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Published In Shock And Vibration, August 2004

# Fatigue Damage Descriptors for HALT and HASS

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Vibration step stress is the basis for most HALT/HASS procedures. The accepted metric for the stress is gRMS of the loading excitation. However, it has been shown that for uncontrolled vibration spectrums as produced by 6DOF machines, equivalent loading gRMS values can, and do, have significantly different PSDs [1]. It follows that although the gRMS values for two different loadings can be identical, differences in spectral intensity at product response frequencies $f_r$ will occur. The end result is differences in fatigue accumulation among screened products. This causes non-uniform results in product life status. Examples of this are products with defects that slip through the process and escape detection, or those that are over-tested into premature failure. Analysis of an early paper by McLean raised the possibility of these conditions. The data in the paper summarizes the failures during modified HASS screens. The failed components were on PC cards loaded at fixture locations in a 6DOF chamber [2]. The paper does not report any measurements of spectral intensity at the different fixture locations or on the circuit cards themselves to determine if acceleration loading was reasonably uniform. This leads to conjecture as to the cause of the failures.

**Fatigue.** In 1995, Sound & Vibration published a paper by Allan Piersol and this author, that described a spectral method for estimating damage potential from accumulated fatigue due to vibration loading [3]. This method converts the acceleration power spectral density, PSD, into a damage potential spectrum based on velocity. Fatigue is related to the velocity of the first bending mode of the vibrating component, not its acceleration. The Piersol-Henderson DP(f) method produces a velocity spectrum that is compensated with three key physical parameters needed for fatigue determination: the estimated damping ratio ζ, the material's fatigue constant β, and loading exposure time t.

**The Micro and Global Fatigue Rations.** The DP(f) is a spectrum of damage potential magnitude values, $Mag^2/Hz$, at each frequency within the analysis band. These values are analogous to the $g^2/Hz$ values of the PSD, except that they relate to fatigue damage potential ratios rather than acceleration power. These values are exact for the associated frequency, and are known as "micro" values. They are used to determine the damage potential at a specific frequency. At the same time, and depending somewhat on the shape of the DP(f) spectrum, it is possible to infer a fatigue accumulation "intensity" by estimating a value analogous to the gRMS of the PSD.

This is the fRMS value of the spectrum over a given bandwidth. This value, known as the "global" value of the spectrum, is useful for comparison of the potential fatiguing ability of two shaker systems; two locations on shaker tables, two fixtures, or other sets of acceleration loading points.

**Illustrative Example.** Two similar 6DOF chambers at a major producer of medical systems were measured. The first machine (#1), a newer model, had six pneumatic hammers driving a 36 inch table. The older machine (#2) had four and a 24-inch table. Most users would instinctively believe that a machine with six hammers should be the more effective than one with four. To investigate the question, the two machines were instrumented in the Z-axis, at a left-front-quadrant table location. Both machines were then run using 10 gRMS as the vibration control set point for intensity. Time histories were recorded from both machines in real time.

The time histories were processed with a spectrum analyzer with DP(f) [4] and the resulting spectrums were overlaid for comparison. The spectrums are shown in Figure 1.

**Discussion.** Although the machines are technically "different" it can be seen that there is comparable damage potential over the lower frequency portion of the band - up to 250 Hz, the DP(f) micro values are quite similar. However, over 250 Hz and above, the micro values are very different. In fact, the data readout box shows that at a cursor frequency of 508 Hz, the damage potential ratio is 385 in favor of the older machine.

The global fRMS values, over the entire bandwidth, show a difference ratio of 2:1, again in favor of the older machine. In other words, the older machine with four hammers, when compared to the newer machine with six hammers, is on average capable of producing twice as much fatigue in the same period of time, when running at the same gRMS!

If the fRMS value were estimated over a bandwidth from 250 Hz to 2 KHz, a frequency range that envelopes most electronic components, the global ratio between the two machines' would increase to a ratio of 10:1 or higher. This can be visualized in Figure 1 as a large gap between the two spectrums over this bandwidth.

**Conclusions.** The gRMS metric, on which most processes of HALT and HASS are based, provides no indication of damage potential. It therefore is a false indicator of increasing stress during a step stress process. This is, of course, not true for controlled spectrum shakers with definable PSDs. However, for pneumatic hammer-excited machines, equivalent values of gRMS between two machines, processes, etc., do not guarantee equality of applied stress. For these shakers, this determination falls to either the PSD, for loading intensity measurement or DP(f), for fatiguing potential. A description of the PSD process is found in Oliveros [5]. An application validation of the DP(f ) equations was described by Connon [6].

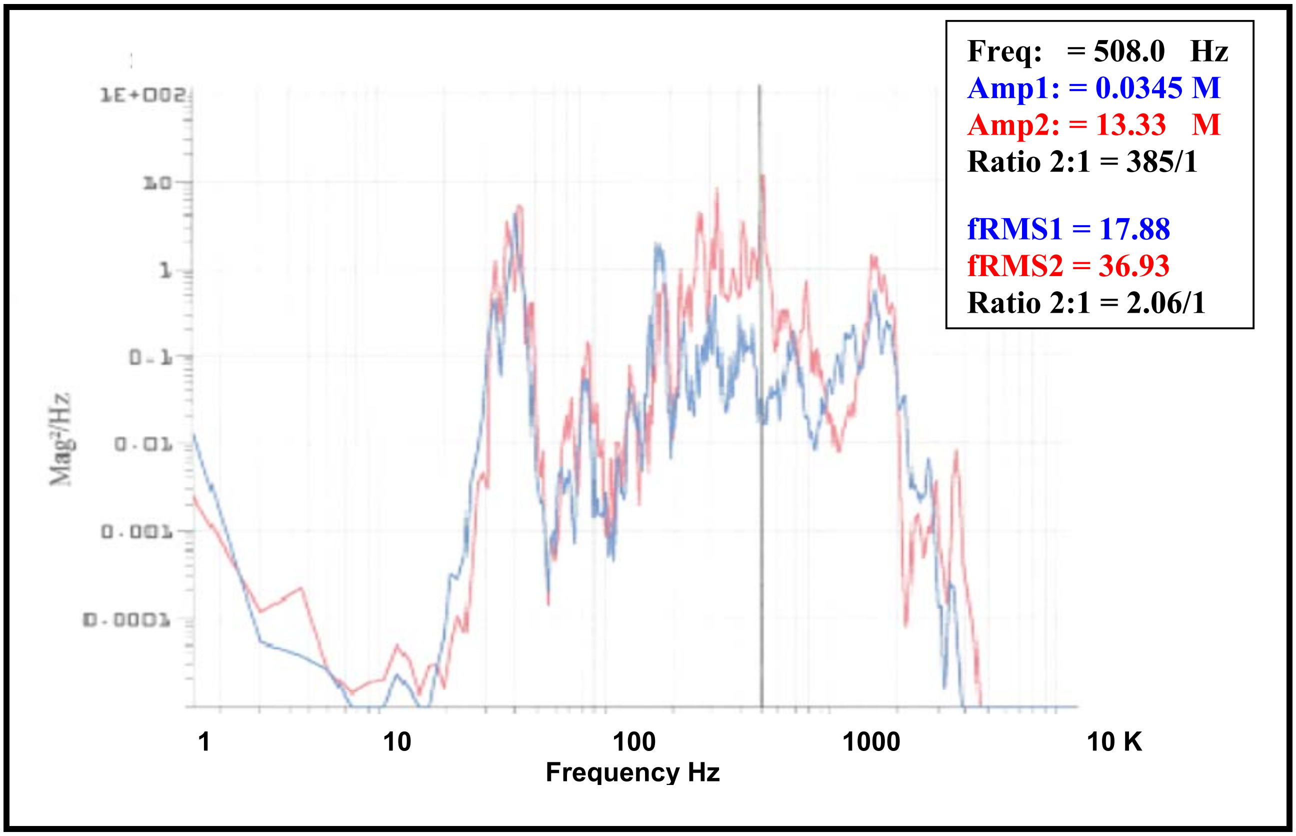


**Figure 1. Overlaid DP(f) spectrums from two different 6DOF machines running at 10 gRMS.**

## Bibliography


1. Henderson, G., "Dynamic Characteristics of Repetitive Shock Machines", *Proceedings, 39th Annual Technical Meeting of IES*, Vol. 29, No. 10, pp. 232-249,1993.
2. McLean, H., "Highly Accelerated Stressing of Products With Very Low Failure Rates", *Proceedings, 1992, Annual Technical Meeting of IES,* Vol. 2, 38th Technical Meeting, pp. 443-457. Nashville, TN., May 1992.
3. Henderson, G., and Piersol, A. G., "Fatigue Damage Related Descriptor for Random Vibration Test Environments", *Shock and Vibration, Dynamic Testing Reference Issue*, pp. 20-24. October, 1995.
4. Ibid. #3.
5. Oliveros, J., "Application of Using a Pneumatic Triaxial Simultaneous Vibration System in a Production ESS Environment", *Proceedings, 40th Annual Technical Meeting of IES*, Vol. 2, pp. 150-157, 1994.
6. Connon, W. H., "Assessment of Hydraulic Surge Brake Effects on Fatigue Failures of a Light Trailer", Aberdeen Test Center, US Army, 2002.