

COMPUTER SHOCK AND VIBRATION CONCERNS

By Tom Irvine

Dynamic Labs tomirvine@aol.com

INTRODUCTION

Digital microcomputers are ubiquitous.

Computers inside the space shuttle control its descent from orbit until it slows to Mach 1, the speed of sound. At this time, the pilots gradually take over control and prepare for landing.

Computers inside satellites provide a myriad of functions. For example, a satellite computer might record sensor data for later transmission to Earth ground stations. Computers with analog-to-digital conversion modules are replacing strip chart records for seismic monitoring.

Obviously, computers are becoming increasingly common in home and business settings, where they are used for calculations, word processing, data storage, Email, internet access, and entertainment.

Computers and other electronic equipment must withstand shock and vibration environments during assembly, shipping, and at other times. Computers must also function accurately during shock and vibration exposure. For example, the space shuttle computers must accurately control the vehicle while it undergoes the aerodynamic buffeting from re-entry into the atmosphere.

The purpose of this report is to give some design, testing, and analysis guidelines for computers with respect to shock and vibration environments.

EXPECTED ENVIRONMENTS

Notes

Design engineers must understand the shock and vibration environments to which their computers will be exposed. A few examples are given in this section.

Assembly

Power screwdrivers are often used to install components inside computer chassis. These screwdrivers produce bursts of pulses having high amplitudes and very short duration. Hard disk drives may be particularly susceptible to these shock pulses. The International Disk Drive Equipment and Materials Association (IDEMA) addresses this concern in Reference 1.

Transportation and Shipping

Transportation and shipping environments are a concern for all computers. For example, a computer might be shipped inside a truck that runs over potholes and railroad tracks at imprudent speeds.

A well-designed shipping container with foam inserts should be able to reasonably protect a computer from shock and vibration. Packaging techniques are discussed later in this report.

Motor Vehicles

Some computer systems must be permanently mounted in vehicles. These systems must operate during the shock and vibration. For example, computers in emergency rescue vehicles must function accurately even when the vehicles travel on washboard roads. The author has experience measuring washboard road vibration. Most of the energy was in the 0 to 20 Hz frequency range. A notebook computer data acquisition system was used to measure the acceleration. Ironically, the computer suffered hard drive lock up problems during the worst of the vibration.

MECHANICAL



Technology Training that Works

Contact IDC

<http://www.idc-online.com>

Aircraft

One of the author's clients designed a computer system that provides entertainment for airline passengers. Aircraft are exposed to low-frequency excitation as they fly through turbulent air. Landing shock is a similar concern. Landing shock obviously depends on the runway surface, wind conditions, pilot skills, and other factors. Much of the energy for both turbulence and landing shock is in the 0 to 20 Hz frequency range. Unfortunately, isolator mounts are ineffective for electronic equipment in this frequency range. One problem is that isolators may cause excessive relative displacement below 20Hz.

Satellites and Launch Vehicles

Both satellites and launch vehicles have flight computers and other avionics components. Launch vehicles are subjected to harsh vibration environments, particularly as they accelerate through the transonic velocity and encounter the maximum dynamic pressure condition. This buffeting tends to be dominated by high-frequency energy above 400 Hz.

The satellite is typically housed inside a nosecone fairing which partially protects the satellite from these buffeting effects. Furthermore, solid rocket motors have pressure oscillations that may excite the satellite. A typical motor pressure oscillation frequency is 60 Hz. In some cases, the entire satellite can be mounted via an isolator system to attenuate these excitation sources.

Stage separation and deployment are further concerns. Note that linear shape charge and other pyrotechnic devices are used to initiate these events. These devices tend to produce high-frequency energy, with much of the energy above 1000 Hz. The near-field acceleration time history amplitudes can reach 10,000 G, particularly if linear shape charge is used.

As an aside, note that hard disk drives require some air pressure to function properly. A vacuum condition exists in space, however. This is a challenge for satellite computers with hard disk drives. The solution is to mount the computer inside a pressure vessel within the satellite.

Arcade Video Games

An engineer who designs arcade video games reported that enraged teenagers sometimes kicked the housing. The shock loads were transmitted to the internal hard disk drives. As a result, the drives suffered head slaps that sometimes locked up the drives and even destroyed data.

FIELD MEASUREMENTS

Ideally, the engineer has measured data for the expected environments. The engineer could, for example, attach accelerometers to a mass model of a computer that is packed in its shipping crate. The engineer could then record the shock and vibration levels as the box falls off a forklift, is transported in a truck over a washboard road, and is exposed to other rough handling. Battery-operated data acquisition systems are available that can be inserted inside a shipping container to measure the transmitted shock and vibration. Incidentally, these units have static RAM memory rather than hard disk drives.

Furthermore, the author has taken numerous accelerometer measurements on rocket vehicle modules undergoing stage separation shock. These levels are a serious concern for flight computers and other avionics components, as previously discussed.

The author has also analyzed flight accelerometer data from rocket vehicles. The data was sent via telemetry links to ground receiving stations. Field measurements can be expensive. As an alternative, some generic shock and vibration level for transportation and other environments are given in References 2 - 4.

TEST LEVEL SPECIFICATION TOOLS

Shock

Shock specifications are typically represented in these formats:

- Classical pulse, such as a half-sine pulse
- Shock response spectrum
- Drop height above floor

A thorough shock testing program should give separate specifications in each of these formats. Further information on these shock formats is given in References 5 - 7.



Technology Training that Works

Contact IDC

<http://www.idc-online.com>

Vibration

Random vibration is typically specified in the form of a power spectral density. Sinusoidal vibration is typically represented in terms of a magnitude spectrum. The magnitude may be in terms of displacement, velocity, or acceleration. Further information about vibration formats is given in Reference 6.

TEST TAILORING

Test Level Derivation

References 1 - 5 give methods for transforming measured field data into shock and vibration test specifications. This is sometimes called "test tailoring." Safety margin is a big issue in this regard. The margin is needed to account for statistical variability and other unknown factors. A factor of 3 dB is a typical margin.

Parts and Workmanship Screening

Foremost, the derived test levels must envelop the expected shock and vibration environments. In addition, the test levels should screen for defective parts and workmanship. This screening test can either be performed separately or in combination with other qualification and acceptance tests.

A cold solder joint is an example of a workmanship defect. The proper method of deriving a workmanship level is to first produce components with "seeded defects." The components are then subjected to increasing vibration levels until the latent defects are exposed. Note that the components should be powered and monitored during this test. The resulting exposure threshold can then be adopted as a lot acceptance test level. This type of testing is sometimes called environmental stress screening (ESS). Note that ESS has different meanings to different people, however. For example, some argue that ESS is not a test at all but rather a screening of the manufacturing process.

DESIGN CONSIDERATIONS

Overall Design

Computers come in many forms. A typical computer consists of a chassis, a power supply, a CPU motherboard, I/O boards, a hard disk drive, and other peripheral components.

Hard Disk Drives

Hard Disk Drive Cost Considerations

A mass data storage device is typically chosen on the basis of cost rather than on ability to withstand shock and vibration. Furthermore, the hard disk drive is typically the most sensitive component with respect to shock and vibration. Spacecraft must withstand severe shock and vibration environments during liftoff, powered flight, and deployment. Thus, spacecraft flight computers often use nonvolatile static RAM chips in place of hard disk drives. The flight computer aboard the Mars Global Surveyor is an example of a computer that exclusively uses RAM memory for mass data storage.¹ Static RAM mass storage is one of several reasons that a flight computer can cost \$100,000 or more.

The aerospace industry is under pressure to lower costs. One satellite vendor thus reports that customers are requiring commercial hard drives for data storage. Hard drives are available in two classes for personal computers: the notebook class and the desktop class.

Basically, notebook hard drives are more rugged but more expensive. Notebook hard drives have smaller parts. Thus, notebook hard drives tend to have better dynamic stability than desktop units.² Consider an engineer who requires a 3.2 GB hard drive for a certain design. The engineer can either choose a notebook or a desktop hard drive. Some choices are given in Table 1, obtained from a web search of mail order vendors.

- Older probes such as Voyager used digital tape recorders for data storage.
- On the other hand, the satellite vendor reports that his company has successfully flown desktop hard drives in satellites several years before notebook hard drives became commercially available.



Technology Training that Works

Contact IDC

<http://www.idc-online.com>

A satellite vendor could easily justify the cost of a notebook hard drive for the sake of reliability. On the other hand, cost pressure would drive a vendor to implement a desktop hard drive in a mass-production arcade game.

Vendor	Product	Computer Class	Typical Price
IBM	2.5" U/ATA	Notebook	\$327.00
Toshiba	2.5" Slim IDE	Notebook	\$224.00
Fujitsu	Ultra DMA	Desktop	\$148.00
Maxtor	Ultra IDE	Desktop	\$175.00
Quantum	Ultra DMA	Desktop	\$159.00
	Fireball SE		
Samsung	Ultra DMA	Desktop	\$148.00
Seagate	ST-33240A IDE	Desktop	\$176.00
Western Digital	Ultra DMA	Desktop	\$159.00
	Caviar		

Table 1. Candidate 3.2 GB Hard Drives

As an example, consider that a design engineer must decide between the Toshiba notebook hard drive and the Fujitsu desktop hard drive. Note that each of these drives is the lowest price in its class. The dynamic specifications for the two drives are given in Table 2 as obtained from web site information.

Parameter	Toshiba Notebook Hard Drive	Fujitsu Desktop Hard Drive
Spin Rate (rpm)	4200	5400
Operating Shock	100 G	10 G (half-sine pulse, 11 ms duration)
Non-operating Shock	350 G	75 G (half-sine pulse, 11 ms duration)
Operating Vibration	0.5	0.5 G (5 to 300 Hz)
Non-operating Vibration	Not given	4.0 G (5 to 400 Hz)

Table 2. Dynamic Specification Comparison for 3.2 GB Hard Disk Drives

Note that the Toshiba specification is vague as to how the shock test was performed. The shock specification does not mention whether the shock test was a half-sine pulse or a shock response spectrum. On the other hand, the Fujitsu specification clearly states that its shock method was an 11 millisecond, half-sine pulse.

The design engineer must thus contact Toshiba to obtain further information. Ideally, each hard drive vendor should supply the design engineer with a test report which documents that at least one unit was actually tested to the specification. Verify! Nevertheless, the Toshiba Notebook Hard Drive appears to withstand ten times the operating shock level of the Fujitsu Desktop Hard Drive. The design engineer must decide, "Does the shock reliability of the Notebook Drive justify the \$76.00 unit price difference over the Desktop Drive?"

Hard Disk Drive Mechanics

A disk is made from metal or some other rigid material. The disk is called a platter. It is coated with a magnetic material that is used to store data as transitions of magnetic polarity. Each polarity corresponds to a "1" or a "0." One or more platters are mounted on a single spindle shaft. The drive platters are divided into cylinders. Multiple platters provide more data storage surfaces in a small package. A typical spin rate is in the range of 3600 to 7200 rpm. Seagate has a hard disk drive which spins at 10,000 rpm. Note that a higher spin rate reduces latency. A read/write head is mounted on the actuator arm. There is typically one head on each side of every platter. The heads move in unison back and forth across the platter according to a control algorithm. The algorithm compensates for the flexibility of the actuator arm, platter vibration, shock and vibration imparted to the drive housing, and signal latency.

Hard Disk Drive Failure Modes

A thorough discussion of failure modes is given in Reference 1. A particular concern is that the head or arm might impact against the surface of one or more disks, thereby creating voids in the recording film.



Technology Training that Works

Contact IDC

<http://www.idc-online.com>

This damage could cause data errors. There are several means by which this impact could occur. For example, the vibration could come from an external source that propagates into the arm, possibly exciting a head/arm natural frequency. Another scenario is that excessive disk vibration causes the disk to impact against the head of arm.

Stack shift is also a concern. This occurs when individual disks shift from their initial center of rotation. This shift could occur if the shock and vibration forces overcome the initial clamping forces. Stack shift may produce a sinusoidal position error signal with a frequency equal to two times (2x) the spin frequency.

Octave Rule Applied to Hard Disk Drives

As an example, a spin rate of 5400 rpm corresponds to 90Hz. Rotating unbalance, misalignment, and other faults could thus produce excitation at 90Hz as well as integer multiples thereof. Reference 5 gives an excellent table which relates the integer multiple to the specific fault type.

The spin frequency must be considered with respect to the chassis natural frequency. Preferably, the spin frequency is separated from the chassis frequency by one octave, in order to avoid dynamic coupling. A one-octave separation means that the higher frequency is at least twice the lower frequency. Note that this is a "rule of thumb".

Ideally, the disk drive would be rigidly mounted to a very stiff chassis. The engineers who design the hard drive control algorithm probably make this rigid mounting assumption.

In reality, the chassis itself could have a natural frequency near 90Hz. Rotating unbalance could thus excite the chassis natural frequency. This could affect the stability of the control algorithm.

Furthermore, consider the possibility of mounting the hard drive unit via isolator grommets to the chassis. The isolators would turn the hard drive unit into a spring-mass system. The resulting natural frequency could coincide with either the spin rate frequency or the chassis frequency. Either case would present potential problems.

Compact Disc Drives

Compact disk (CD) drives are apparently less prone to shock and vibration problems than hard disk drives. Note that music compact disk drives are often mounted in automobiles. A potential problem is that the CD could "skip" if the automobile drives over a bump.

Cables and Connectors

Cables should be tied down so that they cannot apply a pulling force on the connectors. This recommendation comes from Reference 8.

Circuit Boards and Piece Parts

Sockets

Sockets are often used to mount IC chips to circuit boards. Unfortunately, chips in socket mounts can easily be detached from circuit boards that are exposed to shock and vibration. The author personally experienced this problem several years ago with a numeric coprocessor chip in a 386 computer. Ideally, IC chips would be soldered directly to circuit boards. The desire to allow for upgrading the CPU and RAM requires a socket approach, however. On the other hand, the furious rate of technological change would seem to make "upgrade-ability" of an existing system a moot point. The consumer must typically buy a whole new computer system to run the latest operating system and software.

Crystal Oscillators

Crystal oscillators can shatter when exposed to shock and vibration. Care should be taken to choose an oscillator that has been designed and tested to withstand shock and vibration.

Staking

Piece parts should be staked to the circuit board with an epoxy substance to protect the part from detaching. A solder connection alone does not necessarily preclude detachment. This is particularly important for large components such as DC-to-DC converters.



Technology Training that Works

Contact IDC

<http://www.idc-online.com>

Coating

Ideally, a layer of thick conformal coating should be applied to each board. This layer adds damping. It also protects against shorting due to stray solder balls. Unfortunately, the coat makes rework difficult.

Fasteners

Fasteners may come loose during vibration environments. Screws must be torqued properly during assembly. In addition, lockwashers should be used to maintain preload. Again, a power screwdriver can induce shock pulses. Use a manual screwdriver if practical.

Cooling Fans

Pentium chips produce heat. Cooling fans must remove this heat so that the chips do not overheat. Cooling fans produce vibration, typically at their 60 Hz operating speed. The vibration energy that propagates from the fan to the circuit boards is probably negligible. Nevertheless, the fan must withstand its own vibration because a fan failure could cause a chip to overheat. Likewise a simple decrease in fan performance could cause overheating.

Shipping Containers

The shipping container should be made from heavy cardboard with foam inserts. The foam should allow the computer to have some relative displacement. This reduces the force transmitted to the computer per Newton's law of impulse and momentum.

On the other hand, the relative displacement must be limited so that the computer does not strike the inside of the box. Note that Styrofoam peanuts and crushed paper are unsuitable materials for shipping containers. The foam inserts must be carefully designed with respect to the computer dimensions, weight, and shipping method.

Testing can be used to evaluate the best packaging method. Further recommendations are given in Reference 8.

CONCLUSION

Computers are being used in increasingly harsh environments. Engineers must carefully consider shock and vibration issues in order to design computers which can withstand these environments. Field tests are important tools for characterizing these environments. Components can then be designed and tested accordingly. Other tests, such as modal tests, can be used to verify that there are no significant dynamic interactions between a chassis and a hard disk drive, for example.

REFERENCES

1. Anon., *HDD Handling Environment Assessment & Simulation Test Procedure Using Test Tailoring*, The International Disk Drive Equipment and Materials Association (IDEMA), Santa Clara, 1998.
2. MIL-STD-810E, *Military Standard, Environmental Test Methods*, Department of Defense, Washington D.C., 1988.
3. MIL-STD-1540C, *Test Requirements for Launch, Upper-Stage, and Space Vehicles*, Department of Defense, Washington D.C., 1994.
4. ASTM D4169, *Standard Practice for D4169-96 Performance Testing of Shipping Containers and Systems*, American Society for Testing and Materials, West Conshohocken, PA, 1977.
5. Cyril Harris, *Shock and Vibration Handbook*, 4th edition, McGraw-Hill, New York, 1995.
6. Dave Steinberg, *Vibration Analysis for Electronic Equipment*, Wiley-Interscience, New York, 1988.
7. Tom Irvine, *An Introduction to the Shock Response Spectrum*, Rev B, Dynamic Labs Tutorial, 1998.
8. Anon., *Shock and Vibration*, Chassis Plans Inc., 1997.



Technology Training that Works

Contact IDC

<http://www.idc-online.com>