Copyright © 2005 IEEE. Reprinted from RADECS Proceedings

This material is posted here with permission of the IEEE. Such permission of the IEEE does not in any way imply IEEE endorsement of any of Jet Propulsion Laboratory's products or services. Internal or personal use of this material is permitted. However, permission to reprint/republish this material for advertising or promotional purposes or for creating new collective works for resale or redistribution must be obtained from the IEEE by writing to pubs-permissions@ieee.org.

By choosing to view this document, you agree to all provisions of the copyright laws protecting it.

# The Effect of Total Ionizing Dose Degradation on Laptop Hard Disks

D.N. Nguyen, *Member, IEEE,* S.M. Guertin, *Member, IEEE,* and J.D. Patterson, *Member, IEEE*

*Abstract*: A series of Total Ionizing Dose (TID) measurements were performed on commercial hard drives to explore the possible uses of the devices for the high radiation mission, and to help the understanding of the reliability of current hard drive technology. Three different models from three major manufacturers were tested with the aid of a commercial hard drive test system.

## I. Introduction

Prior to recent Cassini spacecraft's flight to Saturn, previous space projects utilized mechanical tape recorders for their storage of data. Space shuttles and the space station relied on computers and hard drives for autonomous functions and scientific data collection. Today's hard disk drives (HDD) have evolved into a complex mixed electro-mechanical system. The mechanical portion includes a slider holding a read/write subsystem that flies about 10nm over a disk rotating at 4500 rpm. Data are stored in tracks or physical concentric circles of a plate. Linear density or bits per inch (bpi) is the number of bits stored per unit length of the track. Track density or tracks per inch (tpi) is the number of tracks per unit length along the radial direction. Areal density or bits per square inch is the product of track and linear density. The capacity per disk is the product of the areal density and the available surface area. The technology of disk media has improved its capacity by increasing the hard disk's areal density 25 million times since the first hard drive was introduced by International Business Machine (IBM) in 1956, where original old iron-based material was replaced with multi-layer thin-film. The magnetic bit recording of 1Tb/in$^2$ is already proposed by four different sources [1-5] with the giant magneto-resistance (GMR) writing and reading heads. The hard drive's read head detects changes in electrical resistance as it hovers over the magnetic thin film coated on top of the spinning disk. The coated grainy materials are magnetized in one of two opposite directions differentiating bit 0 and 1 of the digital world. The writing head stores data by turning the small region of the disk's plate into microscopic magnets. Laptop and notebook computers have gradually replaced the larger desktop counterparts and consequently their hard drives have shrunk in size and weight.

The work described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

The authors are with the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, 91109, USA.

In this workshop we evaluate the behavior of laptop hard drives following TID exposures. The laptop hard disks were tested with Co-60 to probe their susceptibility to total dose effects.

## II. Test Devices

Three different manufacturers were used in the evaluation tests. The Hitachi units are commercially off the shelf, Toshiba and Fujitsu hard disks are OEM products removed from external hard drive cases. The Toshiba drives use serial ATA interfaces.

| Mfg | Model | Size | # sectors | RPM | Qty | Interface |
|---|---|---|---|---|---|---|
| Hitachi | 428080F9 | 80G | 63 | 4200 | 2 | ATA |
| Toshiba | 2188C | 80G | 488 | 4200 | 2 | SATA |
| Fujitsu | 2080BH | 80G | 63 | 4200 | 1 | ATA |

The Toshiba products come from Japanese manufacturers, while the Hitachi drives are made in Philippines, and the Fujitsu disks are manufactured in Thailand. Figure 1 shows an actual x-ray picture of a Hitachi hard drive. The magnetic plate can be seen as a transparent circle over a printed circuit board at the bottom of the hard disk drive. The write/read head is spotted in the bottom left parking in the home position outside the plate area. The voice coil motor controlling the load/unload/retract of the head is in the top left corner.

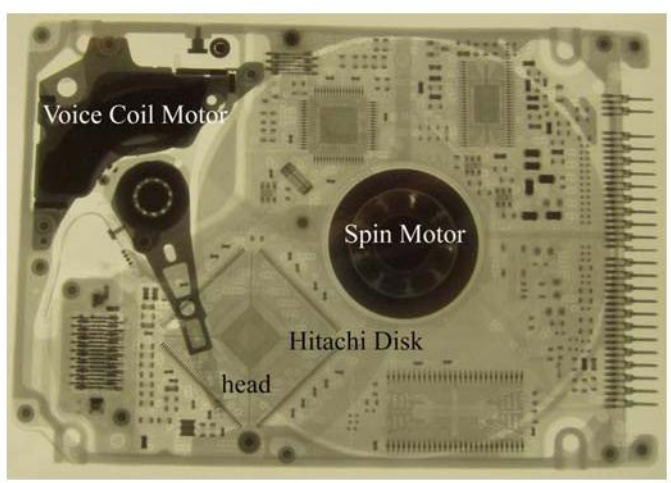


**Figure 1: X-ray picture of the Hitachi hard disk**



Authorized licensed use limited to: Jet Propulsion Laboratory. Downloaded on March 17, 2009 at 13:08 from IEEE Xplore. Restrictions apply.

A total of five disk drives were used for the study. Two are Hitachi units with the following serial numbers 2PS170 and 2K7978. Two Toshiba were also tested and their serial numbers are 34H31767A and 24H31758A. The serial ATA hard disk, serial number 48256LM, is from Fujitsu.

## III. Test Parameters And Apparatus

There are several portions of the system where radiation effects can be categorized and discussed. The first is the data storage area, or the magnetic domains. These are intrinsically insensitive to TID, and except for displacement damage effects are likely robust to all other radiation effects (relative to the rest of the system), provided the storage elements are large compared to radiation track lengths. The rotating assembly, or stack, has only one function, and that is to spin at a given frequency. This includes startup and shutdown circuitry to keep from allowing instantaneous switching of the motor. The structures on the surface of the disk are expected to survive greater radiation doses than the ICs, so they are not a major concern. Thus the rotational speed is not likely to change unless the clock, or some other part of the circuit, is somehow dominated by noise. Noise in the system can be increased by TID resulting in leakage currents, or by SEEs creating transients on timing lines. In any case, since the stack most likely operates on a heart beat type signal, such noise would have to be rather prominent to be a problem. It is likely that the stack will only fail catastrophically due to these radiation effects.

The next item to consider is the set of read/write heads. The read/write electronics sub-assembly is mainly composed of two main modules, the read-signal-amplifier and the write-head-current-driver. Both modules are carefully integrated into one unit and are electrically shielded to avoid cross-talk signals getting into their read or write waveforms. The sub-assembly is housed in the head positioning system which has two control modes: seek control (moving the head onto the target track) and following control (tracking the target). Positioning of the read/write heads is expected to be similarly robust compared to the rotation of the stack. However, read/write heads, once they move, often sit at a given location for a while, and are thus susceptible to noise on their positioning circuit. This type of noise, like that above, can be caused by TID induced leakage currents, or by transient signals on the positioning strobes. In addition to positioning problems, the read/write heads also are required to act as magnetic sensors for the material on the disks as well as electrically controlled magnetic sources to write to the disk. The circuitry involved in this sort of operation are all considered suspect under TID effects because TID can easily cause modifications to reference voltages used to set signal discrimination during read and magnetic field strength during write. Similarly, the timing response to these shifts can suffer due to TID. SEE effects on this part of the read/write head's operation are not very clear. It is possible that much of this work is done with a DSP which might be highly susceptible to SEE, and on the other hand it could be done with discrete transistors that are not easily upset by SEE.

The processing unit that times in and out the data to the read/write heads, operates the on-board cache, and handles the ATA interface, is a major source of concern. Data In/Out circuits are known to be susceptible to radiation effects. Some SEE phenomena can be catastrophic, such as SEL, which could damage the processor before power can be removed from the system. (This scenario likely occurs since you must spin-down the stack before disconnecting power to avoid damage.) Similarly, it is possible that the processor chip will simply fail to function correctly after only a small amount of TID.

The last distinct portion of the electronic system to discuss is the cache. The cache allows the processor to take data in fast, tiny, packets from the stack and order and store them for transmission on the ATA bus (or vice versa for writing). Since hard drives do not require the cache to be active, this could be an interesting place for isolating a particular portion of the system for failure. The cache is usually a memory device such as an SRAM or SDRAM. As such, the cache could very well fail at levels below that of the processor. It is likely that if one of these fails due to TID, it will simply corrupt all the data, but won't lead to any analog-type voltage shift effects.

The following tests were performed: Device Interface Test, Ramp Load Test, Delay Block Search Test, Response Time Test, Transfer Rate Test and Error Rate Test. Six combined tests ensure the survival of motors, cache, control logic circuitry, interface circuitry, and the emergency head retract subsystem. The cache of the hard disk drive was enabled during tests.

Error Rate Test: It requires writing the pattern to disk, read and compare the result and calculate the error rate. The pattern can be all ones, all zeros, any single of 16-bit value. This is the most time-consuming test.

Transfer Rate Test: It measures the data transfer speed in MegaByte per second for specified addresses or the whole range of the disk drive. The data can be obtained in minimum, maximum, speed and an average per selected block count. There are six different seek modes of operation: increment, decrement, convergence, divergence, random, and repeat.

Response Time Test: It measures the response time in Write, Read, Read compare, Verify operation.

Delay Block Search Test: It identifies the slowest block sector in the hard disk.

Ramp Load Test: It is the durability test for hard drive's mechanical components through power cycles for the specified duration. The output results are error bit count and error rate.

Device Interface Test: It identifies the hard disk information such as serial number, model, firmware version, and size of



Authorized licensed use limited to: Jet Propulsion Laboratory. Downloaded on March 17, 2009 at 13:08 from IEEE Xplore. Restrictions apply.

sectors. There are, however, rigorous standards that are placed on the hard drive's interface ports, which aid in developing a test regime for radiation characterization. Information about this interface can be found at http://t13.org, which includes links to the ANSI standards published by the ATA standard committee.

The test system overseeing the above measurements is the YEC King-Deca. In our application, there are two other tests that were not included: Fix Point Access and ECC Performance. The Fix Point Access test performs continuous read operation while the hard drive's head is forced to position at the same track over a specified length of time. The ECC Performance test evaluates the data error correction of the hard drive.

## IV. Test Results

Five 80GB drives from three manufacturers were tested to determine their TID limits. The testing was carried out using the Co-60 source at JPL. To facilitate the testing, various built-in test capabilities of the King-Deca were used. This included in-situ operation, and required the King-Deca be remotely operated while it was inside the Co-60 chamber. For this testing the arrangement is shown in Figure 2. Note also that a series resistor was placed along the DUT power to monitor device current. The resistor used for two of the DUT types was ½ ohm with a maximum drop of 400mV. The resistor used for the remaining type was a 0.01 ohm and resulted in a maximum drop of 10mV.

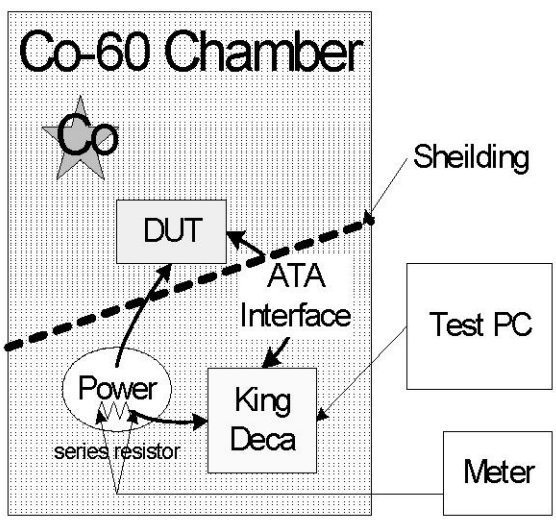


**Figure 2: Layout of the test set-up. The meter and test PC are outside of the chamber. Note that the power connection includes a series resistor to make the current measurement**

For HDD TID testing, we employed the following methods. First the test is divided into dose levels. Each dose level is further divided into three types of time frames, pre-rad, in-situ, and post-rad. During each of the segments of the test, the set of operations on the DUT is considered a characterization. Finally, at any time during any segment, there are end-of-test conditions where upon observation the test is ended. The primary knowledge obtained in this testing, besides the TID level at failure, is the failure signature itself.

The DUTs were operated, one at a time, as shown in Figure 2 while positioned in the Co-60 chamber. With the source exposed, the dose rate was 10 rads/sec. In addition, all DUTs were operated at room temperature. DUT voltages were set by the King-Deca at 5V, with an inline voltage drop due to the series resistor used to monitor the DUT current.

Before irradiation a set of initial conditions for end-of-test were considered. These were based on three categories. The categories are operation, power control, and interface. For operation failure, the DUT was expected to fail during a read or write instruction. For power control, the DUT was expected to fail to maintain an internal power requirement, thereby having unreliable read or write operation or throwing an error code. The final failure type is for the DUT to stop responding to the interface.

Two failure types were observed. The first was the complete interface failure. This was observed when the DUT stopped responding to requests for its configuration data, like the serial number and the number of sectors. The second failure type was an incorrect response to a device information request.

The actual radiation results follow. The results are also summarized in Figure 3. Three DUT types were tested. The first type to be tested was a 4200 RPM 80 GB drive from Hitatchi. Two of these drives were tested. All in-situ testing was carried out with the King-Deca's Error Rate Test (ERT) operated incrementally, and allowed to continue after irradiation and become part of the post-rad data set. The first DUT was irradiated to TID levels of 1, 3, 5, 10, 20, and 50 Krads(Si). The second was irradiated to TID levels of 18, 20, and 22 Krads(Si). After each irradiation, the Transfer Rate Test (TRT) was executed, once in write mode, and once in read mode. There was no indication of device failure until the DUTs completely failed to respond in the middle of an ERT, as part of a post-rad characterization, which was to take 12 hours.

The second DUT type tested was a 4200 RPM 80 GB Toshiba drive. Two of these drives were tested. The failure mechanism was basically identical to that of the Hitatchi, with the communication interface failing. These drives were tested as follows. The first DUT was irradiated to 10 Krads(Si). It failed during a 12 hour ERT. The second DUT was tested to levels of 3.6, 5.6, 7.6, 9.6, and 10 Krads(Si). It also failed on the 10 Krad(Si) post-rad characterization



Authorized licensed use limited to: Jet Propulsion Laboratory. Downloaded on March 17, 2009 at 13:08 from IEEE Xplore. Restrictions apply.

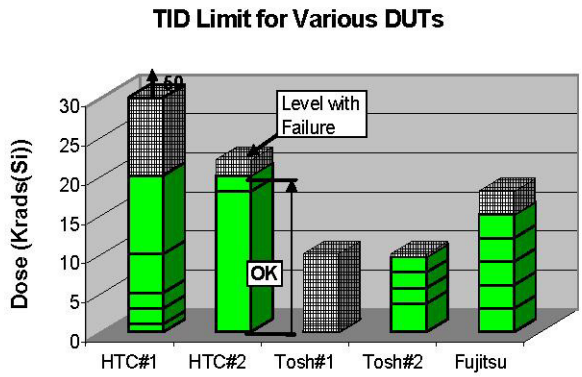


**Figure 3: This figure shows the results of all five DUTs. The solid pattern represents the TID levels where DUTs continued to operate. The hatch marked area of bar indicates the last irradiation dose prior to failure.**

The final DUT type tested was a 4200 RPM 80 GB Fujitsu drive. This drive was the only SATA drive in the group. The radiation levels were 3, 6, 9, 12, 15, and 18 Krads(Si). Only one drive was tested.

## V. Conclusions

All hard disk drives passed the intensive Error Rate test during irradiation. They were also subjected to the twelve-hour post irradiation run to weed out reliability failure. Both Hitachi and Toshiba hard disks failed to communicate over the ATA interface port after receiving a total dose of 22Krad(Si) and 10Krad(Si) respectively. The Fujitsu drive provides the incorrect device information after accumulating 18 Krad(Si) dose. The defective mechanism of the Fujitsu lies in the read-back circuitry. The TID test results provide clear evidence that the hard disk drive's interface circuit and its read subsystem are the weakest part of the sophisticated electro-mechanical device. Potential usage of laptop hard disk drives is limited to the space station where new drives can be backed up and replaced at the 20 Krad(Si) interval. Earth orbit missions can also utilize the commercial laptop drives. The same study might include Proton TID effects in the near future. These devices are commercial products, and TID response can easily vary given the large set of parts used to construct these hard drives.

Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not constitute or imply its endorsement by the United States Government or the Jet Propulsion Laboratory, California Institute of Technology.

## VI. References

[1] R. Wood *et al.*, "Recording technologies for terabit per square inch systems," *IEEE Trans. Magn.*, vol. 38, pp. 1711-1718, 2002.

[2] R. Wood *et al.*, "The feasibility of magnetic recording at 1 terabit per square inch," *IEEE Trans. Magn.*, vol 36, pp. 36-42, Jan. 2000.

[3] M. Mallary *et al.*, "One terabit per square inch perpendicular magnetic recording," *IEEE Trans. Magn.*, vol. 38, pp.1719-1724, Sept. 2002.

[4] R. Victoria *et al.*, "Aerial density limits for perpendicular magnetic recording", *IEEE Trans. Magn.*, vol 38, pp. 1886-1891, Setp. 2002.

[5] K. Gao and N. Bertram,"Transition jitter estimates in tilted and conventional perpendicular recording media at 1 Tb/in$^2$," *IEEE Trans. Magn.*, vol 39, pp. 704-709, Mar. 2003.



Authorized licensed use limited to: Jet Propulsion Laboratory. Downloaded on March 17, 2009 at 13:08 from IEEE Xplore. Restrictions apply.