Reprint From TEST Engineering & Management, August/September 2004

Correlating End-Use Environments and ESS Machine Excitation Using Fatigue Equality

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Introduction

The end-use-environment, EUE, is often simulated in the test lab for product testing. It is replicated by spectrum controlled shakers, which have the ability to produce acceleration loading that is nearly identical to that of the EUE. This paper describes a method that allows the inclusion of pneumatic hammer excited shakers (6DOF) to correlate field failures in the environment with failure levels determined from HALT/HASS programs. The link between the EUE and 6DOF cases is equivalent fatigue. The method also applies to the spectrum controlled shaker case.

The Pneumatic Hammer Excited 6DOF Machine

The only "control" possible for 6DOF machines is over amplitude of the excitation produced. The loading spectrum is set by physics of vibration modes being driven by hammer harmonics [1]. The resulting power spectrums (PSDs) from multiple table locations have high variability. Control involves reading the root of the mean square of the acceleration, gRMS, from either a single location or from an array using averaging. This is then compared to the desired reference gRMS set point. However, there is no correlation between the magnitude of gRMS and the loading at product response frequencies. Correct loading is required for fatigue accumulation [2]. Since the gRMS is the root of the area under the PSD curve, completely different PSDs can have the same gRMS, but not the same effect. This is illustrated in Figure 1.

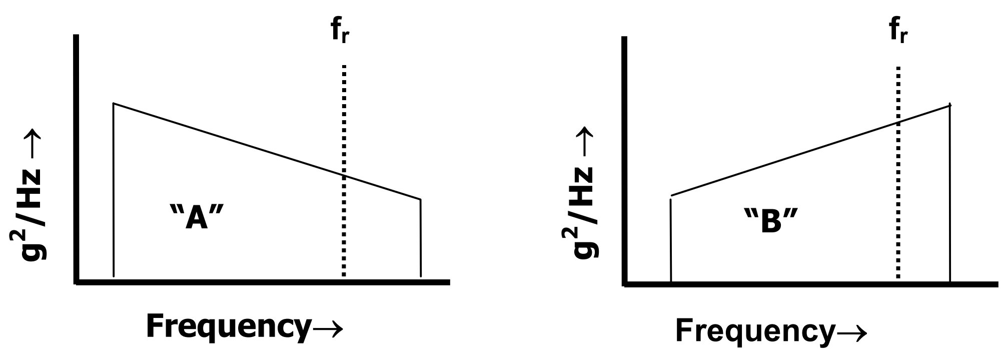

Figure 1. Two PSDs with the same area have the same gRMS, but a product resonating at $\mathbf{f_r}$ would receive more fatigue from spectrum B than A. Fatigue cannot be determined from gRMS alone, nor from a PSD which is a snapshot of power at one instant in time.

Summary of gRMS Rules for 6DOF Shakers

#1. Equal gRMS values are not equally effective in describing the stress loading on a component. The PSD must also be identical because an infinite number of different PSDs can have the same gRMS.
#2. The g^2/Hz magnitude of the PSD at the natural frequency of the component, is what effects potential fatigue accumulation, not the gRMS [3].
#3. gRMS magnitude does not equate to fatigue potential.
#4. The gRMS readout on a 6DOF chamber is not an indicator of fatigue potential.

A Fatigue Metric for EUE and 6DOF Machine Use

A spectrum analysis tool capable of measuring relative fatigue damage is the Damage Potential Spectrum, DP(f) [4]. The primary difference between the DP(f) and the PSD is that the DP(f) is based on velocity, not acceleration. A second difference is that the DP(f) includes the duration of stress loading which equates to fatigue accumulation. The PSD does not involve time. Stress that produces fatigue is directly related to vibration modal velocity, not to acceleration [5].

The DP(f) allows the comparison of different vibrations, such as from EUEs or any type of shaker including the 6DOF shaker. The comparison is based on the degrees of damage potential DP(f) accumulated by a product when subjected to different stimuli. It should be recognized that the DP(f) involves test duration time as an input parameter since exposure time can vary. This is important since some EUEs may be benign while the 6DOF machine is usually very intense and exposure times to failure will not be the same. Adjustment of exposure duration for DP(f) makes possible relating differing excitations with different duration, such as EUE and 6DOF.

The Experiment

An EUE from a Diesel truck engine had previously been recorded. The engine's vibration intensity was causing a throttle body sensor to fail prematurely. During analysis, it was found that the sigma peak range of the Diesel vibration was five times greater than the expected one sigma value of 7.5 gRMS, for which the sensor was designed. It was then desired to experimentally determine how long it would take a 6DOF machine to duplicate the failure level due to fatigue that the EUE caused.

To make the comparison, the DP(f) was used to analyze both the EUE Diesel engine data and that of the target 6DOF machine, then adjusting exposure time in order to yield the same degree of comparative fatigue from both environments. However, it was first needed to estimate the resonant frequency of the failing component, or at least a narrow spectral band in which it existed. This was done by using a Fast Fourier Transform (FFT) on the component's response data. This data contained the lightly damped self-resonance of the failing component. A resonant frequency of approximately 612 Hz was isolated.

The second determination that needed to be made was the statistical MEAN of the time to failure of the component in the EUE. Using warranty estimates by the automobile manufacturer involved, a value of 10 hours +/- 1 hr was determined. This would be important when running the fatigue analysis program since time is an input parameter. When the DP(f) spectrums from both the EUE and 6DOF machine were first overlaid, a time adjustment was indicated in order to achieve the same degree of damage potential at the f_r of the failed component. These spectra are shown in Figure 2. The EUE spectra appear in blue, while the 6DOF data is in red. Note that the blue EUE DP(f) spectrum has a slope, indicative of a velocity spectrum of a white noise function. The nature of the EUE Diesel engine excitation with the accelerometer mounted on the valve cover bolts is close in structure to random white noise.

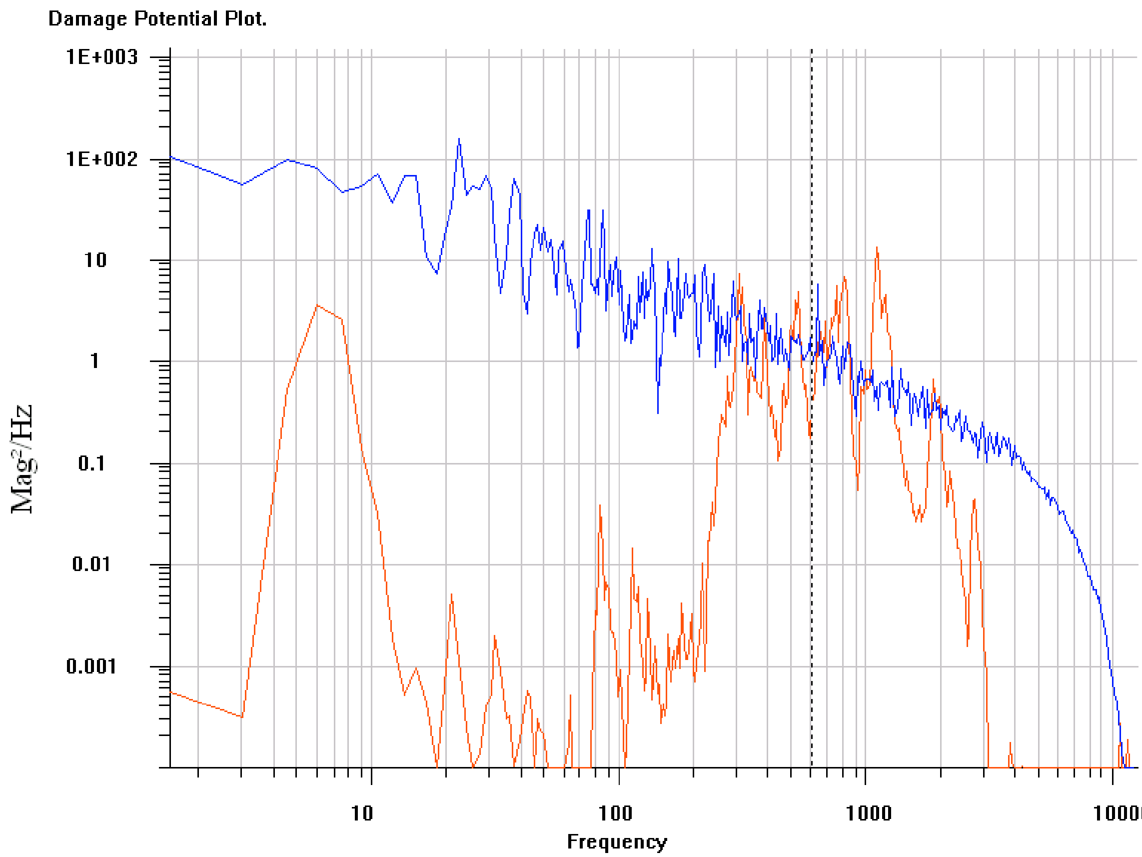

Figure 2. DP(f) spectra of both Diesel engine EUE and 6DOF shaker cases. The cursor is located at the 612 Hz part self-resonance frequency.

The resolution of the plot shown in Figure 2 may be increased to the limit of the analyzer by using a zoom function. A zoom compresses the portion of the complete spectrum to only a narrow bandwidth about the frequency of interest. Using the zoom function produced the DP(f) plot as seen in Figure 3. In this case, the relationship between the two spectrums at the f_r can be seen more clearly.

The root of the area under the DP(f) spectrum may be estimated. This is known as the fRMS. It gives a general measure of the worst case magnitude of fatigue potential of an excitation across all frequencies. Normally, when comparing two 6DOF or any type of shaker, of the same type, there are smaller differences between the fRMS of the two related fatigue spectrums. This is not the case with these two spectra. The are very different in structure and hence have greatly different fRMS just as the gRMS values of the two excitations have large differences. For this reason, the more exact DP(f) value at the particular failed component's f_r is used. This value is something akin to the g^2/Hz spectral amplitude of the PSD which gives us the loading power at a specific f_r.

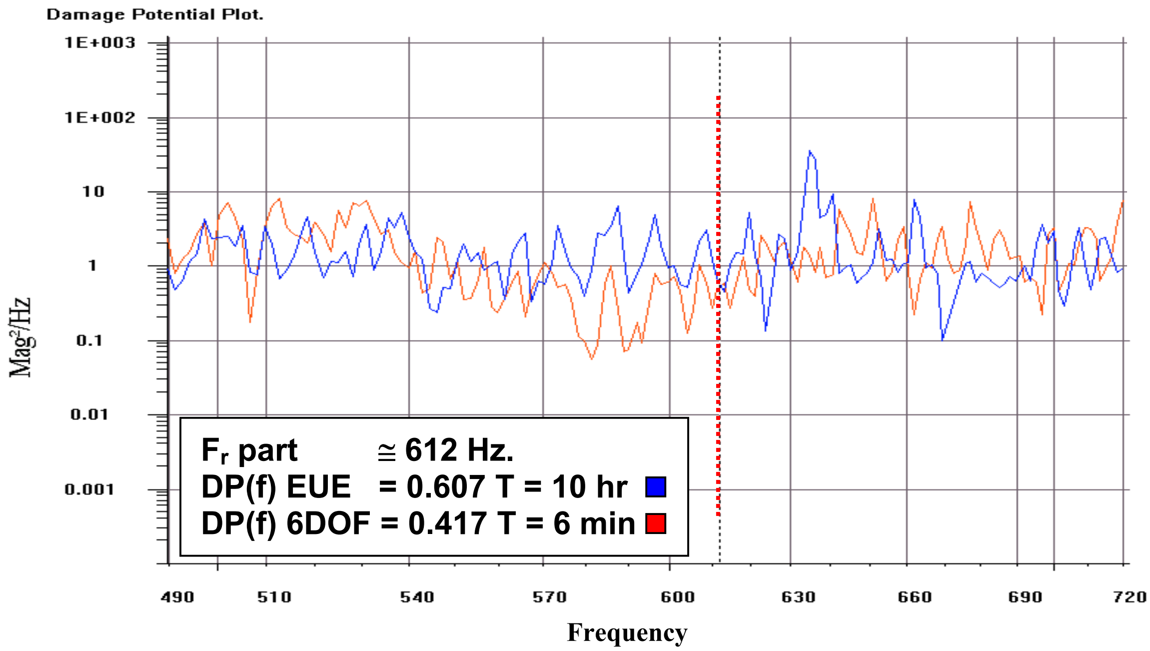

Figure 3. DP(f) spectra of both Diesel engine EUE and 6DOF shaker cases. The spectrums have been zoomed (reduced) to a bandwidth of approximately 490 Hz to 720 Hz.

At the exposure times indicated, the values of DP(f) differ by a ratio of only1.173 to 1, which is essentially equal fatigue.

Conclusions

The DP(f) has been shown to overcome the shortcomings of gRMS for 6DOF shaker analysis. It has also shown the possibility to estimate the exposure time in the EUE for end-of-life, EOL, using comparative fatigue analysis. The relative magnitude of fatigue accumulation during 6DOF testing can be effectively determined knowing the time to failure. EOL estimates in the EUE can then be made by correlating with the degree of fatigue accumulated at the time to failure during HALT/HASS testing. This answers an important question not addressed by HALT/HASS testing. That question is projecting the EOL in the EUE and by implication, the adequacies of product design strength.

References:

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