Accelerated Service Simulation with Edited Test Track Data

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This article covers the use of amplitude edited test track data as input for acclerated vibration testing of automotive components. The technique is demonstrated by a case history for an automobile power distribution junction box.

Downsized staffs within the automotive industry have limited the availability of vibration spectra on which to base product testing in the vibration laboratory. As a result, electronic component manufacturers find that the burden of obtaining environmental information rests more and more with themselves if they want to circumvent the use of nonrelevant, "cookbook" test specifications mandated by car manufacturers. This case history describes one supplier's successful efforts to replace questionable sine sweep qualification testing by obtaining amplitude edited service environment vibration spectra, and then applying PSD exaggeration for use in life qualification tests. This article describes the steps taken – a combination of three principles of test acceleration: 1) eliminating (editing-out) low level stress portions of service environment data recordings; 2) producing PSDs from these edited records to serve as the basis for shaker input specifications; and 3) exaggerating these PSDs in order to perform a life verification test in a reduced period of time. A previously unpublished method is described that uses digitizing transient recorders with amplitude triggering to edit field service data during acquisition, thereby bringing the benefits of sophisticated vehicle test compression methods to individual components.

Edited Amplitude Recording

The first step in producing an accelerated service life test using shakers is to define the service environment in usable terms. This is usually done by obtaining a power spectral density (PSD) function that represents the environment. The idea is to record, usually by tape or other means, the broad-band vibration loading experienced at locations of interest on a vehicle being driven over a test course or typical road surface. PSDs are then produced from this record. The raw records may be used without further enhancement to produce test specifications that would allow testing at service environment equivalent levels. However, it is possible to edit the raw data records to obtain a degree of test time acceleration.[1] To do this, the time records are edited to remove blocks of low, non-stressing vibration events, while preserving the higher ones. Since the lower stress levels produce minimal damage to the test item, they are of no concern and can be edited out.[2]

Editing of time domain records is usually done by amplitude discrimination methods involving analytical software. The result is a record in which only stress levels over a predefined amplitude threshold are retained. A degree of test acceleration (compression) will have taken place equal to the degree of time compression of the time record. The PSD of the edited data can be used at this stage to provide spectral control of large shakers. These shakers can subject a laboratory test vehicle to the same level of stress history in just a few hours as would be accumulated during days on a test track. This process is valid because fatigue damage to structures is due primarily to the highest levels of stress encountered.[2] Single channel editing techniques are adequate for sequential axis testing.

Modern digital transient recorders have a unique ability for this application. They have an amplitude-trigger function that can be set to a desired stress level for "editing" incoming data and only stress events that meet or exceed this level will be captured. These individual time histories can then be streamed to memory. The transient recorder captures records with fixed durations and also has the ability to capture a selectable amount of time data prior to and after the trigger event. If the recording time window used is of sufficient duration, closely spaced events will be captured in the post trigger portion of the recording.

A transient recorder memory operates in a "merry-go-round" fashion. High speed transient recorders save data to on-board RAM buffer memories during the digitizing process. This overcomes the low bus bandwidth problems of host PCs. Prior to a trigger event, the recorder continuously fills memory with digitized values. As the data capture process continues, new data are written over the old until a trigger event occurs. Many minutes of this continuous digitizing operation may take place prior to and in between, amplitude-triggered events. When each record is captured, it is saved to hard disk storage and the trigger is reset for the next event.

The modern transient recorder allows specification of the number of amplitude-triggered events, or alternately, the sum of time for all records to be streamed to hard disk. In this fashion, an amplitude edited trip history of only high stress events is obtained. It is common to compress a road test into fewer than 10 to 100 event records or by typical time ratios of hundreds to one. The time records are then available in a computer for post-processing, either in the field for quick-look test verification or for more formal analysis by archiving to floppy disk and uploading to a compatible work station.

Computation of Spectral Data

Since vibration-induced structural and equipment failures are highly dependent on frequency, it is necessary to reduce the triggered-event time history records into some form of spectrum. Assuming the vibration data are basically random in character, the most appropriate spectrum is the autospectral density function, which is also called the power spectral density PSD function. Specifically, each streamed-to-disk record is processed using fast Fourier transforms FFTs. This is done by producing a sequence of 50% overlapped and windowed FFT blocks from the time data file and producing a PSD. In this specific case history, a total of thirty-one such FFTs from each 16 kB streamed file were processed to obtain the PSD for one event record. After the first streamed data record is processed, the PSD data are saved in the computer RAM arrays. The same process is applied to each subsequent streamed time record and the resultant PSDs are ensemble averaged.[3] The sum of FFTs processed to yield the final PSD is simply the total of those from each streamed record times the number of records. In the following case history, this totaled 126 FFTs per final ensemble-averaged PSD.

Test Acceleration by PSD Intensification

If the PSD resulting from time editing is used without further adjustment as a shaker specification, a moderate degree of compression will have been obtained. However, to reach a greater time compression, it is possible to use the same PSD shape with increased intensity as a shaker specification. This is justified by applying the concept of vibration exposure-time equivalency based on equal fatigue damage accumulation.[2]

The acceleration of vibration tests is commonly performed

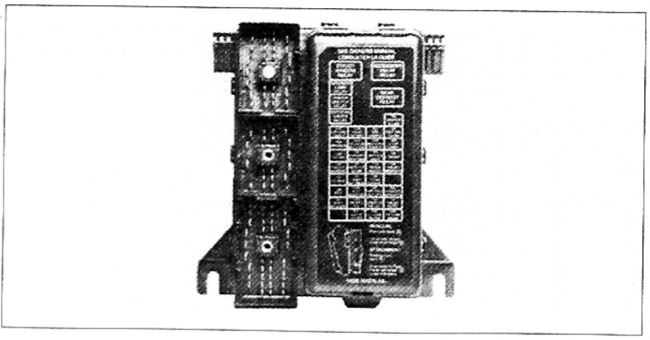

Figure 1. The case history junction box.

by assuming an inverse-power law relationship between RMS stress and time-to-failure,[4] which makes a good fit to a simplified fatigue-damage relationship. Specifically, if it is assumed that: a) the PSDs of the service and test environments have the same shape; and b) the vibration-induced stress at a given frequency is proportional to acceleration, then the inverse-power law can be applied to the RMS value of the vibration environment to obtain:[4]

$$T_t = T_s(\sigma_t / \sigma_s)^{-b} = T_s(\sigma_s / \sigma_t)^b \qquad (1)$$

where T_s = duration of service environment, sec
T_t = duration of test environment, sec
σ_s = RMS vibration of service environment, g
σ_t = RMS vibration of test environment, g
b = fatigue coefficient.

The ratio σ_t/σ_s in Eq. (1) is called the test exaggeration factor. The fatigue coefficient b in Eq. (1) has a value that varies widely depending upon the test item materials, but $b = 8$ is recommended in Reference 5 for basic vehicle structures. On the other hand, $b = 4$ makes a better fit to the failure data for complex equipment items. However, it should be emphasized that many test items are manufactured from several different materials, meaning any single value of b may be inappropriate for at least some of the materials. In such cases, a large exaggeration factor can lead to inaccurate, accelerated test results, i.e., a highly accelerated test can produce failures that would not occur in the service environment.[6]

Case History

The test component was an automobile power distribution junction box shown in Figure 1. This box consists of a metal fret layer separated by molded insulation plates and enclosed in a molded housing with snap-together upper and lower halves. The stamped circuit serves as a high current interconnection between vehicle power distribution cables, fuses, relays, flashers, etc.

In many cases, in the absence of valid engineering vibration data, the car manufacturer's product engineer relies on "cookbook" specifications to guide his vendor's qualification testing. In this case history, a sine sweep product qualification test was specified by the car manufacturer. This type of vibration test is typically done on a single axis shaker onto which several products are mounted. The test specified by the vehicle manufacturer for this product consisted of 30 sec. sine sweeps from 5 to 50 Hz at 1.5 mm constant displacement. A total test duration of 8 hours was to be run in each plane. The problem with the sine sweep is that it's relatively slow and intense. The result is that when applied to products with component resonances within the frequency range of the sweep, those components with low damping can be driven to unrealistically high responses, thereby damaging them. This tends to overstimulate these particular components and raises the question as to equivalence with the real world environment. In this particular case study, this overstimulation resulted in very rapid component failures.

For the specified test, the junction box was mounted on the shaker table via a vertical-sided fixture using light gauge "Z" brackets, as used in the vehicle when mounted on the interior firewall. During the initial tests, a major problem developed with the integrity of the mounting bracket. During the sine sweep, the junction box on the bracket combination resonated at a 17 Hz fundamental and 34 Hz harmonic with a very high response. After only a few sweeps, the bracket would fail from fatigue accumulation, terminating the test. At this point, it was decided to redesign the Z bracket to pass the qualification tests. After the bracket design was reinforced sufficiently to completely stop the junction box response, the box latches failed. This posed an expensive and illogical solution to the problem – redesign the product to pass an arbitrary test specification.

At this point, product engineers learned that if the valid environmental vibration spectra could be obtained, product qualification and life testing using accelerated methods based on field service PSDs would be acceptable in place of the sine sweep qualification test. This was a major improvement. The reason the swept sine test produced erroneous results is that it did not simulate the basic characteristics of the service environment, i.e., the service environment is not a swept sine wave. Hence, simply going from a swept sine test to a random test with the PSD of the service environment constitutes a major improvement in the accuracy of the laboratory test.

To accomplish this, a test series was scheduled on a test track with a prototype vehicle that uses the junction box. Two triaxial accelerometers were used during vehicle tests. The first was attached to the base mount location of the bracket used to mount the terminal box to the firewall. The orientation of the sensor axes was: Z vertical, X longitudinal and Y transverse. The second accelerometer was mounted on the corner of the box lid and in the same orientation. The transient recorder and analyzer used was a GHI Systems sixteen channel LapCAT with integrated ensemble averaging PSD software. Signals from ICP type accelerometers were fed directly into the ICP conditioning inputs of the LapCAT. Multiple passes of the 1996 prototype test vehicle were made over the cobblestone section at speeds of approximately twenty miles per hour. Only three successive passes over the cobblestone section were needed. Two trial runs for trigger sensitivity adjustment and quick looks at the resulting PSDs, were made before the final run. The recording trigger level was set to ±1 g in the Z axis, the transient time record was set to 1.3 sec per captured file and the number of triggered events per run was set at ten due to the shortness of the cobblestone section of the track and the lower than expected peaks in the time history. Of these ten events, six were judged acceptable and were processed in the vehicle. Larger record totals could have been used but may not have significantly altered the results.

Figure 2 shows the ensemble-averaged PSD from the vertical Z component at the product attachment point (input). Note that the computed overall excitation of 0.22 g RMS of the PSD curve is very low compared to the original sine sweep requirement. Except for the spikes in the curve due to local sources, it is similar to typical vehicle spectral signatures for locations partially isolated from suspension and engine components. The low intensity is related to the damping afforded by other components on the test vehicle firewall, such as sound absorbing materials. With a sequence of six records, each 1.3 sec in length, the compressed time containing the high stress events was 7.8 sec. The time the vehicle was on the cobblestone track section was approximately 60 sec. The time compression in this case was about 8:1, but could have been greater by making the trigger threshold higher.

Figure 3 shows the +3 dB intensified test track PSD profile as used with an Unholtz-Dickie shaker, for the purpose of product validation testing. Four additional product samples were then subjected to the test track profile intensified by +6 dB for the 575 hour accelerated-life testing which also combined vibration cycling simultaneously with temperature and power cycling.

As a result, the part manufacturer achieved high-confidence verification of part reliability. The 575 hours of shaker simulation time represented a 150,000 mile life or 5500 hours on

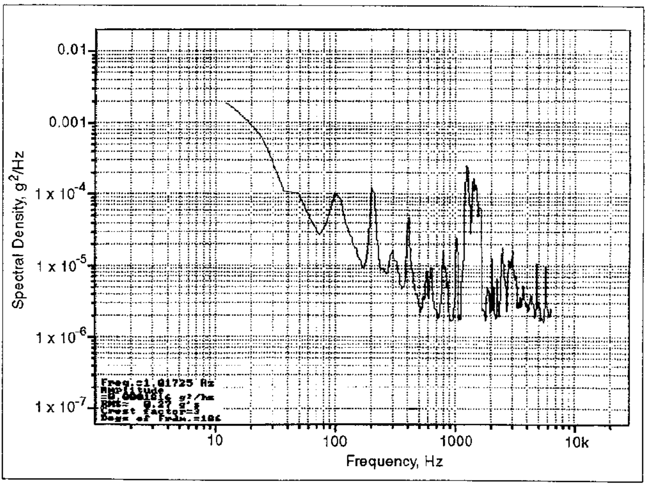

Figure 2. Ensemble averaged PSD spectrum from service records.

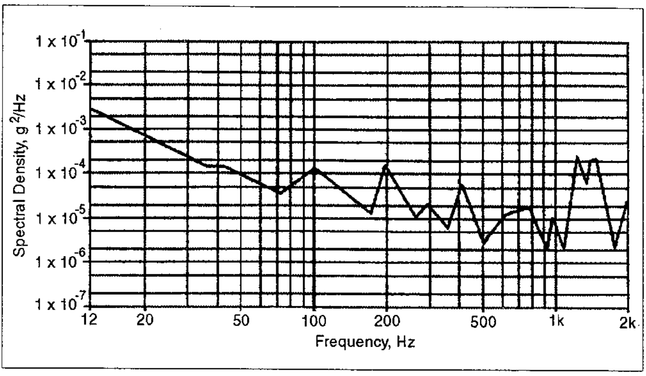

Figure 3. Exaggerated shaker drive PSD spectrum resulting from amplitude edited field data.

the cobblestone road. This test was based on a total edited time record of only 7.8 sec of track data.

Conclusion

Practical and inexpensive engineering methods are available to augment reliability testing of automotive components to improve product reliability. The engineering methods used in this case history are based on a combination of time editing of vibration data obtained directly from vehicles on test tracks, ensemble-averaging PSDs from the edited results and shaker time compression through PSD intensity exaggeration. These tests can be conducted, at minor cost, by component manufacturers in cooperation with vehicle manufacturers. This is a mutually beneficial arrangement for both parties since the part producer has a more realistic test specification with the potential of large dollar savings and the vehicle manufacturer receives a more reliable product at a lower price, without significant investment on his part.

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