assure high reliability and describes some actual usage examples.

2 Outline of HALT

HALT is a form of destructive testing that applies stresses exceeding the guaranteed environmental performance from the operating limits to the destruct limits to confirm design margins in an accelerated time period. By testing from the operation to destruct limits, it is possible to uncover latent weaknesses in products that can then be strengthened to improve product reliability.

As shown in Figure 1, the test procedure applies cooling, heating, rapid thermal transitions, vibration, and combined environment stresses to the DUT in a series of five phases to stress the DUT up to its operating limits in each phase.

When some abnormality is confirmed during testing, the causal fault location is specified, improvements and strengthening are made and then the test is applied again with higher stresses.

By using this procedure, HALT does not perform Pass/Fail testing against fixed reference values, but helps strengthen product weakness through repeated test/analysis/repair/test iterations to improve product quality by widening the product operation and fault margins. Figure 2 shows an image of the widened operation and fault margins using HALT.

The HALT concept first appeared in the USA in the 1980s as a method for improving the quality of military hardware. It spread subsequently to aviation and automotive industries centered in both Europe and N. America. HALT was late in reaching Japan with the first applications to improve the quality of electronics and industrial products appearing around 2000.

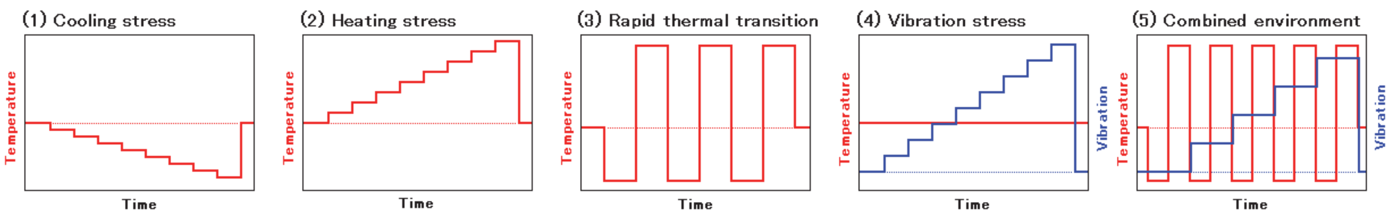

Figure 1 HALT Procedure

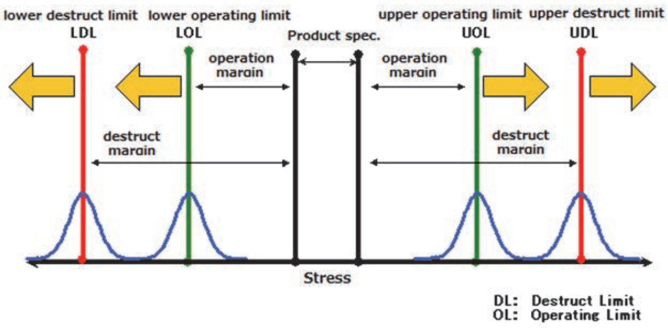

Figure 2 HALTS Terms and Concepts

3 Anritsu HALT Introduction

Anritsu first introduced HALT at its US R&D section in 2001, followed by a trial period between 2005 and 2007 at external test sites and then full-scale introduction in the R&D section of the Atsugi plant.

The in-house HALT facility locations were determined based on meeting the following conditions.

(1) Installation Location:

Since HALT must support real-time monitoring and analysis of fault conditions during testing, engineers with a good knowledge of the DUT's internal structure must participate in the tests. Consequently, the HALT facility is located in the same building as the R&D section.

(2) HALT Chamber:

The size of the chamber was selected to provide room to spare for testing standalone desktop instruments.

The installed HALT chamber is a Typhoon 2.5 model with the following main specifications manufactured by QUALMARK Corporation of the USA.

- Table Size: 762 mm × 762 mm
- Vibration Stress
  - Max. Acceleration: 50G rms (10 Hz to 5 kHz)
  - Max. Deployed Mass: 145 kg
  - Vibration Method: Wide Band, 6-axes Random
- Temperature Stress: –100°C to +200°C
  - Temp. Ramp Rate: 70°C/minute
  - Heating Method: Ni-Cr Heater
  - Cooling Method: Liquid N_2 Jet

Figure 3 shows the external view of the installed HALT chamber.

Figure 3 External View of HALT chamber

(3) Safety Considerations:

The HALT chamber uses large volumes of liquid N_2 for cooling and purging to prevent condensation. When liquid N_2 becomes a gas at room temperature, its volume expands to about 700 times. Since liquid N_2 leaks can purge oxygen from an enclosed space and create a risk of hypoxia for anyone nearby, both a low-oxygen warning system and linked ventilation system are essential from the safety viewpoint.

4 HALT Procedure

4.1 Preparation

The key points in implementing HALT tests are scrupulous monitoring of the DUT operating conditions during testing and specification of any fault locations based on the monitoring results.

Most of the internal parts of an electronic measuring instrument are mounted on PC boards and the parts count can range from several thousands to many tens of thousands. Even when an abnormality is discovered by random testing, if the location of the causal fault cannot be specified, simply evaluating margin values will not lead to improve reliability.

To locate fault locations quickly, it is important to prepare well by having a thorough understanding of the DUT operating principles and circuits so that the optimum monitoring procedures can be followed.

The following list describes some examples of HALT preparations.

(1) Using FMEA

When using instruments constructed from multiple circuit blocks, it is very important to have a thorough prior understanding of what types of faults can occur in which blocks. The Failure Mode and Effect Analysis (FMEA) method can be very effective for this purpose. In other words, knowing possible faults for each block and the relationship with abnormalities occurring in the DUT can assist early discovery of the causal fault location. Furthermore, specifying fault locations can help optimize monitoring locations and check items in each test phase.

(2) Monitoring Internal Signals

When an instrument is constructed to pass signals via several circuit modules, the wiring between modules must be extended beyond the HALT chamber to easily pinpoint circuit modules causing abnormalities.

In particular, even when externally monitoring characteristics to check an instrument, sometimes with feedback circuits where operation abnormalities cannot be monitored, monitoring the conditions in the feedback loop can help confirm changes and reproducibility in key device characteristics.

Figure 4 shows the Phase Locked Loop (PLL) of a synthesizer circuit as a typical feedback type circuit. Simply monitoring the output signal cannot find circuit abnormalities because the PLL synthesizer maintains the frequency lock automatically using a loop even when the characteristics of the voltage controlled oscillator (VCO) forming a key part of the circuit change. As a result, changes in the VCO characteristics can be confirmed by monitoring the VCO tuning voltage.

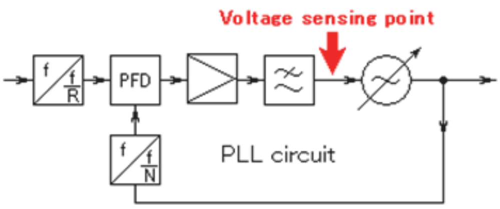

Figure 4 PLL Circuit Monitoring Example

Figure 5 shows an example of the monitoring wiring run from the DUT in the HALT.

(3) Confirming Operating Section Operability

To prevent condensation in the HALT chamber as a result of the rapid temperature changes, the chamber is flooded with N_2 gas. Consequently, the construction must form a gastight seal, meaning an operator cannot touch the DUT during testing.

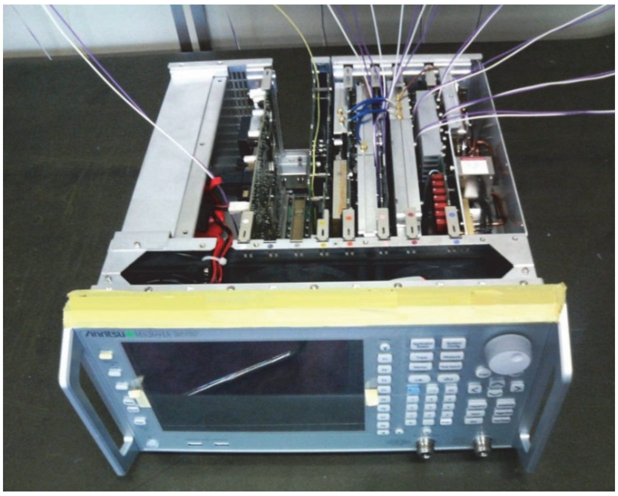

Figure 5 DUT Monitoring Example

As a result, confirmation of operation functions such as panel keys requires a remote operation assembly. To resist the vibration stresses and extreme temperatures in the HALT chamber like the DUT, this assembly must also have a simple and strong structure. Figure 6 shows a concrete example of remote panel operation using a wire.

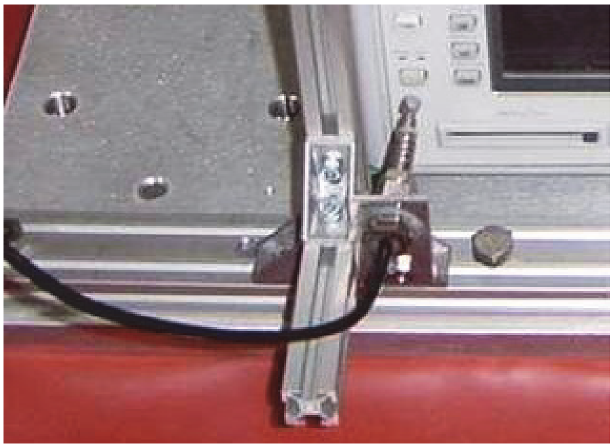

Figure 6 Panel Key Operation Equipment

(4) Considering Devices Without Tolerance to HALT

Unit parts such as commercially available power supply and CPU Boards also have operational limits detected by extreme stresses. When the DUT contains these types of items, it may be necessary to stop operation of protective circuits so as to prevent test obstacles.

Additionally, already known parts that may fail under extreme testing, such as hard disks and LCDs, etc., may require removal from the stress factors, by connecting them outside the HALT chamber, etc.

4.2 HALT Operation and Fault Location

As described in section 1, HALT performs a dozens of series of related tests to confirm the operation of the DUT. Some parts of the procedure for confirming the conditions of as many circuit blocks as possible are automated.

If an abnormality is confirmed from the test results, the operation settings are changed and detailed monitoring is performed to pinpoint the exact location of the operation fault. Additionally, the temperature and vibration stressors may be reduced to check whether or not normal operation is recovered.

4.3 Improvement Evaluation Based on HALT Results

It may not be necessary to improve every abnormality found by HALT. The necessity for improvement has to be evaluated based on factors, such as the usage environment.

Some bases creteria are explained below:

(1) Items requiring improvement:

- Items where the characteristics change irreversibly under stress and where the amount of change has no margin relative to the design specifications.
- Items with no margin relative to the product specification range when stressed to the abnormal conditions and where abnormality may occur even under normal operating conditions due to random dispersion in parts quality, etc.

(2) Items not requiring improvement:

- Items with sufficient margin relative to product specifications when an abnormality occurs and when normal operation is recovered when the stressor is removed even the functions and performance are damaged by temporarily imposed stress.
- Items with predefined stress tolerances that have protection mechanisms or usage warnings for operators.

5 Weaknesses Found by HALT and Improvements

The following types of phenomena can be expected at each HALT test phase.

- Lo and Hi Temperature Stresses: Drift in device characteristics and abnormal operation
- Rapid Thermal Transition Stress: Physical damage due to thermal expansion and contraction
- Vibration Stress: Parts detachment, damage, solder breaks, connector and relay contact failures

Some concrete of weaknesses that have been discovered using HALT and the improvements are outlined in the following section.

(1) Change in Characteristics of Time Constant Circuit

Under low temperature stress of –30°C, an aluminum electrolytic capacitor used in a monostable multivibrator IC time constant circuit (Figure 7) showed an increase in the ESR value. As a result, at the monostable multivibrator IC reset, the capacitor discharge was inadequate and no pulse was output. The aluminum electrolytic capacitor was replaced by a polymer organic semiconductor type with low ESR temperature dependency.

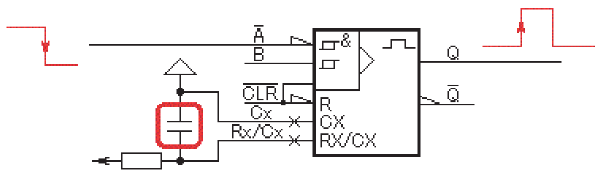

Figure 7 Monostable Multivibrator IC

(2) Loss of Frequency Lock in PLL Synthesizer Circuit

Under low temperature stress of –55°C, the 100 MHz PLL synthesizer circuit lost the frequency lock (Figure 8). The 100 MHz quartz resonator used in the reference signal generator of this synthesizer suffered frequency drift causing the PLL to go out of range. However, since the part had sufficient margin for the normal operating environment when the oscillation frequency returned to normal, there was no need to take corrective actions.

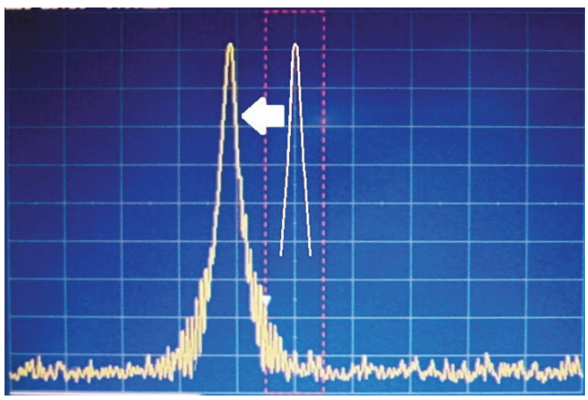

Figure 8 Unlocked Signal Drift (Span = 5 kHz)

(3) Misoperation Due to Swelling of Acryl Panel Keys

Under low temperature stress of –60°C, the acryl front panel contracted and the panel keys failed to make contact. Since this problem did not occur under normal usage and storage conditions, it was evaluated as not requiring corrective action.

(4) Logic Circuit Design Error

Under low temperature stress of –20°C, the logic circuit did not operate against to the design. Applying 5 V at the logic signal input of the 3.3 V FPGA caused misoperation. The FPGA logic input circuit has a body diode between it and the power supply. In normal operation, current does not flow through this body diode but inputting a voltage exceeding the power supply voltage caused damage allowing current to flow, and an increase in the leak current (Figure 9). This circuit mis-design was not discovered because mis-operation did not occur because the leak current was extremely small in the nominal product operation temperature range. However, the increased leak current caused by the HALT temperature stress forced the condition to a constant High level. Since this circuit error was discovered at the design stage, it could be remedied at an early stage.

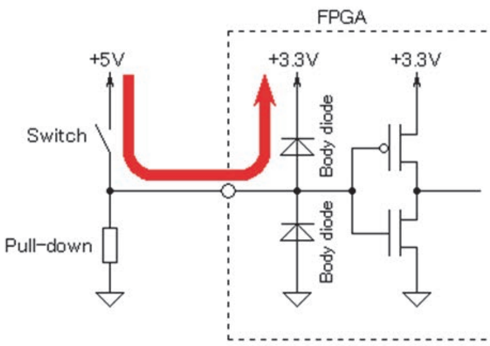

Figure 9 FPGA Input Circuit

(5) Detached Electrolytic Capacitor

Under vibration stress, an aluminum surface mounted electrolytic capacitor became detached from the PC board. The case was not a solder break but was actually breaks at the part leads (Figure 10). This problem happens in all DUTs, but since damaging-vibration stress levels do not occur in the normal usage environment, corrective actions were not deemed necessary. However, because the part detachment caused failure in the HALT tests, we reinforced the part mounting with an adhesive.

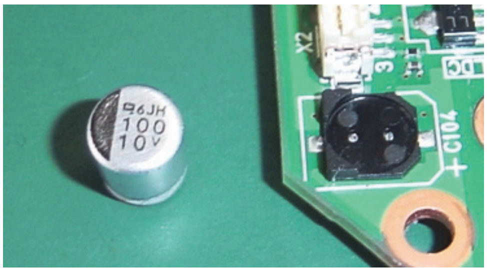

Figure 10 Detached Aluminum Electrolytic Capacitor

(6) Cracked Backup Battery Lead

Under vibration stress of 45G rms, the leads of the backup primary battery mounted on the PC board cracked (Figure 11). Although similar to the previously described broken leads of the aluminum electrolytic capacitor, a cracked battery lead runs a risk of internal short circuit, so the battery mounting was strengthened with an adhesive, especially in handheld-type devices.

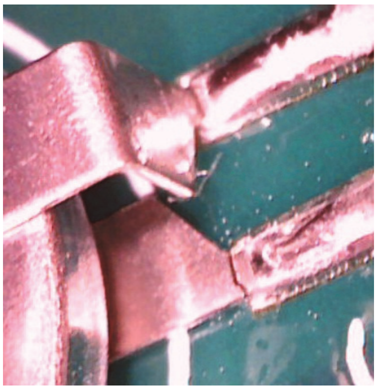

Figure 11 Fractured Backup Battery Lead

(7) Disconnected CF Memory card

Under vibration stress of 25G rms, the compact flash (CF) memory card used for saving data internally slipped out of its connector to lose contact (Figure 12). The CF card connector had a short mating fit causing lost contact when the card moved slightly so the corrective action was apllied to another CF card used products.

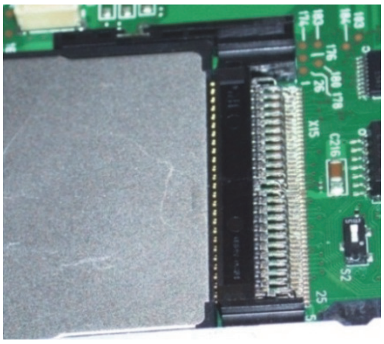

Figure 12 CF Card Slipping from Connector

(8) Damaged Crystal Resonator

Under vibration stress of 50G rms, the equipment measurement drifted. The cause was found to be damage to the crystal resonator holder of the oven-controlled crystal oscillator (OCXO) used as the reference frequency source (Figure 13). This OCXO is used in many products but since there have been no reports of this type of fault, corrective actions were not taken and this was only recorded as a weakness of this part.

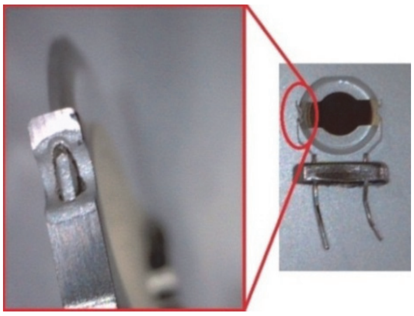

Figure 13 Damaged Crystal Resonator

(9) Faulty Serial-ATA Connector

Under vibration stress of 20G rms, the serial-ATA connector to the hard disk drive suffered disconnection and loss of function. Since this was a problem with the connector form and materials, it was solved by changing to a different part maker.

6 Effect of Improved Reliability using HALT

So far, we have run HALT tests on more than twenty products. Figure 14 shows the types of faults that were discovered during the HALT stress phase. The cooling, heating and vibration stress phases suffered broadly similar rates, whereas the rapid thermal transition and combined environment stress tests suffered just a few failures.

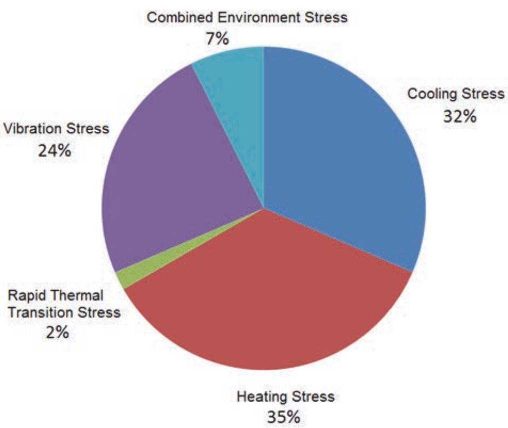

Figure 14 Faults Found by HALT

In addition to electrical weakness, the cooling and heating stress tests revealed mechanical weaknesses caused by the characteristics of materials (thermal expansion, etc.). The vibration stress tests naturally uncovered mechanical weaknesses with many cases of damage.

Among the abnormal phenomena uncovered by HALT, about 20% had specific causes that were improved. The remainder were evaluated as not requiring corrective action because they had very low probabilities of occurring under normal usage conditions.

The purpose of HALT is to improve reliability by strengthening these types of weak points in products, but it also helps troubleshoot faults occurring in the market by identifying known product weaknesses.

Furthermore, knowledge about weaknesses uncovered by HALT can be fed-back into designs for the next generation of products to help improve design reliability knowhow and product quality.

7 Conclusions

We have outlined HALT introduced at Anritsu and explained some actual usage examples.

HALT has fixed execution procedures, but analyzing uncovered abnormalities and improving product reliability depend on the product type.

However, introduction of HALT does not always immediately improve product reliability. It is a continuous procedure based on knowhow, showing its usefulness through specification of the fault causal locations, evaluation of whether or not strengthening is required, and strengthening methods, etc.

In the future, HALT is expected to spread into other fields, such as household electrical goods and industrial machinery. We hope this article will help explain the usefulness of HALT.

References

1) G. K Hobbs: Accelerated Reliability Engineering, Halt and Hass
2) M. Kimura: “機器は壊して強くする 新試験手法 HALT が離陸”, Nikkei Electronics, December 1, 2008
3) M. Kimura: “壊して作る HALT 活用設計 コスト競争力の源泉に”, Nikkei Electronics, October 17, 2011

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