Results of Audits of Hard Disk Drive Handling Shocks During PC Manufacture

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I. Introduction

In 1996, the MTBF Committee of IDEMA appointed a subcommittee to develop a hard disk drive handling test specification. The subcommittee was comprised of representatives from drive manufacturers, PC integrators and interested third party experts. During the development of the test procedure, no data base of consistent and accurate field measurements of environmental handling events on which to base a procedure could be found. For this reason, it was decided to perform handling audits at volunteer PC integrators. A series of five site audits were made using a *3.5"* x 1" format drive surrogate. The audit data, particularly with regards to peak shock acceleration levels, was found to be much higher than previously reported. This was found to be due to amplitude inaccuracy of very low digitizing speed 'logger' type event recorders when capturing very short duration shock pulses. The audits proved that the time durations of potentially damaging shocks in the handling environment have a duration MEAN of less than one millisecond and can have amplitudes as high as several hundred g's. The results are summarized in this document.

II. Theoretical considerations

Some PC integrators have specified max accelerations and pulse durations as part of their procurement selection process. The object of these specifications is to purchase drives that are rugged enough to reduce distribution, integration, and early life failures. Some of these performance specifications appear to have originated with drive manufacturers where they resulted from engineering and testing sources. However, certain PC integrators have selected specifications for velocity shocks that appear to have been borrowed from older test specifications [1]. In particular, specifications with very long durations have been established which have little relationship to modem HDD design which do not have critical components that can be set into destructive resonance by pulses of greater than 2 msec, yet specifications from 2 msec up and beyond 11 msec are common. These types of long duration, low amplitude specifications relate more to distribution packaging and not to drive handling. Private conversations with engineers within the drive industry indicate that shock pulses as short as *0.5* msec or less are more commonly used in design and development testing. This duration is set more by physics governing the destructive resonances that can occur to drive components upon external shock excitation.

There is a relationship between the half sine input shock pulse duration and the 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 500Hz, then the driving shock duration should be related to 3KHz. This would equate to a pulse duration of 0.33 msec.

The above observations influenced 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 test procedure. It was also theorized that many handling events exceed the design max handling specifications of some drives.

The committee reviewed case studies including one by Jedrzejewski which described the use of short duration, high acceleration, rotational vector shocks to simulate real handling environments [4]. Handling damage was causing failure rates of 50,000 parts per million on a particular product line. Studies using failure analysis, FEA simulation, and rotational shock test validation indicated that short duration rotational shocks excite out-of-phase motions. These complex motions resulted in media damage due to suspension, arm and swage impacts. Jedrzejewsky's findings proved that very few handling shocks in the environment are truly linear. Engineering changes reduced the failure rate to a more acceptable 3000 parts per million. Jedrzejewski described the testing of hundreds of drives with shocks simulating a specific PC integrator's environment using a rotary shock machine.

III. Data management considerations

Two important factors need to be recognized in order to accurately record short duration velocity 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 have been developed to insure that periods between samples are short enough to guarantee minor loss of waveform detail, in particular amplitude peaks.

Transient shocks are not continuous periodic events and therefor can not be digitized using low rate Nyquist sampling criteria. The digitizing process must be much faster, since only one look at the complete shock waveform is possible. The rule of thumb for shock recording is known as "the rule of 10 for transient capture" [3]. For example, for a shock pulse with a duration of 0.5 msec, it can be graphically shown that at least 10 amplitude samples, taken at fixed periods of 0.05 msec, are needed to guarantee an amplitude error of no greater than *5%* in capturing the 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 may be captured with no greater than 30% to *50%* of the true amplitude. In addition, a pulse as short as 0.2 msec could fit between the slow digitizer's time samples and not be detected at all! This fact explains why many previous audits produced data with much lower shock amplitudes than actually occur. The Committee was the first to report the high amplitude, shorter duration shocks in the handling environment.

The second factor needing consideration is that the tests are intended to measure shock inputs, not drive response. For this reason, an accelerometer can not be mounted to an disk drive in order to take data. The resulting drive response will be superimposed on the input shock data, resulting in invalid amplitude and pulse duration readings. For this reason, a surrogate was built up using the main base of a *3.5"* x 1" format drive from which all components were removed. Two triaxial accelerometers were installed at opposite corners where case stiffness was maximum. Sensor cables exited through a small 0.050 inch deep notch in the upper lip of the base. The entire unit was then impregnated with damping wax to return it's weight to the same as the unaltered drive.

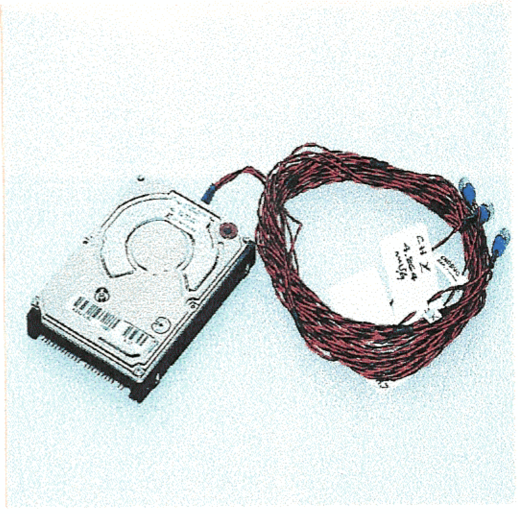

Figure 1. Typical instrumented HDD surrogate. This is a *2.5* inch format.

Figure 2. Portable digitizing recorder used to capture up to 6 channels of shock signals at 1.25KHz/sec.

The surrogate was connected to a portable GHI Systems multi-channel high speed transient recording system. The system captured and digitized each of the six channels of shock acceleration data at a sampling rate of 125,000 samples/sec. This oversampling rate insured that shock pulses as short as 0.1msec would be digitized with no greater than 1% amplitude error. Laboratory tests prior to the audits demonstrated that shocks with very short durations, such as 0.0lmsec with amplitudes of several thousands of g's were captured faithfully for worst case metal-to-metal impacts. Figure 1 shows a *2.5* inch form factor mobile drive used for some audits. Figure 2 shows the GHI Systems portable data capture system. An excellent reference document covering all conceivable instrumentation and data capture subjects is found in Reference *[5]*.

IV. The audits

Arrangements for the audits were made with major PC integrators. Events to be measured included any potential handling risks that might occur between removal of the drives from shipping packaging to the packaging of the final computer product. The major focus was on human handling which is non-systematic, and where most severe handling events occur. Some audits done by drive manufacturers used a 'hidden' event recorder within a dummy drive. This device was passed through the handling environment, after which is was downloaded. The main problem with this method is that the events that are recorded are random and constitute variables of a severity distribution. The statistical accuracy of the distribution depends on the number of variable measurements made. Without a statistically valid and complete distribution, the three sigma extremes (the worst case handling events) are not predictable. For the IDEMA audits, in order to perform the audits with the minimum number of events, the author observed the handling actions of the workers. This allowed exaggerated replication of the highest probable severity shocks. Some of the simulated handling actions, such as edge drops, were done by the author, while others were done by line workers when it was determined that the worst case severity was being experienced. This was the case for such events as screwdriver operations, loading HDD's's into programming stations or PC bays, etc.

Simulated worst case events of HDD drops onto padded work surfaces were performed by setting one face of the surrogate on the padded surface, then lifting one of the three principal edges to a height of 5cm above the work surface, and then releasing the drive such that the impact was as flat as possible. This is sometimes referred to as a "book drop." Drops in the X, Y, and Z drive axes were made. Each shock event was recorded using six sensor channels, 2 each in the X, Y, and Z axes of the surrogate. The highest acceleration for each event and it's duration were identified and used in the analysis. In addition, shock response spectra (SRS) analysis was performed on each maximum event. It was observed that short duration, high g shocks resulted from old or hardened work surface pads, while new pads provided better cushioning for drops.

A second source of high severity shocks was adjustable torque screw drivers. Several hundred repetitive shock events were recorded. These types of events occur when attaching rails to the drive or installing the drives into bay slots.

High severity shocks occurred during aggressive insertion of drives into bay slots. Latching the drives into front loading bays by forcing shoulder screws into locking recesses, more or less like putting a cartridge clip into an assault rifle, resulted in short duration, high acceleration events.

Parts kits were monitored while on conveyor systems. The surrogate was inserted into the compartment assigned to a drive. Shocks did not occur but vibration was present. In some cases, nearly stationary vibration with amplitudes between one and two gRMS were measured with bandwidths from 6 Hz to 3 KHz.

Possible shock and vibration were monitored during software down-loading into drives not yet installed in PC's. This involved the use of metal programming bay structures with matching connectors for the drives. Drives were centered and pushed into the bay until the connector pins bottomed and then down-loading proceeded. No significant events were recorded, but it would be possible to impact a hand held drive against the frame of the programming station. This would have resulted in very high amplitude and very short duration shocks. This was not simulated.

Finally, the surrogate was monitored after installation in completed computers moving along conveyors. No significant shock or vibration excitations were found here, probably due to the damping provided by the computer structure.

V. Results of the Audits

Drops onto poorly padded work surfaces constitute one of the two high risk handling events. Accelerations as high as 470g's with durations of 0.52 msec were recorded on older hardened work surface pads. At facilities with excellent padded surfaces, the readings were as low as 5g's at 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.

The second of the high risk handling events is the use of screwdrivers. 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. It is well understood that such events can cause the response of resonant structures to increase drastically due to the damping related gain of such structures. This can be shown by using SRS to evaluate these events, since it is very sensitive to the gain increase caused by repetitive signals acting on resonant elements. Lightly damped resonant elements will respond with increasing amplitude motion until possibly damaged.

One series of events involved the loading of the drive surrogate into a front loading bay in the same manner as loading an ammunition clip into an assault weapon. 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 differences relate to variations in handling methods, work surfaces, tooling and fixtures, worker training and experience level, between PC integrators. It would be justified to treat each integrator as a separate environment group with it's handling specifications 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 integrators environments.

VI. Summary of analysis

The analysis used all events that were considered damaging (exceeding HDD manufacturers non-operating shock handling specifications) for developing statistics in terms of max amplitudes and durations. The MEAN of shock acceleration of all events is 1 *56g's* with a STANDARD DEVIATION of 107g's, indicating a very wide range of values. For durations, the MEAN is O.86msec with a STANDARD DEVIATION of O.67msec.

It must be kept in mind that within the raw data, there are zones of readings that relate to specific PC integrators. Audits at integrators who invested more money to reduce handling losses produced data that was of low severity. Their handling losses were also reportedly lower. In fact, perhaps 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. The same integrator used non-ratchet release clutches on their power screwdrivers and this resulted in highly reduced risks due to these operations.

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 *[5]*, 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 55g's to 700g's. The SRS analysis used a damping ratio of *5%,* which results in a maximum gain often in response.

Table 1. Resulting Statistical Data From All Audits.

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 SRS SD**
Pad drops	197g	119g	1.127	0.65	289g	276g	1.192	0.59
Screwd'vr	99g	67g	0.72	0.65	235g	226g	3.78	3.13
Slide	188g	-	0.36	-	302g	-	2.15	-
All Events	156g	107g	0.863	0.67	269g	192g	2.56	2.49

Table 2 lists both selected 'damaging' data and some unselected data for comparison. The data is listed for each integrator audit set.

Table 2. Worst Case Audit Results

Site	Event	Axis	Linear Accel. g's	Pulse Duration, msec.	Rotational Accel. KR/s^2	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,~~	~~6.18~~	~~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

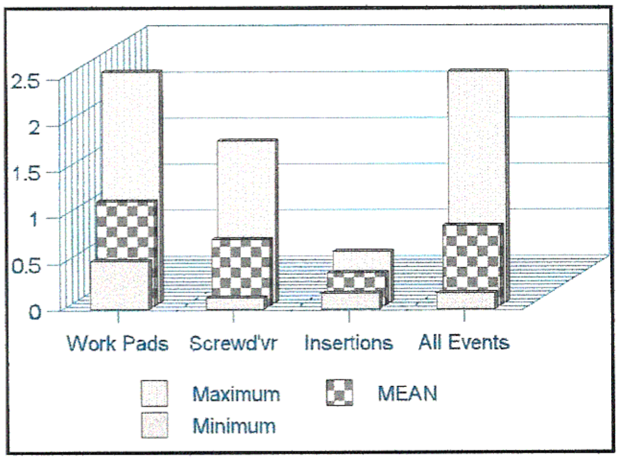

Figure 3. Plot of Max, Mean, and Min shock duration of all events, by class.

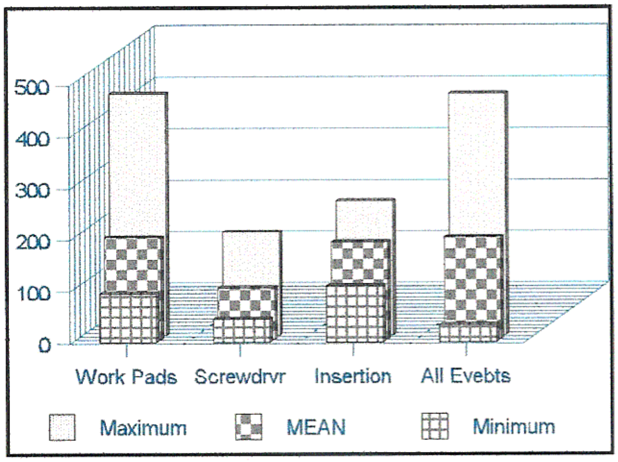

Figure 4. Plot of Max, Mean, and Min amplitudes of all events, by class.

The events are classified by drive axis. These axes are: 1) Z axis, normal to the media plane, 2) X axis, tangent to the long direction of the drive, and 3) Y axis, tangent to the short (wide) direction of the drive. Figures 3-6 show the boundaries for the statistical data for each type of event. In general, Z axis drops onto work pads were more severe than drops on other axes, probably due to differences in static loading.

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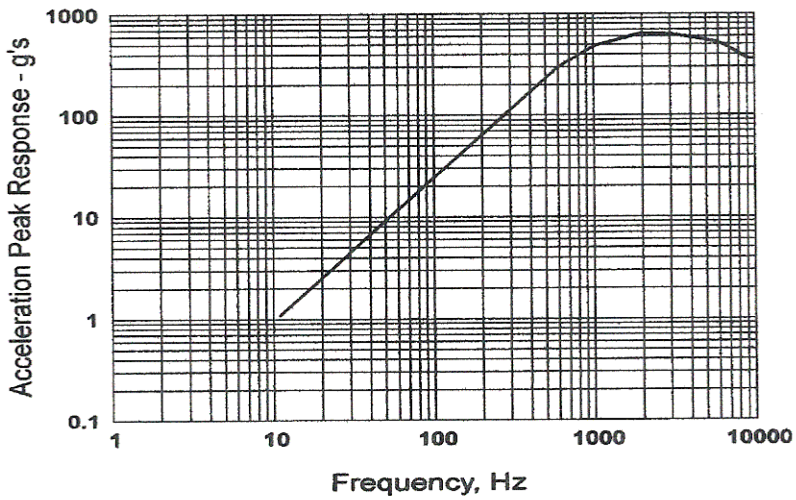

Figure 5. Tailored SRS specification from field audits. This SRS may be satisfied with a 0.5msec, 350g peak half sine.

VII. Conclusions

The field audits proved that the handling environment is potentially damaging to hard disk drives, 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 should be noted that audits that may have been conducted with low digitizing rate shock monitoring devices have understated amplitudes of very short duration shocks by large amounts. This is a major concern since these very high amplitude, short duration shocks are most damaging. It is likely that drives, regarded as defective due to failures at the inaccurate lower amplitudes as measured by loggers, were actually damaged by the environment that was, in fact, much higher and exceeding manufacturers handling specifications. In this case, manufacturers have been incorrectly penalized for the integrator's handling environment.

References

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