Notes on Constant Fatigue Control Tests

Or

Why gRMS Control Using Table Feedback Doesn't Work

During recent repetitive shock ESS machine (RSESS) control tests at Ford, Dearborn, performed by GHI Systems, Inc., the importance of controlling test item fatigue during highly accelerated life tests (HALT) and highly accelerated stress screen (HASS) processes was demonstrated conclusively.

The underlying problem when using RSESS machines is that they are inherently non-stable with regard to vibration spectral intensity. This is due to their low impedance, modal table design. The variations give rise to spectral density differences of as much as 5:1 or greater, as a function of vector direction and table zone. These differences have a profound effect on fatigue rate on the product, and hence the management of a successful stress screening program.[1]

The variation problem complicates the basic aim of the RSESS machines, that of precipitating latent defects through the accumulation of stress fatigue. The fatiguing process is greatly affected by the variations in vibration intensity. In fact, it has been found that gRMS differences of a factor of two give rise to fatigue differences of 50:1 or more, depending on shaker spectral characteristics.[2] These wide variations in fatigue make the process of defect precipitation uncertain, and in many cases, unrepeatable. This may not be a problem during the typical product design verification or HALT test, where the table is probably driven at multiples of the necessary excitation level to insure that a product is adequately excited. However, it can become critical during later production screening when table intensity levels are reduced to insure that product life is not lost.

PRODUCT RESPONSE UNIFORMITY TEST

The object of the test was to illustrate the variability of product response as a function of attachment (fixturing and/or location) on an RSESS machine table. To insure a constant level of excitation on the item under test, product response was used for feedback. This is not the typical table feedback arrangement used by various machine manufacturers. While product response feedback is a significant departure from present RSESS machine manufacturers practice, it is typical practice on electrodynamic and servo hydraulic shakers.

The experiment was set up on a typical RSESS machine using electronic rear suspension control modules from a Ford Car Line. The modules were approximately 1.25" thick, by 4" wide, and 6" long, and weighed a little less than one pound. An internal single circuit board is supported in the plastic housing and connects to automobile cabling via card edge connectors protruding through the housing.

Vibration sensing accelerometers were bonded to the top covers of the modules in a location where primary mode vibration would occur. The oscillation mode of the cover is very similar to that of the internal circuit board. Therefore, was a reasonable representation of the circuit boards response.

Two separate vibration tests were done, the only difference being the location of the test items on the shaker table. In both cases, the module was held tightly to the shaker table with machinists hold-down fixtures. The physical arrangement of the test item is shown in Figure 1.

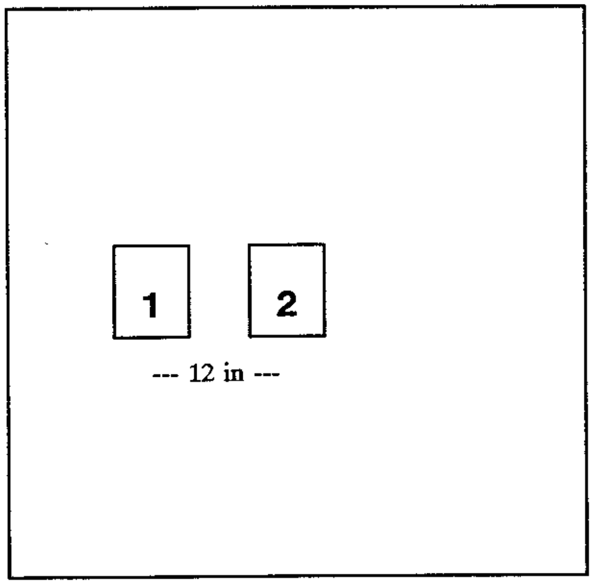


Table is approximately 36 inches on side.

Figure 1. Arrangement of Test Items on Shaker Table, Top View.
Two electronic modules were located about 5 inches apart.

Twenty minute combined thermal and vibration profiles were designed. These are shown, along with the chamber temperature and vibration responses in Figure 2. The starting product response intensity was programmed for 10gRMS. After 6 minutes, the response was ramped-up to 15gRMS and held for four minutes, after which it was allowed to decrease linearly to 0gRMS at the end of the screen. This test also gave an evaluation of the low gRMS starting and operating abilities of the table hammers.

While the test proceeded, the vibration level at the RSESS machine manufacturers table feedback pick-off point was observed. Although it was not used for control, this feedback signal gave a direct measurement of the vibration intensity needed to produce the constant response on the items under test. The feedback accelerometer was located on the bottom of the table. Experience indicates that it has little relationship to the vibration response intensity that exists on products on the table.

The results of the two sets of tests are as follows:

Table Location	Product Response gRMS*	Table Imput gRMS**	Gain/Loss
1.	10gRMS	2.5gRMS	4X Gain
1.	15gRMS	3.5gRMS	4X Gain
2.	10gRMS	25gRMS	2.5X Loss
2.	15gRMS	45gRMS	3.0X Loss

* The product response level, used as the servo feedback reference; chosen to maintain constant fatigue rate screening.

** Table input intensity needed to maintain required product response. Shows the problem associated with table zone "hot spots."

Total variation measured at two table locations that produced a constant fatigue rate on the item under test was 2.5-25gRMS, a factor of 10 times.

From the above, it is immediately obvious that the single or multiple point vibration control methods provided by machine manufacturers do not necessarily equate to the excitation that a test item experiences.

To restate the problem, the variability in intensity that is inherent in RSESS machine table drive will cause variations in accumulated fatigue within the products being screened. This fatigue variation will result in non-uniform screening with non-reproducible results. This in turn may be costly through inadequate design evaluation, with less than a robust product resulting from highly accelerated life tests (HALT), and letting defects through the production screening process during highly accelerated stress screening (HASS).

PRODUCT FATIGUE CONSIDERATIONS

At the same time the gRMS measurements were made, the product response was processed using rainflow analysis which produces a peak probability distribution.[3] While the shaker table produces non-Gaussian vibration with extremely high sigma occurrences exceeding three sigma, the monitored product was seen to self-resonate as a Gaussian oscillator, producing a Gaussian peak probability distribution. This distribution was three sigma limited. The distribution is seen in Figure 2. In other words, the high kurtosis and some 6DOF characteristics of the RSESS machine have little to do with the fatiguing process at the product.[4]

The fatigue of a resonating component of an item under test is directly related to its own vibration spectrum, not to that of an outside stimulation. This was established some time ago by Papoulis[5] and was redemonstrated during the Ford tests. It is true, however, that the PSD amplitude of the excitation, at the frequency of the fatiguing component, is the forcing function that causes fatigue. Some machines produce a repetitive impulse type excitation whose PSD is like that of a white noise source (flat and broad band), and which brackets the resonance frequency of a majority of a products fatiguing components.

Of recent concern has been the report of several machine users that success rates on certain products are very low. In particuar, users attempting to "break" completed products have had little success. Also one user reports that for large capacitors with mounted resonances of 100Hz the RSESS machine was unable to produce a field defect in any reasonalble time. This is because the provide low frequency momentum but not displacement.

It is this displacement that drives products into resonance. Displacment from about 100 Hz upward appears to be adequate for test acceleration for light mass components, such as circuit cards, etc. However, at the extream, one would not expect to HALT a truck transmission. We believe there is a crossover, as far as useful product resonance of 100-200Hz. Above this range, successful screening can be accomplished in short time with an RSESS machine. Below these frequences, time will be longer than when screened on an electro-dynamic or servo-hydrawlic shaker.

The shape of the peak probability distribution function of the response for one electronic module under test is shown in Figure 3. This distribution is a near Gaussian, 3 sigma limited, peak probability function, showing no evidence of the wide sigma, non-Gaussian excitation of the RSESS machine. While the response of the item under test is more Gaussian than that of the tables excitation, the fatiguing rate of this oscillation may be quantified in exactly the same way as a non-Gaussian excitation[6].

The good news is that, in order to control the response of an item under test to guarantee a constant rate of fatigue, it is not strictly required to perform a rainflow and accumulated fatigue analysis during real time. However, once the test items fatigue response is calibrated through the before mentioned methods, then control may be affected in real time. The fatigue rate will be proportional to the product of the fatiguing elements resonant frequency times the standard deviation of the stress raised to the power of b, as below:

$$FDAR \propto f_r \sigma^b$$

where

FDAR = fatigue damage accumulation rate
f_r = resonant frequency of the structure
σ = standard deviation of structure vibration response
b = reciprocal of slope of log-S versus log-N curve for the structural material
(ranges between 6 and 25 for all materials, MIL-Std 810E uses b=8)

EFFECTS OF TABLE VARIANCE ON PRODUCT LIFE.

It has been shown with conservative estimates that small changes in gRMS have large changes in the amount of accumulated fatigue and hence product life[7]. Oliveros shows a mathematically valid reduction in fatigue of 5.9 for a gRMS change of onoy 20%, when using a materials beta of 6. Our measurements of actual change on certain chambers shows changes of 50:1, fatigue versus gRMS. Our measurements agree exactly with findings of the GM Proving Grounds, where gRMS changes of 2 shorten product life by 50%.

Fatigue is accumulated during HALT and HASS tests, and is one of the principal reasons they are performed. Given the table variabilities that exist in all machine tables due to modal response, it can be seen that differences in accumulated fatigue of 100 for changes in gRMS of 2 will effect the results of tests. Two ojects mounted on a table have a very high probability of being excited at gRMS values that differ by a factor of two. Hence, the difference in accumulated fatigue produced. These different products will have different results to the HALT or HASS screen, and will make the screen highly unreproducible and the quality process invalid. While I am conditional agreement with certain experts in HALT concerning table variations, you can turn the machine up all the way and effectively have all products under adequate stibulation, I have concern about variations with the more tightly controlled HASS process where stimulation is lower than the HALT level.

The obvious solution to the table variability problem is to measure the actual degree of fatigue building up in the product. In this way, there is a measurement of the degree of accumulated fatigue that can be used correlating results from both HALT and HASS. It also allows correlation between different types of tests done on different types of shakers[8].

The technical details of control based on constant fatigue rate have been developed by GHI. They are now included in the standard GHI RSCAT Control system software. This software allows control by either traditional gRMS methods as well as by the more consistent Constant Fatigue method. With this software, the user is able to establish the correct fatigue rate through calibration, and then control the RSESS shaker to maintain a specified constant rate. This method requires product response servo feedback and will does not depend on the machines proprietary table referenced control means. Direct fatigue control may be applied to any type of shaker, although the algorthims developed by GHI are meant for air pressure actuated table hammer excitation.

1. Hu, J.M., Barker, D., Dasgupta, A., and Arora, A., "Role of Failure-Mechanism Identification in Accelerated Testing," The Journal of the IES, July\August, 1993, pp. 39-45.

2. Henderson, G.R., "Dynamic Characteristics of Repetitive Shock Machines," Presented at The Institute of Environmental Sciences National ATM, Las Vegas, NV, May 1993, and Published in The Proceedings.

3. Ibid, #2.

4. Ibid 1,2.

5. Papoulis, A., "Narrow-Band Systems and Gaussianity", RADC-TR-225, Rome Air Development Center, Griffis AFB, New York, NY., Nov. 1971.

6. Ibid 2.

7. Oliveros, Javier, "Use of Impact Hammer Type Shakers for Performance with NAVMAT Testing", To Be Presented At IES Natinal Convention, 1994.

8. Ibid #7.

Thermal Profile

GHI SYSTEMS, INC. CAT SYSTEM

DATE / TIME : Fri Aug 13 93 01:14
TEST ITEM :
IMPACT LOC. :

TEST ENGINEER :
TEST TYPE :
TEST MACHINE :

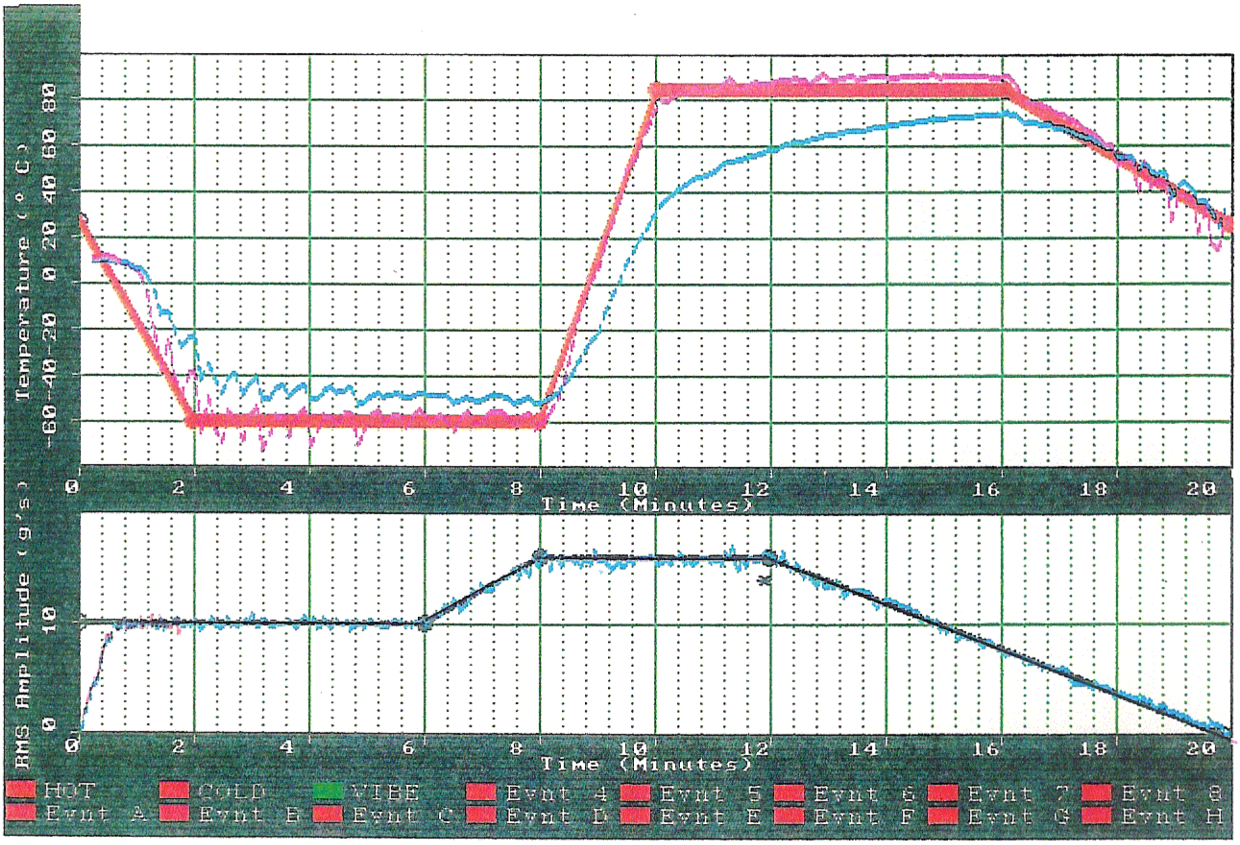


Figure 2. Split screen display of combined thermal/vibration control performance of test chamber.

TOP PORTION OF SPLIT SCREEN - Temperature command (set-points) and responses.

Heavy Trace	Command Profile
Oscillation about Command Profile	Chamber Air Temperature
Lagging trace	Unattached Product Air Temperature

BOTTOM PORTION OF SCREEN - Vibration gRMS versus time profile.

Heavy trace	Command Profile
Oscillation about the command profile	gRMS feedback from part.

COMMENTS:

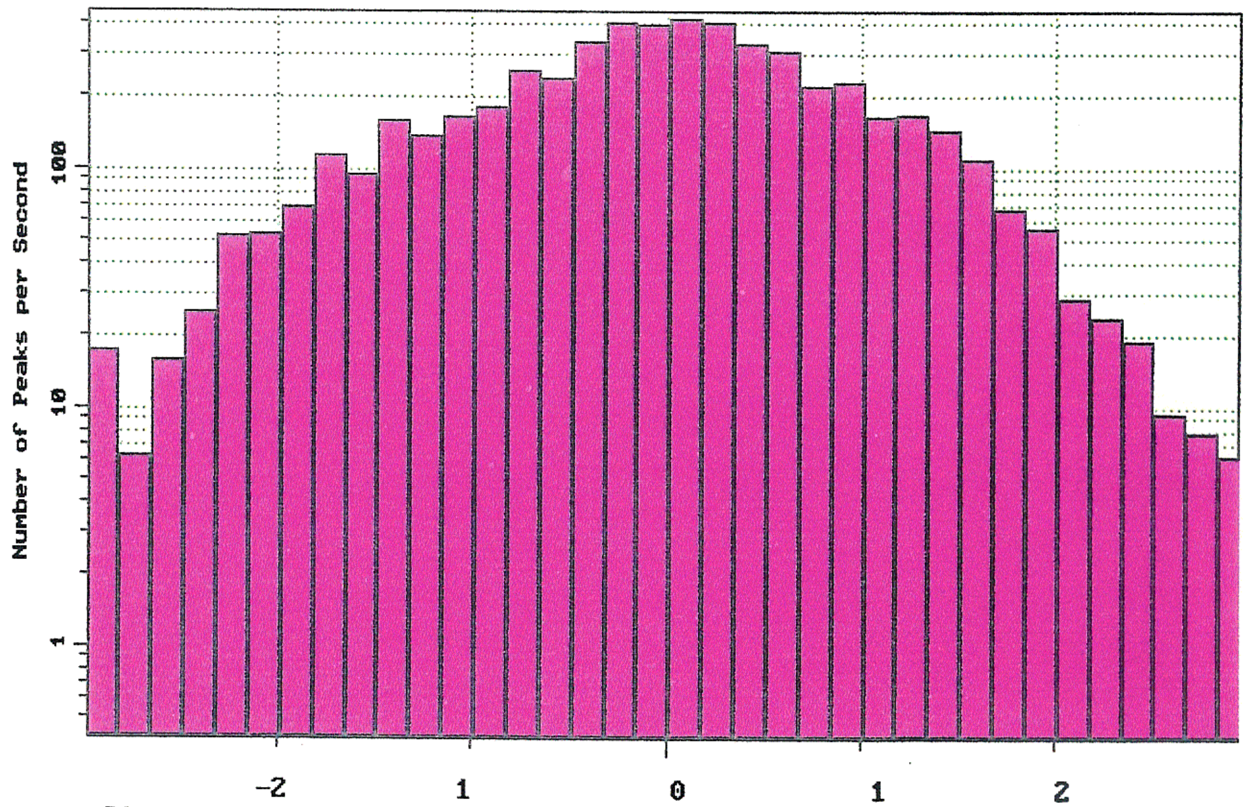
The part internal air temperature lags behind because the thermocouple was pushed into the integral air space of the module and was not contacting anything.

The gRMS variation in constant fatigue control is seen to be about +/- 3% of set point. It should also be noted that the hammers on this machine started at 1-2gRMS. The combination of smooth hammer performance and GHI part feedback control provided very constant fatigue accumulation versus time control to maintain a constant, and controlled, fatigue damage accumulation rate at the part under test.

Peak Distribution

GHI SYSTEMS, INC. CAT SYSTEM

DATE / TIME	: Fri Aug 13 93 01:14	TEST ENGINEER	:
TEST ITEM	:	TEST TYPE	:
IMPACT LOC.	:	TEST MACHINE	:



RMS = 47.2 g's

AFDF = 9.38E+016/second & 1.43E+005/second (>2σ)

Figure 3. Peak amplitude Probability Distribution, PPDF, from item under test during constant fatigue tests at Ford.

Plot is log amplitude of number of occurrences of stress levels, sigma. AFDF is accumulated Fatigue Damage Factor by solving the PPDF for Miners Rule. The distribution is Gaussian, although the driving excitation is highly non-Gaussian with multi-degrees of freedom.