Enhanced HALT Techniques Boost MTBF Prediction

By improving HALT processes it's possible to provide accurate product life values. The gathered knowledge helps military system designers build rugged, reliable electronics for harsh environments.

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There's a commonly accepted notion that HALT and repetitive shock (RS) vibration cannot provide mean-time-between-failure (MTBF) values for electronics. Military and aerospace electronics systems are often too expensive to allow an adequate sample size for statistical predictions (required for MTBF). Moreover, HALT chambers typically lack accurate control of vibration excitation in frequency ranges critical to circuit card assembly (CCA) failures. This makes it a challenge to obtain a numerical definition of damage excitation.

Major advanced military programs like Future Combat Systems (FCS) and Joint Strike Fighter (JSF) (Figure 1), for example, are striving to reduce maintenance costs through high-reliability requirements and application of prognostics for the programs' electronic systems. HALT (highly accelerated life testing) is not intended to simulate an actual field environment. Its intent is to stimulate natural responses that will find assembly weaknesses. By finding product weaknesses, understanding causes of failure and redesigning to obtain a more rugged product, product ruggedness and reliability can be increased. MTBF is not an important number if product life capability greatly exceeds design requirements—if product life capability is known. The term "greatly" is used because the distribution of failure of electronics under vibration is wide and, with limited testing, not often well defined. For effective HALT, understanding failures and understanding the improved product are critical to reliability improvement.

Frequently, when the military asks suppliers to improve electronics due to

Figure 1

Major advanced military programs like Joint Strike Fighter (JSF) are striving to reduce maintenance costs through high-reliability requirements and application of prognostics for the programs' electronic systems. HALT's intent is to stimulate natural responses that will find assembly weaknesses. Shown here, a new F-35 Lightning II Joint Strike Fighter makes its initial flight over Fort Worth, Texas.

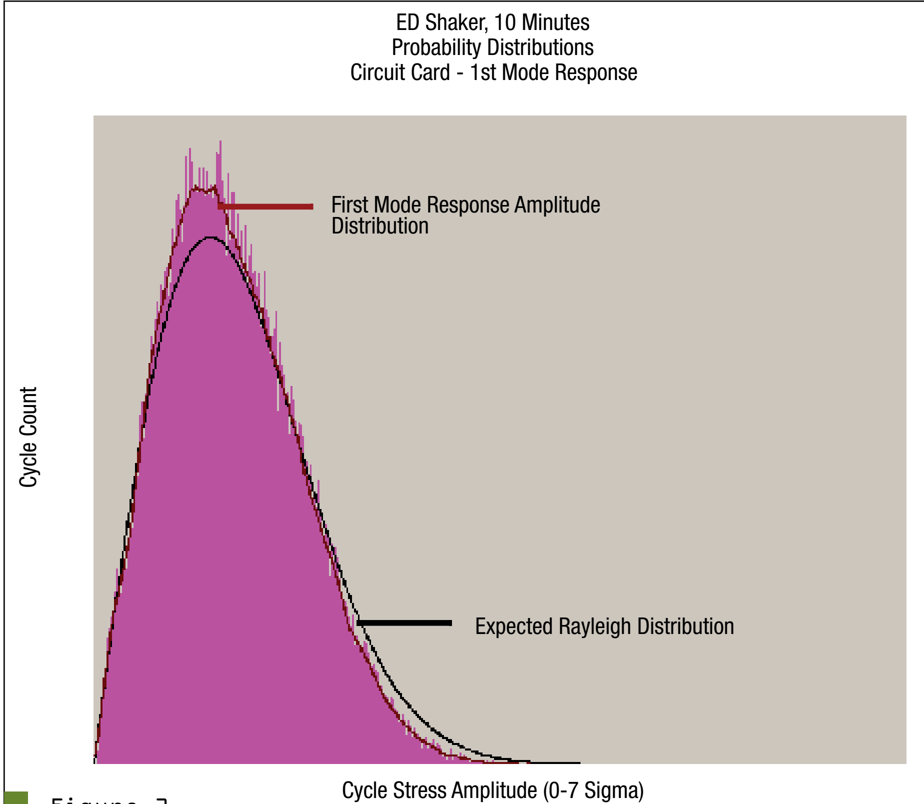

Figure 2

Shown here is the ED Shaker circuit card assembly First Mode Response Amplitude Distribution. The ED Shaker circuit card response closely matches the expected Rayleigh response.

shortfalls in reliability, the redesigned product has even lower reliability. Electronic assemblies are very complex. Testing performed without an in-depth understanding of the product and the test equipment can give misleading results.

As an example, HALT vibration excitation is quasi random. The chamber cannot impose a continuous flat vibration spectrum. It can excite some natural frequencies of an electronic assembly at much higher levels than others. When comparative HALT is performed—a process where two different products are tested to find fragility levels—one might conclude that a product that failed in HALT at 35 g's is more rugged than another product that failed at 25 g's. This can be the wrong conclusion. The real answer can be found in how much damage each HALT vibration test imposed relative to the expected damage exposure in the service life environment.

Consider a service life vibration environment that has characteristics of a continuous flat spectrum and chamber excitation that is isolated from the 35 g product weakness but coupled well to the 25 g product. The 35 g product may fail at higher g levels, not because it is more rugged, but because "frequency separation" protects its weakness from chamber vibration. The 35 g product might be far less reliable in service life. Understanding both product and test will avoid judgment error.

Service Life Vibration

The assumption that HALT cannot provide definable product life values is true only if technology advancements of the past decade and a half are ignored. Vibration damages the product using some fraction of the available service life. Quantifying response can relate vibration exposure to life use. Equivalent service life vibration has historically been performed on ElectroDynamic (ED) shakers because they are capable of providing relatively well-defined and consistent vibration excitation. The expected distribution of natural frequency response peaks of the product on an ED shaker is represented by the Rayleigh Distribution. Figure 2 shows the distribution of measured peak CCA responses from an actual test of an electronics assembly on an ED shaker as well as a perfect Rayleigh distribution. Life predictions have historically been made by calculation of damage assuming a perfect random response distribution of peaks of first mode response.

Exponential advancements in computer power since the introduction of HALT have greatly expanded both test measurement and fatigue damage analysis capabilities. These advancements have made detailed evaluation of life-use (fatigue damage) possible under any excitation type: HALT chamber or ED shaker or other.

Measuring Responses

Even when the excitation profile cannot be controlled, response can be measured. Test measurements allow accurate response cycle count. Figure 3 shows first mode response cycle count data (same CCA as in Figure 2 test) from a HALT chamber, showing cycle count plots for two locations within the chamber. The distributions of responses, performed under identical vibration control settings, have different shapes and different peak amplitudes. There are very large differences in damage accumulation for the two locations. Even with differences, the CCA damage at each location can be determined.

Advancements in computer power provide the ability to analyze stresses in CCAs in great detail, understanding how each critical vibration mode contributes to fatigue stress cycles. With the ability to accurately analyze detailed stresses, damage to failure can be determined for any response distribution, which in turn can be extrapolated to time-to-failure for any other response distribution (including field service life loads).

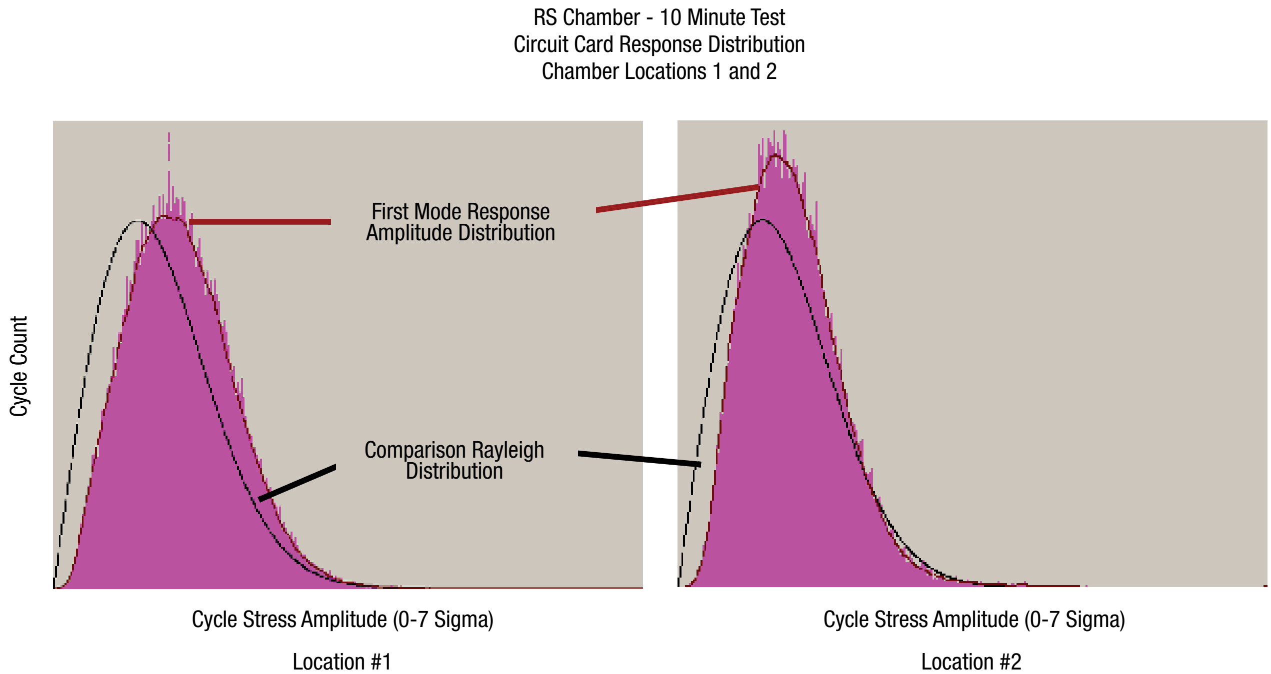

Figure 3

Shown here is the RS Chamber circuit card assembly First Mode Response Amplitude Distribution. The response distribution, critical to damage control, varies significantly with test position

For decades, electronics vibration life has been understood through the combination of analysis and test. Product reliability has required unique development testing for each product or product revision without the benefit of past experience. For vibration, even two CCAs with identical parts but different layouts can differ in MTBF by many orders of magnitude. Identical components in different positions or different assemblies do not have different life capabilities because they are stronger or weaker in different locations. They have different life capabilities because they experience different damage accumulation rates.

Empirical Equations Fall Short

Due to the complexity of CCAs and the high cost of computer analysis over much of the history of HALT, empirical equations have been commonly used for life predictions. Of course, a single equation is not capable of describing all the complexity of stress flow within an electronics assembly with multimode vibration response. In-depth product understanding cannot be developed with that combination of test and analysis (one equation fits all).

Determining Failure

Accuracy of the numerical definition of failure is dependent on the vibration control levels and the accuracy of applied analysis. Vibration equipment—HALT chambers or even ED shakers—do not create perfect Rayleigh response—the first contribution to life prediction error. Additional error occurs by application of an oversimplified analysis.

The advancements in computer technology now allow any company involved in development or production of electronics to have a higher level of analysis and test. Product understanding to the level of knowing which solder joint is at the highest risk of failure can now be obtained with a PC-level of fatigue analysis. CirVibe has developed purpose-built vibration life software that performs detailed component-level fatigue damage analysis for electronics performed on a PC. This analysis includes detailed stresses, both flexural and inertial for CCA multimode response. The analysis model creation is highly automated so the user does not need finite element expertise. Analysis calculates detailed stresses using millions of equations.

Under random vibration, all vibration modes are excited simultaneously. Each response cycle in each mode creates stress distributions in all components. Due to the exponential relationship between cycled stress and life, the combination of stresses causes failures to occur at higher rates than rates that would occur if only one mode was responding. For most CCAs, the assembly fragility is dominated by response within the first 3 modes—usually the first.

Special Cases, Modal Responses

Special cases might have components that fail due to their own modal response, but this is not common for SMT and also not usually resolved by major product redesign, but resolved through local modifications. How much faster a component fails due to the multimode stress condition depends on the magnitude of stress contributions from all modes. Detailed analysis can determine which modes should be measured during tests. Response cycle count can be performed for each critical contributing mode.

Application of detailed analysis increases the value of test. CirVibe can extrapolate component life data across assembly position or design configurations. The ability to extrapolate data across designs makes statistical analysis approaches efficient. Otherwise, every design development would rely on testing performed on that product alone without benefit from previous experience.

Historically, the ED shaker testing and calculation of expected failure time under the expected field service environment has included only first mode damage. The advancements discussed above improve on methods used with well controlled vibration equipment (ED Shaker), but also greatly expand capabilities of HALT chambers.

The greatest obstruction to development of expensive military and aerospace electronics product understanding is the limited samples of items available for test. Understanding can be maximized with numerical definition of failure. Electronic product vibration understanding is cumulative. Since numerical definition of failure is transferable across design configurations, each test benefits from the knowledge gained in previous tests that had failures of similar components. Ruggedness and reliability of electronic products occur through in-depth understanding of the product and understanding of the test.

Upgrading Reliability Design Methods

HALT can be upgraded to provide valuable product life values. For expensive hardware, every vibration test performed with life-use analysis adds information critical to product understanding. If life-use data is in the proper form, data extrapolates across design configurations. Accumulation of knowledge contributes to the growth in ability to produce rugged, reliable electronics for harsh environments. Product improvement and product life comparisons—as in redesign or comparative HALT—can be made with greater understanding and therefore less risk.

These same cycle count plus analysis methods can be used for more accurate determination of life expectations for ALT (Accelerated Life Tests) performed on ED shakers. The methods can also improve decisions on HASS and ESS (Environmental Stress Screening—ED Shaker) testing of electronics for obtaining higher reliability. When products are understood at the component level, reliable and rugged products result. ▮▮

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