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Fatigue Metrics for HALT, HASS and More

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Background:

In 1991, I and others introduced the "Fatigue Domain" for HALT/HASS and related vibration.[1, 2] We pointed out that traditional analysis tools (PSD and gRMS) failed to give good indications of what was happening, not only with 6 DOF repetitive shock machines, but with real life excitations

In 1995, the Henderson-Piersol Damage Potential spectrum, DP(f), was introduced.[3] DP(f) is a velocity spectrum compensated for damping, material strength and time of exposure. As a narrowband spectrum, the DP(f) has the ability to indicate the potential magnitude of fatigue damage for a potential defect site at the component's resonant frequency.

As the use of the DP(f) increased, it was suggested that a scale of the overall amplitude be made available. This resulted in the introduction of the fRMS, the root of the integrated DP(f) spectrum. Analogous to gRMS of the PSD, fRMS is a global, broadband measure of severity for shaker excitations, real-life environments, and the product strengths and hence margins.

Observations:

The opportunity to turn the HALT/HASS process into an engineering discipline has existed since publications dating to 1991 on the "fatigue domain". The element that is needed to catapult HALT/HASS into a more useable process is a metric for 6DOF vibration measurements. It can be a "sanity check" or, in some cases, the last word.

HALT, as a process, is an incarnation of TAAF (test analyze and fix) dating to earlier Mil-Std methods and practices, but now on steroids.
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Both are empirical processes with HALT emphasizing accelerated, exaggerated and combined stresses with the heresy that "finding a failure is a success". From it's beginnings, HALT vibration has been an open loop process—lacking accountability to relevant technical analysis and thus attracting skeptics. Consultants, educators and system manufacturers protected the HALT methods, levels and 6DOF machines from comparison because HALT had "no relation to the end-use-Environment (EUE)", qual test or any other mechanical stimulus related to a product's environmental exposures.

What if?

What if you could relate all of this with a relevant metric?

The turn it ON and trust me waving of arms and specsmanship of the last 25 years dating to the1979 NAVMAT P-9492 era would instantly be transformed into an engineering discipline based on real and useable data. Comparative metrics define machine signatures, product strengths, qual test severity and yield a host of measurements of variances serving as targets for improvement and process modification. Well, you can tie together all of the "black art"! Suggestions as to "how" re presented herein and in the references.

The Henderson-Piersol fatigue metric helps quantify decisions on corrective action. Design of experiments (DOE) and physics of failure (POF) results improve because the metric reflects the physics. The DOE work of Dennis Pachucki (Cisco), and Lloyd Condra (Boeing) and the POF work of Dr. Mike Pecht (CALCE) provide good examples. Decisions could be made using engineering data rather than vested interest anecdotal claims. Brash sounding perhaps, but very reflective of the feedback I've received from users, prospective users and seminar attendees dating back to 1983.

The HALT/HASS process has among its benefits, product reliability and reliability growth. While many decline to call elements of the process "tests", these elements were conducted like other thermal cycle and vibration "tests"-- prescribed, measured and controlled with degrees, change rates, gRMS and occasionally with PSDs.

The larger picture of the process, however, never reaches full potential if the parameters used to prescribe, measure or control the "test" elements are not particularly valid—specifically concerning vibration with chaotic 6DOF machines. These machines can neither be "controlled" in a traditional narrowband sense nor by any method relating to how and why they work -- (fatigue), but the process of using them can be managed.

Reliability, or quality over time (not my phrase), is fundamental in processes like TQM, 6 Sigma Quality and Continuous Improvement. The key point here is that a process element anywhere in quality initiatives, such as HALT vibration, can neither be measured nor controlled without a relevant metric. Lacking a metric, you could be assuming the process is effective but still be losing ground.

What could you do if you knew?

1. Understand how and why the chaos machines work—and when they don't
2. If the market for a product has a limited life – decide when to **STOP HALTING**! If the product goes on the next B-52, **KEEP HALTING**
3. Relate HALT to HASS—a gRMS ratio does not represent fatigue difference
4. Define signatures for chaos machines

• Compare **relevant** performance of one manufacture's chaos machine to another for purchase decisions

• Reconcile use of different chaos machines (in-house, between divisions or, your vendor uses Brand X). How do you converse technically?

• Benchmark machine performance over time—as received, PM cycles, after service and ISO, TQM, customer required or "what am I doing" audits.

• Document table mounting surface spatial variations—all tables, all brands have them

• Use DP(f) fatigue metric to design and evaluate product fixture gains and losses

• Ensure you are getting adequate fatigue excitation to the defect sites

• At what sub-assembly level are you trying to excite the potential defects?

• Document non-linear spectral power and fatigue potential at different gRMS operating set points.

Why Should You Care?

A relevant vibration fatigue metric

1. Defines measurable quality and reliability levels, product strengths compared to environments or spec requirements
2. Yields margins and statistical confidence levels to justify modifying, stopping or continuing the PROCESS

3. Facilitates a basis for competitive evaluation of your competitors' products, your vendors' products and your own

4. Helps communicate specific benefits from the work of others—based on quantifiable processes allowing meaningful tailoring based on product class, architecture and especially defect type

5. Allows one to balance the technical decisions of HALT/HASS with economic considerations

6. Provides a common denominator—"iso-fatigue" as a means of meeting Mil/defense ESS/HASS requirements regardless of available vibration equipment[5]

7. Defines people (design) and process performance goals.

It's not just about chaos machines:

In a 1991 case , the on-engine mean time to failure for a diesel mounted electronic module was less than 10 hours, a stark contrast to the successful completion of a 2000 hour qual test on an E/D shaker at the same 6-7 gRMS level as the engine. Time histories revealed 19σ acceleration peaks in the engine excitation compared with clipped 3σ peaks produced by the E/D shaker. Actual peaks to 137 Gs on the engine compared with 21-28 Gs in the qual vibration. Ratios of the gRMS would be 7-8, not indicative of failure in 1/200 of the time. Though at the time we were using rainflow acceleration peak distributions (the PPDF/AFDF approach) a light went on.

Henderson and Piersol showed that acceleration-based methods are not the better indicators of fatigue.[4] Velocity of the first bending mode moment is proportional to stress, strain and strain rate and is the key.

The DP(f) is also the better indicator of the damage potential of the EUE, in this case at the component mounting flange on the diesel engine. Fatigue accumulates linearly with time (number of stress loading cycles) and exponentially with the material constant β from the S-N curve. PSDs are statistical estimates of the average power intensity (per unit bandwidth) and gRMS is the root of the area under the PSD curve.

If an intermittent shows up in a powered and monitored product in 11 seconds on a chaos machine but seemingly "not in our lifetime" on a 3σ-limited E/D shaker, both at the same gRMS, what conclusions can we draw?
The answer? None with acceleration-based PSDs (a snapshot) or gRMS (an area of the snapshot) because TIME is not considered.

Now what is possible?

The availability of a metric based on fatigue and especially incorporating TIME, opens huge doors. Here are some:

1. Definitions of all vibration environments over the entire product life

2. Using DP(f) and fRMS one can prove that some environments can or cannot be replicated in real or compressed time on certain types of vibration exciters.

3. Relate the EUE to the design verification or qualification test

4. Relate the HALT levels achieved through a step stress process to

- Define "product strength" or robustness for comparison
- Quantify product strength/EUE margins
- Use a previous release or product as benchmarks
- Measure effect of design, component or manufacturing changes over product life
- Quantify corrective action with POF based on fatigue level and time to HALT failures
- Use the time-scalable DP(f) and fRMS algorithm as a calculator
- Quantify the fatigue accumulation over several environments — Connon's Aberdeen Proving Ground test track sequences summed using Miner's Rule based on DP(f).[6]

• Model a virtual HASS for production cycle time planning and costing

• Define HASS limits—operating and destruct margins incorporating TIME and level

• Comparison of EUE based on PSD with EUE based on replication of field time history on E/D shakers.

• Communication of EUE to component vendors (ref diesel engine)

1. Document the Product strength (Robustness), Test Level and EUE variances and predict economic exposure from

• Outside lab HALT protocols, product improvements, re-designs and subcontractors' reliability

• Warranty commitments,

• Reliability targets—incentives and penalties,

• Tracking field failures, causes and relationship to HALT/HASS failures

What's In It For You?

If, having a handle on all (or even some) of the above, you went into your next proposal effort with "verifiable HALT levels" and knowing your cost savings, you'd be more competitive.

• You know how to manage the differences using iso-fatigue comparison of excitations even for different vibration system types

• You require fewer HASS systems because your HALT margin above HASS supports shorter HASS cycles

• You can ensure that all Products undergoing HASS will have the same cumulative fatigue—life used, life remaining-- *One user suggests the metrics are the way to minimize the costly "screen safety" portion of Proof of Screen. Screen safety involves running the same unit through the developed screen(HASS) 20 to 50 times to ensure the screen does not consume an unacceptable part of the product's fatigue life. With the metrics, however, can we begin to quantify what that fatigue life is and hence what the HASS consumes or what's remaining.*

• You have correlated the vibration environments, all test levels and time exposures to product strength – including EUE—HALT fatigue far exceeds Qual test fatigue

• You accept or propose an increase in the warranty, MTBF or MTBUR requirements with engineering data to back it up

• Justify a lower projected failure rate and therefore less costly spares provisions

• All the above--Especially for your subcontractors—that's how you selected them

Conclusions:

This viewpoint and framework for evaluation of end-use-environment, chaos machine and random vibration excitations is offered to allow and improve understanding, analysis and interrelationships not before possible. Many important comparisons and resulting decisions can be reached given a relevant metric for excitations which are not met by the traditional PSD and gRMS tools available.

References:

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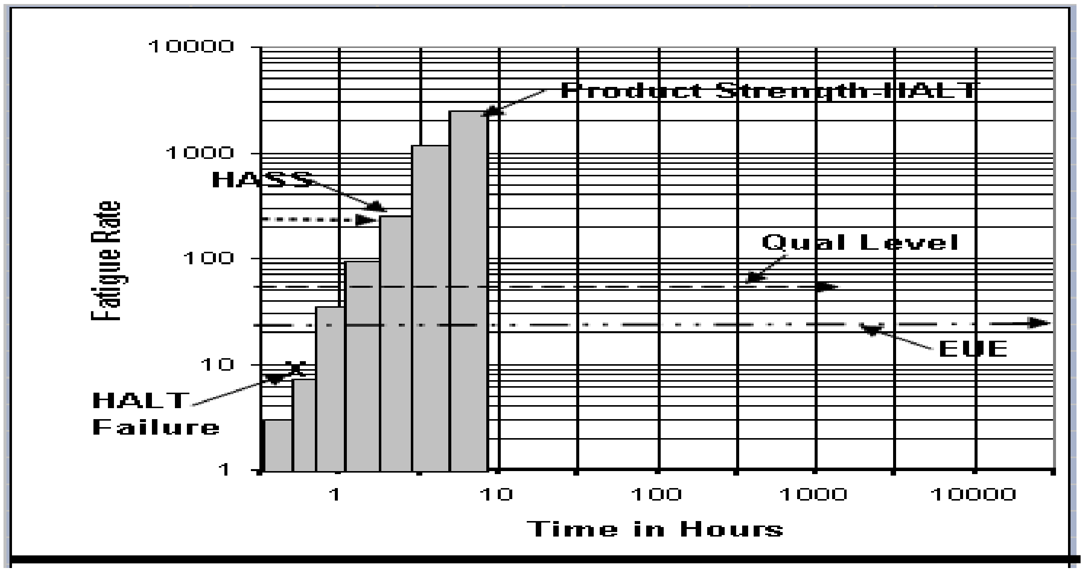

Figure 1 Helps visualize the rapid fatigue accumulation in the HALT vibration step stress compared with the life of the product. EUE shown as a constant from the same origin allows comparison with Qual, HALT and HASS. The arrow at the second step could represent the time to failure of a component and thus the area represents cumulative fatigue and time to failure—intensity over time. Note, for specific part failures, the DP(f) shows the narrowband fatigue, due to response to excitation. The strength of the product is documented by the summation accumulated fatigue steps to the oint at which one STOPS HALTing. Actionable margins come from comparisons of gRMS HASS to HALT fatigue (visually, the ratio of areas). Similarly for HASS to Qual; HALT, HASS, and Qual to EUE, e.., using two hours for HASS and 2000 hours for a Qual test.