Vibration Qualification of Commercial Computers for Use in Military Tactical Environments

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ABSTRACT

Commercial computers are generally designed for commercial use and lack industry specification for tactical use, other than the shipping environment. In order to use commercial computers in rugged military tactical environments, appropriate mounting trays and fixtures with vibration isolators must be designed for installation in tactical wheeled and tracked vehicles. This paper describes the vibration test profiles used in testing a commercial computer and monitor, as isolated, to determine the survivability limitations of these components when subjected to simulated tactical wheeled and tracked vehicle vibration environments.

The Army Tactical Command and Control System (ATCCS) Common Hardware and Software (CHS - 1) acquisition procures ruggedized (militarized) computer equipment and software for fielding in the battlefield environment. With recent improvement in the quality and performance of commercial computer hardware, it is prudent to explore the possibility of using commercial off-the-shelf (COTS) hardware in the harsh tactical environment. The tactical use of COTS hardware has the potential to put state of-the-art technology in the hands of the soldier faster and cheaper, while utilizing industry standards for streamlined procurement. In order to do this, an evaluation of the survivability limitations of COTS computer hardware in a tactical environment must be performed. This paper addresses the environmental constraint of vibration in tactical wheeled and tracked vehicles. Other constraints — temperature, electromagnetic interference and compatibility (EMI/EMC), maintenance, and human engineering issues are not addressed.

OBJECTIVE

The objective of this evaluation is to collect data on the use of a COTS computer and color monitor in simulated tactical vibration environments, and to assess the data to determine the ruggedness of the equipment in these environments.

Keywords: vibration, tactical, computer, commercial, military, wheeled, tracked, vehicle, survivability, isolators.

APPROACH

To obtain information regarding resonances in a typical desktop computer, an ASL 433 commercial desktop computer was fitted with a Plexiglas cover. The computer was subjected to low-level sinusoidal sweeps on a vibration shaker, and internal components were monitored for resonance with a strobe light. Circuit-card resonances were observed as low as 12 Hz in a vertically mounted circuit card. Other cards resonated at various frequencies up to 80 Hz. The hard disk/floppy disk-drive assembly resonated at 29 Hz.

It was concluded from this investigation that this computer and other commercial computers of similar design would benefit from, if not require, the use of isolators for application in tactical vehicles. Vehicular shock is another factor in deciding to mount commercial computers on isolators. Shock levels on the order of 15 to 20 g's are generated in the vehicles due to vehicular transport, rail, sea, and air transport, and handling (transit drop shock). The use of isolators can greatly attenuate the transient energy associated with these shock pulses.

Although the use of isolators can result in first-mode resonances near or within the frequency range of the wheeled-vehicle suspension natural frequencies, the equipment is essentially insensitive to this low-frequency energy, and the disadvantage is outweighed by vibration and shock isolation provided by the isolators at higher frequencies. The isolation system natural frequency is tuned to avoid coinciding with the suspension natural frequencies, which limits stresses in the isolators and mounted equipment.

The computer components were mounted in vibration fixtures that simulated typical mounting arrangements in tactical vehicles. These fixtures were fitted with vibration isolators that would be used with vehicle-mounted equipment. The isolated equipment was then subjected to random vibration inputs for specified periods of time, corresponding, to longer periods of actual field use (i.e., the vibration levels were accelerated for the purpose of time compression). The equipment was subjected to inputs based on composite wheeled-vehicle vibration data, and separately to inputs based on data taken from an M113 tracked vehicle. The latter is considered to be a worst-case, tracked-vehicle vibration environment. The components were operated before and after they were subjected to these vibration environments.

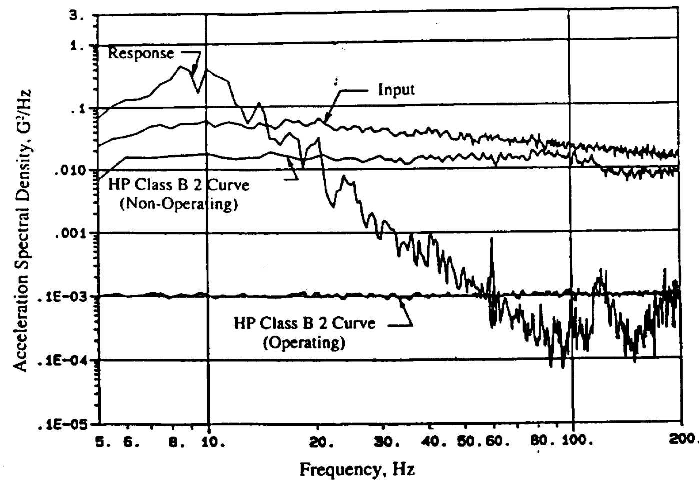


Figure 1. Wheeled-vehicle, vertical-axis input and response for the HP 735 computer.

ITEMS TESTED

Computer Equipment

The environmental tests were performed on a commercial PA RISC HP 735 Computer workstation with a 1-GB hard disk drive and a 19-in. color monitor device (CMD). Hewlett Packard was chosen as a supplier for the components because their components were already being procured under a CHS-1 contract for ruggedized equipment with the U.S. Army.

Vibration Isolators

Commercial computers are generally designed for office (stationary) applications and lack industry specification for transportation in other than a shipping environment. Therefore, appropriate tray fixtures with isolators must be designed for installation in wheeled and tracked vehicles. The selection of isolators is determined by the particular equipment and platform(s) for each application. The vibration isolators chosen for the PA RISC HP 735 Computer and 19-in. CMD are the Shock Tech spring-damped gel-filled isolator FM25-N01. Because the vibration environment in tactical vehicles is characterized by high-displacement inputs at low frequencies, the isolator selected must provide high damping and low transmissibility at resonance in order to limit the response of the test item and the resulting stresses. The FM25-N01 isolator meets these requirements. It has a relatively low natural frequency, 6 to 16 Hz, with 11 to 17 lb of loading per isolator, and a transmissibility at resonance of three or less. In the tracked-vehicle test, the HP 735 Computer was mounted with four isolators, while the 19-in. CMD was mounted with six isolators. In the wheeled-vehicle test, the computer was mounted with six isolators and the CMD had to be mounted with nine isolators. This setup is not considered ideal; however, due to a lack of availability of isolators, it was the best solution at the time of the test. An optimum solution would be to have no more than four isolators for the computer and six isolators for the CMD.

Isolator selection and design and fabrication of the mounting trays for both the computer and CMD were performed by the U.S. Army at Fort Monmouth, New Jersey.

TEST FACILITY/ DATES

The vibration test was performed at the Hewlett-Packard Environmental Test Laboratory at Fort Collins, Colorado. The vibration shaker used is a Ling Electronics Model 520 Shaker. The first series of tests was performed from January 1,1994, through February 4,1994. The second series of tests was performed from March 1, 1994, through March 3. 1994.

WHEELED-VEHICLE VIBRATION TEST

Wheeled-vehicle Profiles

The wheeled-vehicle vibration profiles used in this test were based on Figures 514.3-7, 514.3-8. and 514.3-9, basic transportation, composite tactical wheeled environment. The profiles from MIL-STD-81OD were tailored by using straight-line approximations of the data. The low-frequency ends of the profiles were also tailored to reduce the acceleration spectral density (ASD) to 0.02 g^2/Hz at 5 Hz and 0.05 g^2/Hz at 7 Hz and above. This procedure was used to avoid overstroking the shaker and to prevent unrealistic stresses from occurring in the isolators and test items. The rationale for this tailoring of the low-frequency energy components of the profiles is as follows: The high-amplitude displacements that give rise to these components are present for a relatively short period of time in the vehicular environment (i.e., when road discontinuities such as bumps and potholes cause the suspension of the vehicle to resonate). Thus, the peaks present in Figures 514.3-7, 514.3-8, and 514.3-9, located between 5 and 10 Hz where suspension frequencies are present, are flattened.

The duration of the wheeled-vehicle test, 2 hr per axis, corresponds to a vehicular mileage of 500 miles. This transport scenario is considered mission/field transportation. The road conditions are unprepared (cross-country) terrain and unimproved roads, in addition to paved roads. Based on previous testing of electronic equipment, if the equipment survives a test based on the preceding scenario, there is a high level of confidence that its fatigue life will be acceptable when fielded.

To summarize, the wheeled-vehicle profile levels used in this test have been accelerated for the purpose of time compression. The degree of acceleration is approximately the same as that used in the composite wheeled-vehicle profiles of MIL-STD-810D, and results in 500 miles of vehicular travel compressed into 2 hr of shaker testing per axis in three mutually perpendicular axes. This type of testing has resulted in the qualification and successful fielding of electronic equipment for the army in the past and is used here with confidence.

Test Performance

The HP 735 Computer and CMD, in their vibration isolated trays, were tested separately in vertical-axis vibration, and together in transverse and longitudinal-axis vibration. This was due to the large size of the horizontal-axis slip table. In the vertical axis, only one test item at a time could be mounted to the vibration shaker head/mounting plate. The computer mounting tray used six isolators, and the CMD required nine isolators, in three rows of three, to prevent large displacements and resulting damage to the isolators. Accelerometers were placed directly on the mounting trays of the test items to monitor their response characteristics in three axes of vibration. Each of the test items was vibrated for 2 hr/axis in three mutually perpendicular axes for a total test time of 6 hr. Pre-operability and post-operability tests were performed on both the computer and the monitor to determine successful operation and to display any system errors.

Test Results

Figure 1 shows the wheeled-vehicle, vertical-axis input and response plots for the HP 735 Computer. After an initial increase in power spectral density at low frequency, due to the resonance of the isolator, the vibration levels experienced by the computer are attenuated. The resonant frequency of the isolator is approximately 10 Hz. The transmissibility of the isolation system at the resonant frequency is calculated to be:

$$T_R = \left(\frac{G^2 out}{G^2 in} \right)^{\frac{1}{2}} \approx \left(\frac{0.4}{0.06} \right)^{\frac{1}{2}} = 2.58 \quad (1)$$

where G^2 *out* is the acceleration spectral density (ASD) measured at the base of the computer, and G^2 *in* is the ASD measured at the base of the isolators. This is the ratio of peak acceleration experienced by the computer to the peak acceleration experienced by the base of the isolators when the system is vibrated at its resonant frequency. The ratio of 2.58 is significantly lower than that of most isolators. Above approximately 14 Hz, the vibration energy is attenuated significantly. The computer operated normally after the wheeled-vehicle vibration test was completed.

The results of testing the CMD were similar to those of the computer. The resonant frequency of the isolated CMD was measured to be 15 to 17 Hz in the horizontal axes. Attenuation of the vibration input begins at approximately 20 to 22 Hz and increases significantly at frequencies above 22 Hz. The CMD operated normally after the wheeled-vehicle vibration test was completed

TRACKED-VEHICLE VIBRATION TEST

Tracked-Vehicle Profiles

The M113 is considered to have the most severe vibration environment of all Army tracked vehicles. Therefore, there is a high degree of confidence that equipment able to withstand the M113 environment will survive other tracked-vehicle vibration environments. The tracked-vehicle profiles were based on accelerometer data taken in an M113 tracked vehicle at Aberdeen Proving Ground, Maryland. The data were reduced and grouped into test phases at CECOM, Fort Monmouth, New Jersey. The data points in each phase or plot were enveloped, and the resulting levels were multiplied by a factor of 1.5. The profiles consist of broadband "background" random noise, with superimposed narrowband "spikes." The narrowband spikes correspond to track clatter-periodic or quasi-periodic vibration energy resulting from the vehicle tracks contacting the paved road surface. Thus, the narrowband energy on the left side of the profiles corresponds to the lower vehicle speeds of 8 to 16 km/hr (5 to 10 mph), while the narrowband energy on the fight side of the profiles corresponds to higher vehicle speeds of 48.3 to 56.3 km/hr (30 to 35 mph). Harmonics of the primary narrowband spikes are also present.
These tracked-vehicle profiles are similar to those used to qualify the Any SINCGARS Radio, with one major difference. The test phases corresponding to the lowest vehicle speeds were separated into two subphases, labeled A and B. An example is shown in Figure 2 of the tracked-vehicle vertical-axis, test phase 1A monitor input and tray response, and in Figure 3 of the tracked-vehicle, vertical-axis, test phase 1B, HP 735 Computer input and tray response. The differences between these two input profiles are:

- Figure 2 includes a narrowband spike at a center frequency of approximately 23 Hz, while Figure 3 does not.
- The time duration of testing is 2 min for Figure 2. and 38 min for Figure 3.

The result is that the contribution of energy resulting from low-speed vehicle transport is present for one-twentieth of the total time of testing for test phase 1. This situation more accurately reflects actual conditions in which most of the vehicle transport occurs at convoy speed, approximately 40 km/hr (25 mph).

The preceding test profiles also avoid undue stress on isolators during testing, and possible damage to the shaker due to high-amplitude displacements. For example, test phase 2A. Longitudinal Axis, results in a predicted double-amplitude (DA) displacement of 0.63

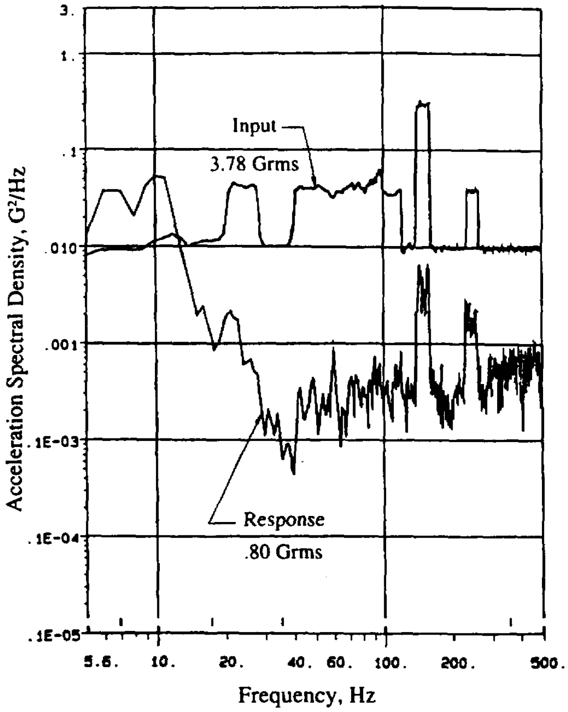


Figure 2. Tracked-vehicle, vertical-axis, test phase 1A, monitor input and tray response.

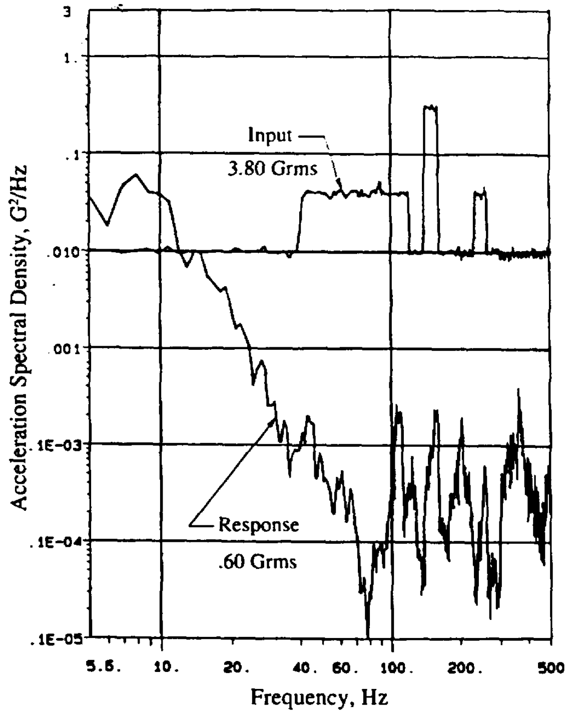


Figure 3. Tracked-vehicle, vertical-axis, test phase 1B, HP 735 Computer input and tray response.

in. While most shakers are capable of this displacement, subjecting an isolated system to this displacement amplitude for 40 min could result in bottoming and premature failure of the isolators.

For brevity, only two of the 15 phases used in the tracked-vehicle vibration test are included in this paper. The remaining 13 phases show results similar to those found in the two phases which were included here. No quantitatively defined stress life is associated with these profiles. However, they have been used successfully to qualify and field army electronic equipment.

Test Performance

As in the wheeled-vehicle vibration test, the HP 735 Computer and CMD, in their vibration-isolated trays, were tested separately in vertical-axis vibration, and together in transverse and longitudinal-axis vibration. The computer mounting trays used four isolators and the CMD used six isolators. Accelerometers were placed directly on the mounting trays of the test items to monitor their response characteristics in the three axes of vibration. Accelerometers were also placed on the top of the monitor, on the central processor unit (CPU) circuit card of the computer, and on the hard drive of the computer. Each of the test items was vibrated for 2 hr/axis, for a total test time of 6 hr. Pre-operability and post-operability tests were performed on both the computer and the CMD to determine successful operation and to display any system errors.

Test Results

The resonant frequency of the isolated CMD is approximately 10 Hz, with attenuation of the input vibration energy beginning at approximately 12 Hz (see Figure 2). The relatively high energy spikes, between 20 Hz and 300 Hz, have been significantly attenuated.

The ratio of the root-mean-square (RMS) G-level of the output to the input is:

$$T_{avg} = \frac{Grms,out}{Grms,in} = \frac{0.796}{3.78} = 0.21 \qquad (2)$$

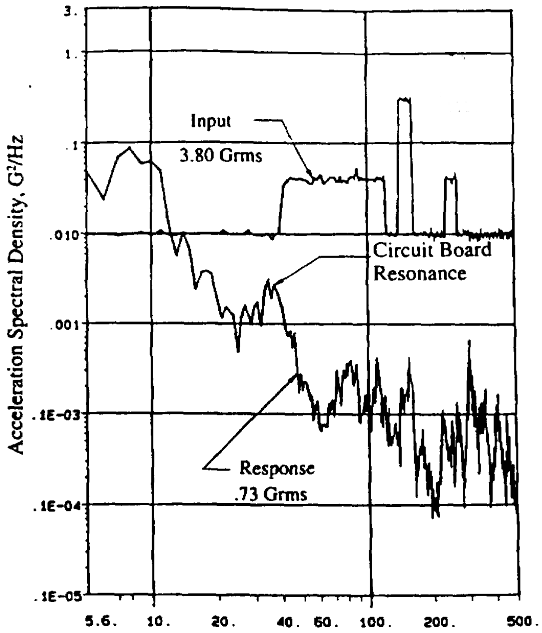
This is equivalent to an average transmissibility over the frequency range of 5 to 500 Hz. The square of this number, 0.044, or 4.4 percent, is the amount of vibration energy transmitted through the isolation system. Thus, 95.6 percent of the vibration energy is removed by the isolation system of the CMD.

Figure 3 shows the vertical-axis, test phase IB, *tray* response plot for the computer. The resonant frequency of the isolated computer is approximately 8 Hz, with attenuation of the input vibration energy beginning at approximately 12 Hz. The relatively high energy spikes between 40 Hz and 300 Hz have been significantly attenuated. The ratio of RMS G-levels is:

$$T_{avg} = \frac{0.602}{3.80} = 0.158 \qquad (3)$$

and

$$\left(T_{avg}\right)^2 = 0.025 or 2.5\% \qquad (4)$$



Frequency, Hz

Figure 4. Tracked-vehicle, vertical-axis, test phase IB, HP 735 Computer input and CPU board response.

Therefore, the energy efficiency of the isolation system of the computer is 97.5 percent. This percentage is even higher for frequencies above 12 Hz, where the damage potential of the vibration input is greater because stress-producing frequencies (resonances) are more likely to be present in the test item at higher frequencies. The energy efficiency of the isolation system is an average figure, and does not necessarily apply at a particular frequency (i.e., it is not related to damage potential, which is frequency-related).

Figure 4 is a plot of the CPU circuit-card response, showing a resonance with a center frequency of approximately 35 Hz. A plot of the hard-drive response shows a resonance centered at approximately 70 Hz. Both of these component resonances were excited by the high-level input spike located between 40 Hz and 120 Hz. Both resonant responses were attenuated significantly by the isolation system of the computer.

SUMMARY

Sufficient data were collected in this evaluation to assess the ruggedness of the commercial HP 735 Computer and 19in. color monitor device. Using six Shock Tech FM25-NO1 isolators for the computer and nine isolators for the CMD during simulated tactical wheeled-vehicle vibration, no test item failures were sustained. Using four isolators for the computer and six isolators for the CMD during simulated tracked-vehicle vibration, no test item failures were sustained. The isolation systems were observed to provide low transmissibility at resonance, and significant attenuation of input vibration energy beginning at frequencies slightly greater than the resonant frequencies. The internal resonances of components within the computer were also significantly attenuated.

CONCLUSION

The results of this evaluation provide a high degree of confidence that the test items can survive the tactical wheeled and tracked-vehicle vibration environments when property isolated.

REFERENCE

1. MIL-STD-810, "Environmental Test Methods and Engineering Guidelines" (July 19, 1983).

ACKNOWLEDGMENTS

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