IDEMA STANDARDS

HDD Handling Environment Assessment & Simulation Test Procedure Using Test Tailoring

I. Scope

This document contains a description of a procedure for testing HDDs that occur in the handling environment. A part of the procedure involves test tailoring methods which are used to develop specific shock amplitudes and time durations that relate to actual handing events. Test tailoring is the preferred method of setting test levels for the procedure. Test tailoring involves the recording of environmental shocks, performing SRS analysis on the resulting time domain data, and then testing the HDDS using the criteria obtained.

II. Reference Documents

“Military Standard, Environmental Test Methods,” MIL-STD-810E, Department of Defense, Washington, D.C., 1988.

“Test Criteria and Specifications,” Chapter 20. Shock and Vibration Handbook, 4th Edition (ED: C.M. Harris), McGraw-Hill, New York, 1996, Piersol, A. G.

Handbook for Dynamic Data Acquisition and Analysis, IES-RP-DTE012.1, Institute of Environmental Sciences, Mount Prospect, Illinois, 1994, Himelblau, H et al.

“Concepts in Shock Data Analysis,” Chapter 23. Shock and Vibration Handbook, 4th Edition, (ED: C.M. Harris), McGraw-Hill, New York, 1996, Piersol, A. G.

ANSI/ASQC Specification Z1.4-1993, ASQC Customer Service Department, P.O. Box 3066, Milwaukee, WI 53201-3066, Phone (414)272-8575.

III. Terminology

G. The acceleration force due to gravity, commonly defined as 32.2 ft/sec^2 in English units, and 9.81 m/sec^2 in metric units.

g. A non-dimensional value that describes an acceleration amplitudes in multiples of the acceleration due to gravity, G.

Peak g. The maximum value of multiples of the acceleration of gravity than an excitation peak obtains.

Duration.	The measured duration of an excitation shock pulse when measured at a defined amplitude. For example, when measured between points that constitute amplitudes equal to 10% of the peak value on the increasing and decreasing slopes of the waveform.
Hard Fixture	A mounting devices designed to rigidly attach a UUT to a shock machine table in a manner that neither amplifies or attenuates the shock input from the machine table. It must not have self-resonant frequencies that are within the band of response frequencies that are inherent in the unit under test.
Rotational X, Y, and Z Shocks.	Rotational shock moments applied circumferentially to the X, Y, or Z-axis of the HDD.
SDOF.	Single Degree of Freedom system composed of a mass, an attached spring, and a damping element. Simple mathematical models of SDOF systems are used to estimate the peak response acceleration/velocity/displacement of real mechanical components.
SRS.	Shock Response Spectrum. An analytical process by which a prediction of the maximum acceleration, velocity, or displacement response of a single degree of freedom (SDOF) mechanical components, with defined damping, will reach if subjected to a specific excitation time history.
Tailored Test.	A test procedure designed to simulate the specific characteristics of environmental shock or vibration excitation to which a product may be subjected during normal handling and use. The result may be a unique test specification that is valid only for a specific product in a specific environment, hence, the specification is said to be tailored.
Translational X-axis Shock	Linear shock applied orthogonal to the spindle axis and parallel to the long dimension of the HDD.
Translations Y-axis Shock	Linear shock applied orthogonal to the spindle axis and orthogonal to the long axis of the HDD.
Translational Z-axis Shock	Linear shock applied parallel to the spindle axis.
UUT.	Unit under test.

IV. Significance and Use

The significance of the test procedure is that it provides a uniform process for defining both the methods and levels for qualifying testing of the HDD handling ruggedness. The procedure provides a means to characterize the failure mechanisms that reduce reliability.

V. Definitions of Predominant Failure Modes, and their Physical Causes.

A. Head/Arm Interaction

When the head and/or arm of a disk impinges upon the surface of one or more disks, the impact may create voids in the recording film and result in data errors. Impingement may also cause deformation of the disk surface subject to impact and abrasion by the close flying head. <u>The initial impact as well as</u> any subsequent impacts create debris that can contaminate and damage the precision components within the disk drive. There are four shock and vibration related head/arm interactions effects.

1. Media Damage:

Media damage can be created by the disk surface striking the base of the head support arm. Since the first disk bending mode of the disk has larger deflections at the outer edge, this damage normally occurs near the first disk OD. Protruding features or small burrs on the actuator arm may exacerbate the level of interaction between the head/arm and disk.

2. Arm Tip Induced Media Damage:

Media damage may occur when the combined arm and disk deflections result in the arm tip hitting the disk. Damage usually results from the swage plate or the head suspension at the arm tip striking the disk surface.

3. Head Induced Media Damage:

Media damage may result from the head slider impacting the media. This damage normally will appear as a full or partial slider indentation on the disk surface. Sometimes only one or two corners of the slider will leave indentations. In more severe cases, indentations from all four corners of the head will be visible.

Two failure mechanisms in the drive can cause media damage. They are:

a. Head Liftoff

Head liftoff media damage occurs when inertia forces acting on a head at rest on a stationary disk exceed the head preload force causing the head to separate from the disk. Damage occurs when the head returns to contact with the disk surface. If the head liftoff separation is small, the head normally lands fairly flat on the disk preventing significant damage. As a result of large shock inputs, the impact of the returning head will cause permanent damage to the disk surface.

b. Head Slap:

Head slaps are caused by mechanical deformations propagated down the arm and through the suspension to the head. These distortions set up a rocking motion of the head about the pitch axis. With sufficient excitation levels, the resulting rocking motion will cause the head to impact the disk surface. Since the motion is due to vibrations propagated down the arm and not due to a single inertia force seen at the head, head slap incidents often involve multiple head edge to disk impacts. One excitation source for this head slap failure mode is disk-to-arm contact near the OD. However, other excitation sources could also cause vibrations to propagate down the arm.

B. Latch Security

A latch restrains the heads of a disk drive from contacting the portion of the disk surface used for data recording. A latch failure occurs when the disk drive is not fully operational and a shock force overcomes the holding force of the latch and frees the head to contact the recording surfaces. A latch failure allows the heads to rest on data recording surfaces exposing the drive to heightened shock susceptibility.

For latches used in most rotary disk drive actuators, rotational shock applied about the actuator pivot axis has the most adverse effect on latch security. Depending upon the design, a latch will often exhibit differing sensitivity to the polarity of the applied rotational shock.

B. Stack Shift

High levels of shock applied orthogonal to the axis of the disk stack may result in inertial forces in one or more disks that exceed the clamping forces within the stack. As a result, individual disks may shift from their initial center of rotation. For servo written disks, this stack shift will result in a sinusoidal position error signal with a magnitude frequency two times (2X) the rotational frequency of the disk stack. Excessive disk slip can result in degraded performance, increased operating vibration, acoustic noise, and reduced bearing life. In extreme cases, stack shift can cause loss of servo control and track following.

C. Bearing Brinelling

When subjected to radial forces in excess of an elastic threshold, the balls in a bearing will permanently press spherical pockets into the surfaces of the mating bearing races in a process known as Brinelling. Inertial forces resulting from shock or vibration can cause Brinelling in both stationary and rotating bearings. The spindle bearings of a disk drive are more vulnerable to shock due to the higher mass of the disk stack, although actuator bearings also have susceptibility. Brinelling of the spindle bearings may result in both increased data error rates due to decreased head positioning accuracy and seek performance degradation.

D. Drive Axis Definition. The following figure shows the principal X, Y and Z-axes of a HDD. These definitions are to be used when tailoring tests and when doing actual handling environment simulation shock tests.

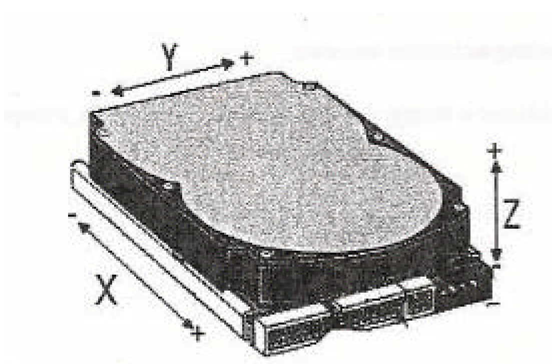

Figure 1. Definitions of X, Y, and Z-axis of HDD.

VI. Apparatus

Specific failure modes are HDD geometry dependent. The test apparatus described below is designed to provide the correct test function for the specific failure mode listed.

A. Head/arm/media interactions

To determine what minimum acceleration levels are required to cause head and arm interaction with media, it is necessary to overcome the positioning force on the actuator arm assembly. A shock machine capable of inputting either translational or rotational Z axis shocks should be used. The test shock shall be aligned parallel to the actuator axis. This type of test is commonly referred to as a "Z axis shock."

B. Latch integrity

To determine what minimum acceleration levels are required to defeat latch mechanisms, it is necessary to overcome the restraining latch force on the actuator arm assembly. A shock machine capable of inputting rotational shocks about the Z-axis should be used.

C. Stack shift

To determine what minimum acceleration levels are required to cause media stacks to shift in alignment permanently, it is necessary to overcome the stack clamping force acting to restrain the media. A shock machine capable of inputting either linear or rotational shocks acting normally to the axis of the media shall be used.

D. Spindle/motor bearing Brinelling and motor acoustics.

The test apparatus for this test is identical to that for Stack Shift, above, except that it shall also include Z-axis shocks.

VI. Test Methods

Specific test methods are required for each failure mechanism.

A. Head/arm/media interactions

The UUT shall be attached to the shock machine table using hard fixtures. If a rotational shock machine is used, the fixture shall be designed to locate the HDD such that the shock vector is normal to the plane of the arm and media surface. This type of mounting is referred to as “Z-axis.”

B. Latch security

The UUT shall be attached to the shock machine table using hard fixtures. The fixture shall be designed to locate the HDD such that the axis of the actuator shaft is co-axially aligned with the test machine rotational table axis This Type of mounting is referred as “X-Y axis.”

C. Stack shift

The UUT shall be attached to the shock machine table using hard fixtures. The fixtures shall be designed to locate the HDD such that the shock vector acts in the X or Y-axis of the HDD.

D. Spindle/motor bearing Brinelling and motor acoustics

The setup for this test is identical to that for Stack shift, above, except that it shall also include Z-axis shocks since they can cause bearing damage and acoustic degradation.

VIII. The Tailored Test Method

The SRS specifications obtained through the following test tailoring procedure will preferable be in SRS break-point bar formats. Alternately, if during the field environment phase of the procedure, well-defined shock pulses, in terms of peak amplitudes and durations, along with vector directions are obtained, then these values may be duplicated on the appropriate shock machine.

A Define the Purpose of the test -It is assumed here that the purpose of the test is to establish a valid simulation of the handling environment shock loads that may occur during transportation, handling, and installation in order to compare failure rates of a HDD. The exact definition should include what failure mode is being tested for and how the excitations that would cause these failure modes are measured.

B Measure the environment -Because of the complexity of the shock environments of concern, careful acceleration measurements of sample HDDs during typical transportation, handling, and integration activities is required. See Appendix A [4] for details of transducers and data acquisition procedures. For HDD environmental testing, the use of onboard multi-channel acceleration sensor hardware is recommended.

B.I Sensor considerations

B.l.l The sensor to be used should be a small, lightweight, accelerometer with no self-resonant frequencies within 10 times the predicted resonance bandwidth of all HDD internal component parts. A sensor with triaxial vectors of sensitivity is preferred.

B.l.2 The sensor should have a maximum shock range of at least I000 g's.

B.l.3 The frequency response of the accelerometer shall extend from at least 2 Hz to 10 kHz, with a variation in sensitivity level that does not exceed +/-5% of actual.

B.I.4 The sensor should be rigidly mounted to the HDD baseplate. Mounting waxes or magnetic means shall not be used. The location should preferable be inside the HDD so as to allow unrestricted normal handling and integration into host products. The axis of either single axis or triaxial sensitive accelerometers shall be coincident with the major axis of the HDD. In mounting the sensor, internal components of the HDD will need to be removed. After sensor installation, weights shall be added to bring the surrogate HDD back up to the weight of the non-modified product. Care in locating the sensor should include mounting on rigid sectors of the HDD base plate, as near as possible to mounting holes as possible in order to be minimally sensitive to plate resonances during shock.

B.2 Recording/Digitizing method considerations

B.2.l The recording means, either analog or digital, shall have a bandwidth that extends from 2 Hz to at least 10 KHz, and the frequency response shall not deviate by more than +/- 5% of input. 2.2.2 For digital recorders, the rate at which the analog data is digitized shall exceed the highest frequency to be captured by a factor of at least 10 times. Specifically, if it is intended to record shock signals that have durations of 0.5 msec, without a loss of peak amplitude greater than 5%, then a minimum digitizing rate of I0 KHz is required.

B.3 Number of records for analysis

B.3.l The number of environmental excitation recordings will depend on several factors, however, there shall be no fewer than 3 recordings of related environmental events per axis of sensor sensitivity. More records will produce more valid results.

C. Analyze the measured data -The data analysis procedure for complex shock data of the type expected during the transportation, handling, and installation environment for HDDs is the shock response spectrum (SRS), as defined and detailed in Appendix A [4,5]. However, the SRS offers several advantages, the most important being (a) it has a theoretical relationship to the damage potential of the shock load, and (b) it is easily manipulated to establish test criteria. Refer to Appendix A [4,5]. This process requires the processing of each time domain record obtained from the environmental recording process with SRS analysis means.

C.1 Analyzer considerations

C.1.l The SRS analysis frequency range shall be from 10 Hz to 10,000 Hz, with at least 12 SDOF filters, or more, per octave.

C.1.2 The SRS analysis amplitude range shall be from 10g's to l000 g's for linear, and between l00 Rad/sec^2 to l00,000 Rad/sec^2 for rotational accelerations. It should be noted that these scale levels are selected to insure unclipped response plots that may be affected by SOOF damping gain and are not the ranges of test shock amplitudes. The resulting excitation causes the SRS plot to be clipped at any frequency, then the amplitude ranges given above shall be increased.

C.1.3 An SRS ana1ysis damping ratio of 0.05 shall be used.

C.1.4 The Maxi-max, absolute acceleration SRS model shall be used.

C.2. Analysis considerations - Certain test specifications allow the simulation SRS to exceed the zone limit over narrow frequency ranges. This can be justified on the basis that the item under test has no specific normal mode frequencies within the frequency range across which the limit is exceeded. This can be implemented by putting break points in the zone limits that correspond to non-failure related response frequencies.

D. Group the computed SRS results into appropriate zones – A zone as defined in Appendix A [3] as a structural region where the shock environment is relatively homogeneous. Because of the small size of HDDs, all measurements on the HDD can be considered a single zone when the sensitive axis of the measuring sensor is the same. This requires that the test data be grouped by HDD axis, as the mechanical response of certain elements of HDDs win depend of the direction of the application of the shock loading.

E. Determine the zone limit -There are a number of procedures to determine a statistically meaningful upper bound for the spectra computed form a collection of measurement, as described in Appendix A [7]. However, all of the statistical procedures assume the computed spectra are for shock measurements from a common population, i.e., shock loads produced under statistically similar conditions. This assumption is probably not valid for the wide array of shocks that might occur during transportation, handling, and integration of HDDs, Hence it is recommended that the zone limit be determined from a simple envelope of all the SRSs computed from the available measurements having the same sensor axis. Such an envelope can be interpreted as a non-parametric tolerance limit if desired, as detailed in Appendix A [7]. The number of measurements required for statistical accuracy is specified in this reference.

F. Evaluate environment -The reduction of disk drive defective rate may be accomplished by making the environment more benign or by integrating more robust disk drives, or a combination of the two. Identify handling practices, equipment handling aids, etc, that are contributing to excessive shock spectra.. From the Field Audit Data (Appendix C) one can see that the integrator can have a significant impact on the severity of the shock environment. IDEMA supports the preventive approach in moderating the handling environment. Refer to the IDEMA Hard Disk Drive Training Manual for recommendations. Evaluate changes that would moderate those shock spectra and consider the one-time cost and opportunity of these changes against the recurring costs of using more robust disk drives. Re-measure the environment as necessary following any changes prior to setting the final test level in Section G.

G. Select final test level- The final test level in terms of an SRS is usually determined by adding an appropriate margin to the computed zone limit so as to assure a conservative test for even an expected extreme environment. However, for tests intended to establish failure rates, it is recommended that no margin be used beyond the natural margin inherent in the SRS enveloping procedure.

H. Select the test apparatus -The selection of test equipment depends greatly on the results of the environmental measurement and analysis phases. The equipment to be used must correlate with the discovered failure modes as defined in Section VI.

I. Perform tests -Using the Apparatus and Setup described in Section VII, perform the defined test(s), Identify any disk drives with degraded performance following the test compared to before the test.

J. Access the results -Identify any product incurring damage from the test levels Determine if the defective rate excess the requirement and make environmental changes and/or product changes as appropriate.

IX. Alternative Shock Pulse Definition

In the absence of a valid tailored test specification, a test shock obtained from the IDEMA field audit results table may be used. This table is contained and statistically summarized in Appendix C. The data from the field audit table indicates that many shocks occur with durations of 0.5 msec, either in rotational or translational orientations.

This shock duration shall be used with amplitudes selected from the table. The pulse shape shall be half-sine.

X. Conditioning

HDD conditioning may be specified as part of this test procedure. No special environmental conditions are specified.

XI. Report

Report the following information:

A. Reference to the appropriate portions of these test methods, complete description of the procedures and test parameters used, and notes of any deviations.

B. Complete identification of the product tested, including type, manufacturer's code numbers, general description and configuration, and pretest condition.

C. Identification of the purpose of the test.

D. Method of mounting the product on the test machine, and directions and/or axes of shock application.

E. Identification of the apparatus and instrumentation used, including manufacturer, and model numbers, dates of last calibrations, and any modifications.

F. Critical Instrumentation settings (sample rates, filtering, etc.).

G. Recordings of the actual test shock pulses employed, including information on peak accelerations, durations, wave shapes, and velocity changes.

H. SRS plots of the shock pulses, as appropriate.

I. Records of the shock machine settings for each pulse.

J. Records of any damage caused by the tests, including data and photographs as applicable.

K. Temperature and humidity conditions at the time of testing.

L. A statement of the number of test replications.

M. If multiple test items are used, record of the sampling methods, average or median test levels, and standard deviations.

XII. Hazards and Safety Precautions. Refer to the manufacturer's safety information for shock test machinery to be used in the performance of this procedure

XIII. Sampling

Sample lot sizes for the purpose of obtaining statistically valid results shall be selected in accordance with Appendix B of this document.

XIV. Test Fixtures

Fixtures which have resonant vibration modes that overlap any of those of the UUT shall not be used. Resonances at frequencies higher than those of the UUT may be used.

XV. Recommended review date for updating the procedure document.

This document may be reviewed on a yearly schedule, or as stipulated by IDEMA.

XVI. Reference Material

This section contains three appendices. The first, Appendix A. is a contribution from an expert in shock and vibration testing. The second, Appendix B, is a contribution of an engineer employed by a computer manufacturer. The third, Appendix C. contains a table summarizing the worst case handling events monitored during an audit of five computer manufacturers conducted by IDEMA.

Appendix A

Design of Tailored Shock Tests for Hard Disk Drives

Contributed to by Allan J. Piersol, Piersol Engineering Company

HDD internal elements are becoming smaller as the pressure of capacity increases. This means that the normal mode frequencies of these structural elements are becoming higher. Since structural responses to dynamic load excitations occur primarily at normal mode frequencies, it follows that the excitation frequencies that will produce failures also increasing. During those environments associated with the transportation, handling, and integration of HDDs into computer systems, it is the shock environment, particularly metal-to-metal impacts, that produce the highest excitation frequencies. Specifically, metal-to-metal impacts produce highly complex transients that involve substantial velocity changes in less than 0.1 msec, causing a dynamic excitation at frequencies beyond 10 KHz [I]. However, many of the shock tests currently performed on HDDs to evaluate their failure rate are based upon simple transient pulse shapes presented in a standard test specification, e.g., [2]. Typical shock test pulses recommended in common specifications are usually either half-sine or approximate terminal sawtooth waveforms with durations of between 6 and 11 msec. Such transients produce very little dynamic energy beyond 10 KHz [3] and hence, may not excite the natural frequencies of small structural elements in a modern HDD. To be effective, any shock test intended to determine a failure rate of a HDD must generate dynamic energy at frequencies up to at least the first normal modes of all the structural elements of the HDD.

The recommended procedure to establish appropriate shock test criteria for HDDs is taken from the general procedures detailed in [3], as follows:

1. Define the Purpose of the test -It is assumed here that the purpose of the test is to establish a failure rate of a HDD in PPM, due to shock loads similar to those that may occur during transportation, handling, and installation.

2. Measure or predict the environment –Because of the complexity of the shock environments of concern, the accurate prediction of the environment is usually not feasible. Hence, careful measurement of sample HDDs during typical transportation, handling, and integration activities is generally required. See [4] for details of transducers and data acquisition procedures. For HDD environmental testing, the use of onboard multi-channel sensors is recommended.

3. Analyze the measured data -The recommended data analysis procedure for complex shock data of the type expected during the transportation, handling, and installation environment for HDDs is the shock response spectrum.

(SRS), as defined and detailed in [4,5]. Of course, there are other data analysis formats that might be used, including Fourier spectra, energy spectra, or direct time histories [4,6]. However, the SRS offers several advantages, the most important being (a) it has a theoretical relationship to the damage potential of the shock load and (b) it is easily manipulated to establish test criteria [4,5]. This process requires the processing of each time domain record obtained from the environmental recording process with SRS analysis means. The frequency range of the analysis should be from 10 Hz to 10,000 Hz, with at least 12 filters per octave and a damping ratio of o.5 should be used. The Maxi-max, relative acceleration SRS should be computed.

4. Group the computed SRS results into appropriate zones -A zone is defined in [3] as a structural region where the shock environment is relatively homogeneous. Because of the small size of HDDs, all measurements on the HDD can reconsidered a single zone when the sensitive axis of the measuring sensor is the same. This requires that the test data regrouped by HDD axis, as the mechanical response of certain elements of HDDs will depend on the direction of the application of the shock loading.

5. Determine the zone limit -There are a number of procedures to determine statistically meaningful upper bound for the spectra computed form a collection of measurement [7]. However, all of the statistical procedures assume the computed spectra are for shock measurements from a common population, i.e., shock loads produced under statistically similar conditions. This assumption is probably not valid for the wide array of shocks that might occur during transportation, handling, and integration of HDDs. Hence it is recommended that the zone limit be determined from a simple envelope of all the SRSs computed from the available measurements having the same sensor axis. Such an envelope can be interpreted as a non-parametric tolerance limit if desired, as detailed in [7]. The number of measurements required for statistical accuracy is specified in this reference.

6. Select final test level- The final test level in terms of an SRS is usually determined by adding an appropriate margin to the computed zone limit so as to assure a conservative test for even an expected extreme environment. However, for tests intended to establish failure rates, it is recommended that no margin be used beyond the natural margin inherent in the SRS enveloping procedure.

7. Select the test apparatus -There are numerous types of test machines used to perform shock tests, including (a) standard drop test machines [8], and (b) complex pulse generating machines of the type used for pyroshock testing, e.g., bounded impact machines. MIPS tables, electrodynamic shakers [9], and (c) recently available programmable shock machines that also provide a rotational component but otherwise function like a drop test machine [10]. Standard large drop test machines deliver a net velocity change to the test item, which results in a shock with substantial low frequency spectral energy. Smaller gravity or mechanically augmented shock machines also deliver a net velocity change to the test item, but the resultant shock has much higher frequency content since these machines are capable of sub millisecond pulses. These machines are recommended to reproduce hard surface drop events. Case histories of HDD environmental measurement programs [11] indicate that many shocks that occur are impulse (velocity) shocks with net velocity changes equal to or greater than several hundred ips, linear, 20 radians/sec^2, rotational, and with very short 0.2 msec to 0.5 msec durations.

These case histories also indicate that HDDs very seldom experience linear orthogonal shocks. On the other hand, the complex pulse generating machines usually do not deliver a net velocity change. Excluding the dropping of a HDD onto a hard surface, or other events involving metal-to-metal impact, most of the other shocks that occur during transportation, handling, and integration of HDDs probably would not involve a substantial net velocity change. Hence a complex pulse generating test machine is recommended for these types of shocks. It is relatively easy to simulate any desired SRS on an ED shaker using wavelets [12]. If the resulting zone SRS plots indicate that half-sine shock pulses may be used for lab simulation, then control of pulse duration and amplitude are important.

8. Analysis considerations -Certain test specifications allow the simulation SRS to exceed the zone limit over narrow frequency ranges. This can be justified on the basis that the item under test has no specific normal mode frequencies within the frequency range across which the limit is exceeded. This can be implemented by putting breakpoints in the zone limits that correspond to non-failure related response frequencies.

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1. Ayre, R.S., “Transient Response to Step and Pulse Functions,” Ch. 8., Shock and Vibration Handbook, 4th edition (Ed: C.M. Harris), McGraw-Hill, New York 1996.
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Appendix B

The Elementary Concepts of Product Sampling for Testing

Contributed by John Baker, Sr., Gateway 2000

General - The sampling plan selection process should be an integral part of the test tailoring process. It is a critical step in the test design, as it will determine the effect upon test resources and potentially the validity of the test results. Sampling, as referred to in this document, means he random selection of hard disk drives from within various lots or batches of manufactured drives. There are several significant considerations in determining the appropriate sampling plan.

Considerations - The ideal sampling plan will produce valid results, but may not satisfy various inherent resource limitations or other concerns of the tester. The following is a list of factors that should be considered to optimize the cost/risk relationship. Weigh these appropriately during the test design phase.

1. Cost of Time and Material
2. Cost of Equipment and Staffing
3. Knowledge of Supplier Process/Capability
4. Analysis of Customer Risk

Sampling Plan - Selecting a plan that supports the recognized test limitations will provide statistically valid results and help guide recommendations to management on the results of environmental testing of the product The most widely accepted industry document today for determining sampling plans is ANSI/ASQC Z1.4-1993. This document is the commercial equivalent and replaced the previous sampling inspection standard, MIL-SID-105E, for the Department of Defense in 1993. The new standard is available by contacting the following source:

ASQC, Customer Service Department P.O.
Box 3066
Milwaukee, WI 53201-3066
Ph - (414) 272-8575 or (800) 248-1946

Recommended Plan- The tailored environmental testing that will be performed on a manufacturer's hard disk drive will most likely subject the drive to forces that are destructive in nature. The sampling plans suggested here are done so to reduce the costly impact of such testing, yet qualify a suspect population of drives or group of drives scheduled for routine sampling for quality assurance purposes. The steps in developing this plan assume that only "Single Sampling" is performed on each lot/batch under "Normal" conditions.

This type of sampling is referred to as "Special" under the ANSI/ASQC standard. There are four (4) levels of inspection for selecting the sample size, S-1 thru S-4. The number of drives to sample increases from level 1 to 4 and could become very costly above level 2. Therefore, levels 1 and 2 are the ones recommended for the purposes described in this document, using an Acceptable Quality Level (AQL) of 1.5 to 2.5.

Calcu1ating Sample Size -The following is an example of how to calculate the sample size for a certain size lot/batch of drives. Knowing the lot/batch size, decide which special inspection level is desired and which AQL is more appropriate given the cost/risks concerns. The applicable tables in ANSI/ ASQC will determine the sample size and Accept/Reject criteria once the above selections have been made.

Note: Cost limitations will undoubtedly restrict any extensive sampling However, it is recommended to limit the sample size to no more than 10 units under test to avoid creating a cost prohibitive situation unless absolutely necessary.

EXAMPLE:	Lot = 1,000 drives
AQL	= 1.5
Level of inspection	S-l, S-2
Sample Size	55
Accept	00
Reject	11

Appendix C

Alternate -Test Specifications

This Appendix contains the information needed to select an alternative shock test specification. It includes summary tables of field audits performed consistent with the prescribed procedure of this document, as well as the summary of statistical analysis of these data.

In addition, it also contains a technical report that describes the field audits that generated the data.

I. Alternate Test Specification

In the event it is impractical to obtain valid environmental shock data and do test tailoring, a table is available from which to select relevant half sine shock amplitudes. In all cases, a shock duration of 0 5 msec is to be used. For example, a 200 g, 0.5 msec duration half-sine shock would meet the requirements of this section. The statistical MEAN from all short duration shocks from the audits is 197 g's. This level may not relate to the actual environmental shock experienced by a particular product in a specific handling environment, and it is this reason that the test tailoring method is the preferred method for this procedure.

Table#1 in the accompanying technical report on the results of field audits of 5 integrator sites summarizes the statistical analysis of the measured handling shocks. Table #2 contains the summary of all recorded shocks.

An Audit of Handling Shocks on Hard Disk Drives within PC Manufacturers.

By George Henderson
GHI Systems. Inc.

I. Introduction

In 1996, tile Disk Drive Reliability Committee of IDEMA (International Disk Drive Equipment and Materials Association), appointed a subcommittee to develop a HDD (hard disk drive) handling test specification. The subcommittee was comprised of representatives from drive manufacturers, PC (personal computer) integrators and interested third party experts. During tile development of tile test procedure, no database of consistent and accurate field measurements of environmental handling events could be found on which to base a procedure. For this reason, it was decided to perform audits within PC integrators. A series of five such audits were made using a 3.5" x 1" format drive surrogate. The results are summarized in this document.

II. Theoretical considerations

PC integrators have recently started specifying max accelerations and pulse durations as part of their procurement selection process. These specifications are intended to provide drives that are ruggedized enough to reduce distribution, integration, and early life failures. Some of these performance specifications appear to have been based on numbers from tile drive industry which in turn may be based on tile physical design of tile product, or actual testing. In other cases, tile numbers selected for the velocity shocks appear to have been borrowed from old test specifications [1]. Old specifications using very long pulse durations appear to be in vogue within certain PC integrators. HDD qualification specifications using these numbers proliferate. Specifically, modem miniaturized drives do not have critical components that can be set into destructive resonance by pulses of greater than 1 msec. Yet specifications from 2 msec up and beyond 11 msec are common within tile PC industry. On thee other hand, private conversations with engineers within the drive industry indicate that many manufacturer are using shock pulses as short as 0.5 msec or less. This duration was set by physics of response.

There is a relationship between the half sine input shock pulse duration and tile lowest primary resonance of the object to be tested for fragility. This number is 1/6th [2]. For example, if a drive has a critical resonance component with a primary vibration mode frequency of 500 Hz, then the driving shock duration should have a duration that is tile inverse of 3 KHz. This would equate to a pulse duration of 0.33 msec.

The above observations weighed on the subcommittee since the literature indicates that hard metal-to-metal low velocity impacts on small products can cause shocks measuring hundreds of g' s with durations as short as 0.01 msec [3]. Since these types of shocks are within the spectral bandwidth of newer miniaturized drive designs with principal resonances at or above 500 Hz, it can be argued that knowledge of the handling environment would be necessary in order to establish any meaningful handling procedure. It was also theorized that there was a very high probability of handling events exceeding the max handling specifications of some drives.

During the committee's deliberations, case studies were presented including one by Jedrzejewski which described the use of short duration, high acceleration, rotational vector shocks to simulate real handling environments [4]. This paper described the testing of hundreds of drives with shocks correlated to a typical PC integrator’s environment. Handling damage was causing failure rates of 50,000 parts per million on a particular product line. Studies correlating PEA (finite element analysis) simulations combined with failure analysis indicated that short duration rotational shocks were causing complex and less phase-coherent vibrations than linear shocks. These findings are important since very few shocks in the environment are truly linear. In the study, out-of-phase motions caused media damage due to read/write head suspension, arm and swage impacts. Engineering changes reduced the failure rate to amore acceptable 3000 parts per million.

III. Data management considerations.

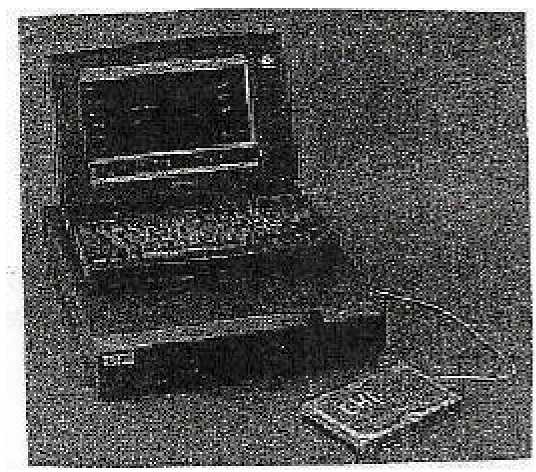
Two important factors need to be taken into consideration in order to accurately record short duration, high velocity change shocks in the environment. The first factor deals with electronic digitizing recorders, which time-sample a waveform at periodic intervals, known as the sampling rate. Rules of thumb are used to insure that periods between samples are short enough to guarantee minor loss of waveform integrity, in particular amplitude peaks.

Transient shocks are not continuous periodic events and analysis is done in the time domain. The result is that the digitizing process must be much faster, since only one look at a shock waveform is possible. The rule of thumb for shock recording is known as the rule of 10 for transient capture [5]. For example, for a shock pulse with a duration of 0.5 msec, it can be shown graphically that at least 10 amplitude samples, taken at fixed periods of 0.05 msec, are needed to guarantee no greater than 5% error in capturing the amplitude peak. This translates into a sampling frequency of at least 20 KHz. If a low sampling rate, such as 4 KHz is used, which is the case with most shock logging devices, a high intensity shock pulse with a duration of less than 0.5 msec could not be captured with any reasonable accuracy. In addition, a pulse as short as 0.2 msec could fit between time samples and not be detected at all! This fact explains why many previous audits produced data with much lower shock amplitudes than actually occurred.

The second factor needing recognition is that the tests are intended to measure shock inputs, not drive response. For this reason, it is not possible to simply add an accelerometer to an existing drive and take data. The resulting drive response will be superimposed over the input data, resulting in distorted shock wave shapes with ambiguous amplitude and pulse duration readings. For this reason, a surrogate was developed. The surrogate was comprised of the main base of a 3.5" x 1" format drive from which all components were removed. Two triaxially sensitive accelerometers were installed, following manufacturer's specifications, at opposite comers where base stiffness is maximum. Sensor cable egress was provided via a small 0.050 inch deep notch in the upper lip of the base at the cover. The entire unit was then impregnated with damping wax to further deaden the unit and also to return it's weight to the same as the unaltered drive.

The surrogate was connected to a portable multi-channel high-speed transient recording system. This system used a sampling rate of 115 KS/sec for each of the 6 channels recorded. Laboratory tests indicated that very short duration shocks as high as several thousands g' s for worst case metal-to-metal impacts were captured faithfully. One such shock approached 5000 g' s with a duration of only 10 microseconds. Figure 1 shows the surrogate and the GHI LapCAT -II data system used for the audits.

Figure 1. GHI portable data capture system and 3.5 inch disk drive surrogate.



An excellent reference document covering all conceivable instrumentation and data capture subject is found in Reference [5].

IV. The audits.

Arrangements with several large PC integrators were made for the audits. Items to be measured included any observed potential handling risks existing between removal of the drives from shipping packaging to the boxing of the final computer product. A major focus was low drop height events onto work surfaces. This was to simulate handing procedures which resulted from inadvertent accidents when installing drives. The drops were performed by lifting one of the three principal drive edges to 1 inches above the work surface, then releasing the drive such that the impact was flat. Drops in the X, Y, and Z directions were made using this method. It was observed that short duration high g shocks resulted from old or hardened work surface pads, and from surfaces that had several layers of padding material overlain. Each shock event was recorded using six sensor channels, leach in the X, Y, and Z axes of the surrogate.

The highest acceleration for each event and its duration were identified and used in the analysis. In addition, an SRS analysis was performed on each maximum event.

In addition to the drops on work surfaces, a second and unsuspected source of high severity shocks were power screw drivers with adjustable release clutches used when mounting drives into attachment bays. A complex shock waveform is produced when screws bottom out and/or the clutch releases. Several hundred such events were recorded. There were two basic forms of this type of event: 1) When attaching rails to the drive or installing the drives into bay boxes on the workbench, and 2) when attaching bare drives into internal bay rails. An similar source of shocks occurred with hard insertion of drives into bay slots with final latching by shoulder screws, more or less like putting a cartridge clip into an assault rifle.

Component kits were monitored on conveyor systems. The surrogate was inserted into the padded compartment assigned to a drive. Shocks were not prevalent, but vibration was. In some cases, nearly stationary vibration with amplitudes as high as 1.2 gRMS was measured with bandwidths from 6 Hz to 3 KHz.

Possible shock and vibration was monitored during downloading software into drives not yet installed in PC's. No significant events were recorded, but it would be possible to drop or impact a hand held drive against the frame of the programming station. This was not simulated.

Finally, the surrogate was monitored while installed in computers moving along post assembly conveyors. No significant shock or vibration excitation was found here, probably due to the damping provided by the computer structure.

V. The results.

Drops onto poorly padded work surfaces constitute the highest risk of significant damaging events. Accelerations as high as 470g' s with durations of 0.52 msec were recorded on older hardened work surface pads. At one facility with excellent padded surfaces, the readings were as low as 5g's with durations stretched to 4.26 msec, but this was the exception. The number of very high g, short duration events far outnumbered the non-damaging lower values. These occurred at four of the five sites audited. For the purpose of statistical analysis, shocks deemed non-damaging due to low intensity or long durations were thrown out of the study. Table 1 lists the resulting statistics for all events.

For screwdriver events, accelerations as high as several hundred g's with durations of as little as 0.280 msec routinely occurred. The compounding problem with these events is that the shocks are repetitive, i.e., bursts of pulses having high amplitudes with very short durations. Shock Response Spectrum (SRS) was used in evaluating these events, since it is sensitive to the gain increase caused by repetitive signals acting on resonant elements. Lightly damped resonant structures will respond with higher and higher amplitude motion until compromised, or the excitation is removed, depending on the damping related gain of the component.

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As mentioned, one series of events involved the loading of the drive into a bay in the same manner as an assault weapon is loaded. In this case, the peak acceleration recorded was 262 g's with a duration of 0.176 msec.

The large standard deviations in the statistics are due to the granularity of the data, caused by the wide variance in group site characteristics. These relate to differences in handling methods, work surfaces, tooling and fixtures, between PC integrators. For the purpose of a tailored specification, it would be more correct to treat each integrator as a separate environment group with its specification tailored using data taken from that environment only. These differences were expected and the test procedure developed by the sub-committee is based on test tailoring methods [6] in order to match the specific PC integrator's environments.

VI. Summary of analysis.

Taking all events included for analysis, and presenting statistics in terms of max amplitudes and durations, The acceleration mean of all events was 156 g's with a standard deviation of 107 g's. For durations, the mean was 0.86 msec with a standard deviation of 0.67 msec.

It must be kept in mind that within the raw data, there are zones of readings that relate to specific PC integrators. The integrators who invested more money to reduce handling losses produced audit data that was more benign. The "best" PC integrator had handling shocks on work pads as low as 5 g's with duration of over 4 msec. These shocks do not produce damage and therefore were not included in the statistical analysis.

As mentioned previously, SRS was also used as an analytic tool. This was done for two reasons: 1) to demonstrate the value of SRS for use in the test tailoring process as described by Piersol [6], and, 2) to predict the max amplitudes of primary resonances of internal drive structures when excited by the input excitations. Primary response peaks and frequencies were read from the SRS plots and analyzed for the audits. These statistical data for SRS analysis are seen in Table 1. The individual SRS values are listed in Table 2. While it is believed that the primary cause of large standard deviations was due to dissimilar data from different integrators, for repetitive shock events recorded from screwdriver use, the cause may also relate to the damping gain used in the SRS analysis. For screwdrivers, the SRS peaks ranged from 55 g's to 700 g's. The SRS analysis used a damping ratio of 5%, which results in a maximum gain of ten during SRS analysis.

Table 2 lists both selected and unselected (dashed-out) data for comparison. Figures 2-5 show the boundaries for the statistical data for each type of event.

VI. Conclusions

The field audits proved that the "real" handling environment is potentially damaging to hard disk drives. This is because there are many sources of high amplitude, short duration shocks with spectral content that overlaps the primary resonances of drive components. The audit focused on typical handling threats specific to each PC integrator. It was also noted that data from audits that may have been conducted with low digitizing rate shock monitoring devices undoubtedly understated amplitudes of very short duration shocks by large amounts, in some cases by as much as 5 to 1 or more due to their inability to capture shocks of less than 2.5 msec accurately. This is a major concern since it is these very high amplitude, short duration shocks that are most damaging. It is probable that drives regarded as defective due to failures at inaccurately measured amplitudes that were lower than manufacturer's handling specifications were indeed victims of a higher than measured environment, shifting the liability for loss from the HDD manufacturer to the PC integrator.

Table 1. Resulting Statistical Data

Event Type	g’s Mean	g’s SD	d msec, Mean	d msec, SD	g’s SRS Mean	g’s SRS SD	Freq KHz SRS Mean	Freq KHz SD Mean
Pad drops	197 g	119 g	1.127	0.65	289 g	276 g	1.192	0.59
Screwdriver	99 g	67 g	0.72	0.65	235 g	226 g	3.78	3.13
Slide	188 g	-	0.36	-	302 g	-	2.15	-
All Events	156 g	107 g	0.863	0.67	269 g	192 g	2.56	2.49

Table 2. Summary of IDEMA Field Audits Data For Handling Shocks

Site	Event	Axis	Linear Accel. g's	Pulse Duration, msec.	Rotational Accel. KR/s²	SRS Max Amplitude g's Peak	SRS Max Frequency KHz
1	2" drop, pad	Z	470g,	0.52	25.5	700	2
	0.5" drop pad	Z	214g,	0.52	11.5	320	2
	" " "	Y	127g,	0.77	6.8	180	1.3
	" " "	X	90g,	0.8	4.8	160	1.25
	Screwdriver 16 events	Z	100g	0.5	N/A	180	2
	" " "	X	38g	1.8	N/A	70	550Hz
	" " "	Y	47g	1.5	N/A	85	660Hz
2.	~~2" Drop Pad~~	~~Z~~	~~28g,—~~	~~0.18~~	~~1.5~~	~~50—~~	~~160Hz~~
	Slide into CPU	Z	262g,	0.176	N/A	400	5
3.	2" Drop Pad	Z	221g,	1.38	11.8	280	700Hz
	" " "	Z	133g,	1.4	7,1	195	700Hz
	Screwdriver 10 events	Z	177g	0.287	N/A	320	3.5
	10 rides on Conveyor,	X	1.2gRMS. 6 to 3kHz.	6Hz to 3KHz Spectrum	N/A	N/A	N/A
	Slide into bracket, 10 events	X	114g,	0.544	N/A	205	1.8
4.	~~2" Drop pad~~	~~Z~~	~~5g,—~~	~~4.26~~	~~0.283~~	~~N/A~~	~~N/A~~
	Screwdriver, 1 event	Z	200g	0.125	N/A	700	8
5.	2" Drop Pad	Z	127g,	2.5	6.8	190	400Hz
	Screwdriver 10 events	Z	34	0.125	N/A	55g	8

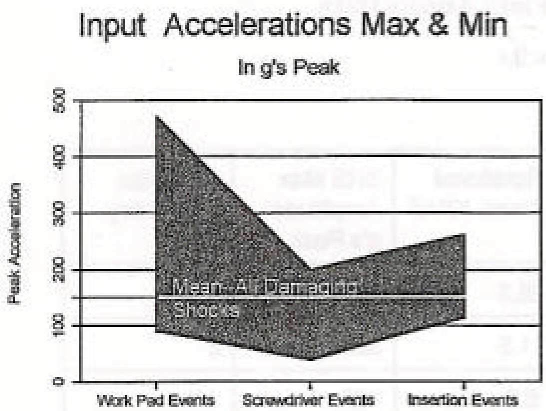

Figure 2.

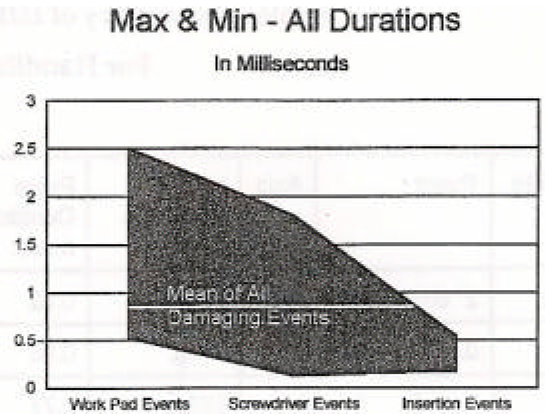

Figure 3.

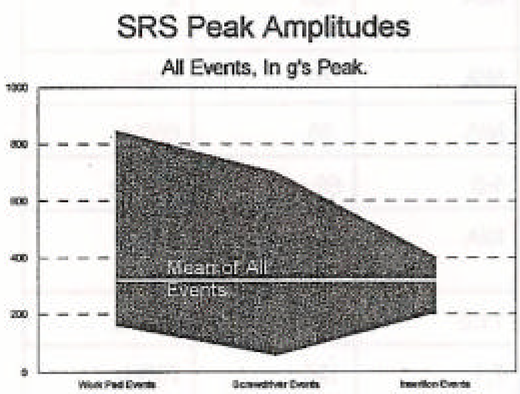

Figure 4.

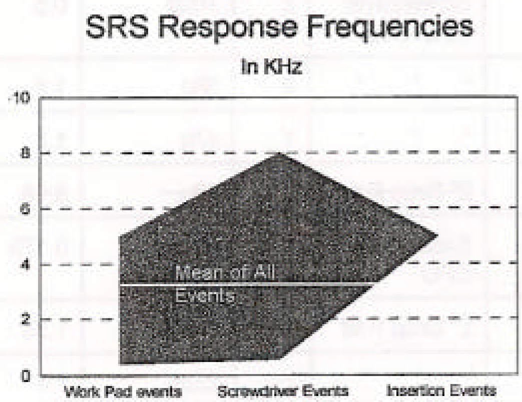

Figure 5.

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