THE COMPLEXITY AND DIVERSITY OF TECHNOLOGIES INVOLVED IN HDD PRODUCTION AND OPERATION – CONSEQUENCES ON RELIABILITY

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Abstract. *The work deals with various improvements of hard disk drive (HDD) reliability taking into account the diverse and complex problems that appear during its production and operation.*
HDD combines turning and reading mechanical aspects with temperature and clean environment controlling in the case where platters and head system ensemble (HSA) are sealed from printed circuit board (PCB) electric and electronic on which are mounted the Micro Unit Controller (MCU), the memory chip, VCM controller (Voice Coil Motor Controller), shock sensor, etc.
The necessity of rotation speed increase contradicts the positioning of the HSA, the reduction of dimensions concomitantly with the increase of storage capacity and access speed.
The compatibility of components and techniques involved in the manufacturing and operation of HDD creates complex reliability issues, more than for any other secondary memory device.

Keywords: *hard disk drive, reliability, complexity, failure mode, head crash*

1. Introduction

The hard disk drive (HDD) is a secondary data storage device, a non-volatile and random access memory, invented in 1954 by an IBM team lead by Rey Johnson. Initially it was manufactured by IBM, since 1956, having large physical dimensions, the first HDD had 24 platters and a capacity of 3,75 MB.

HDD combines a multitude of technologies for writing and reading information: magnetism, electronics, and mechanics. The compatibility between them, the reduction of dimensions, and the increase of access speed simultaneously with the increase of capacity creates more complex reliability problems than any other external data storage device.

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2. HDD basics

A hard disk operates almost as ordinary magnetic cassettes, but the data from the HDD can be written and rewritten very fast and can be kept longer. The registration of the data on the HDD is made through the ferromagnetic platter magnetization. The data is written in binary system, meaning that it stores a string of 0 and 1; under logical blocks usually of 512 B (there are extensions of logic block lengthening up to 4096 B). Data reading is made through magnetic transition detection and decoding with a proper language. Data is saved on the disk as files, a number of bytes with a name. The bytes can be ASCII codes for a text or can be instructions of an application which the computers must operate. The moment a program that runs requires a file, the hard disk read it and sends it to the processor.

When a HDD is low level formatted (manufacture) the surface is divided in tracks and sectors. The tracks are concentric circles on each side of the platters around the central axe. The tracks, equally situated by the platter axe from each platter and each platter side, are grouped in cylinders which are at their turn subdivided in 512 bytes each. The low level formatting means establishing the number of sectors and tracks of every HDD. The high level formatting then writes the system files in certain selected logic blocks, keeping certain blocks available for the guest operating system and its applications. The file system of the operating system uses a part of the disk space to organize disk files, registers their names and the disk area sequence which represents the file.

3. HDD components

A HDD consists of one or more rigid disks "hard" which rotate with a very high speed, named *platters* and a magnetic head which reads and writes data to the surfaces, named *read/write head* whose movement is realized by an operation device, called *actuator*. The logic control of the whole HDD is carried-out by an electronic device called *disk controller* and the rotating of the platters and the movement of the read/write head is realized by the engine (or two engines). HDD has of an electro-magnetic blocking system of the heads. In the picture 1 there is a simplified scheme of the components of a HDD taken from:
http://upload.wikimedia.org/wikipedia/commons/thumb/5/52/Hard_drive-en.svg/525px-Hard_drive-en.svg. [1].

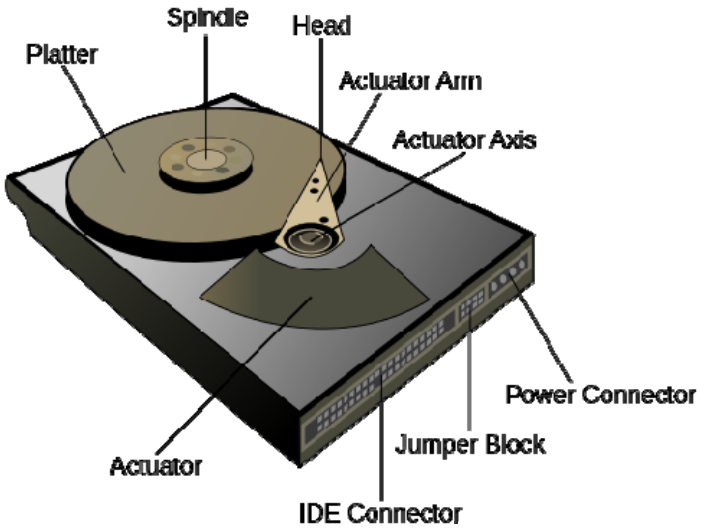

Figure 1. HDD components [1].

The platters are realized from a non-magnetic substratum covered with a thin film of ferromagnetic material that creates the data storage medium. The non-magnetic substratum is made of aluminum alloy, glass or ceramic. Both sides of substratum are covered with a thin layer of material (10-20nm) with very good magnetic properties. Modern HDD use neodymium magnets (NdFeB) which are at present the strongest permanent magnets which are also very stable. Are less sensitive to external magnetic fields but are vulnerable to corrosion and temperature degradation. At high temperatures the magnetic properties may become unstable. For this reason, at surface they are protected by zinc, nickel or epoxy resin.

The platters are completely isolated from the exterior environment; they are positioned in a controlled environment, at a constant pressure, protected from dust and humidity. Usually there are more platters positioned superposed, at constant distances, forming a cylinder, fixed by an axle which rotates the whole platter ensemble at thousand of rotations per minute (4000÷15000Rpm).

The read/write head represents the "translator", the one that processes the digital platter information and transfers it to the disk controller; the disk controller transfers it to the processor. There is one read/write head for each face of the platter, being simultaneous operated through an arm. A photo of read/write head over the platters of the HDD for Seagate Company is presented in figure 2, taken from Artem Rubstev's photos [2].

Figure 2. Read/write head over the platters [2]

The HDD's spindle system relies on air pressure inside the disk enclosure to support the heads at their proper *flying height* while the disk rotates. Hard disk drives require a certain range of air pressures in order to operate properly.

The heads are designed to "fly" at very small distance from the platters (nm) and to touch the platters only when the platters have stopped. Their stop, called "parking" is made from a special area named LZ (*Landing Zone*). It is very easy and short (stiff) and can reach an acceleration of 500g.

The operating system of the read/write head is named HAS (*Head System Assembly*) and it consists from an *arm* and a *voice coil* which assures electromagnetic action. A HAS for HDD manufactured by Seagate is presented in Figure 3 [2].

Figure 3. Read/write head operating system [2].

HAVE pivots on a bearing that insures the fluid movements needed for a smooth flight.

The read/write head is attached to the arm through a system called *Heads Gimbals Assembly*, noted in the figure with HGA.

The flexible extension is called *Flexible Printed Circuit* (FPC) and realizes the link between HAS and the platters through the contact heads.

The devices from the end of the HGA are called *Sliders*, some sort of "wings" that help the reading/writing elements to "fly" on the platter surface. The flying height on modern HDDs is in the range of 5-10 nm.

The read/write elements are positioned at the end of the slider and are so small, that can only be seen through a good microscope, as seen in photo from Figure 4 [2].

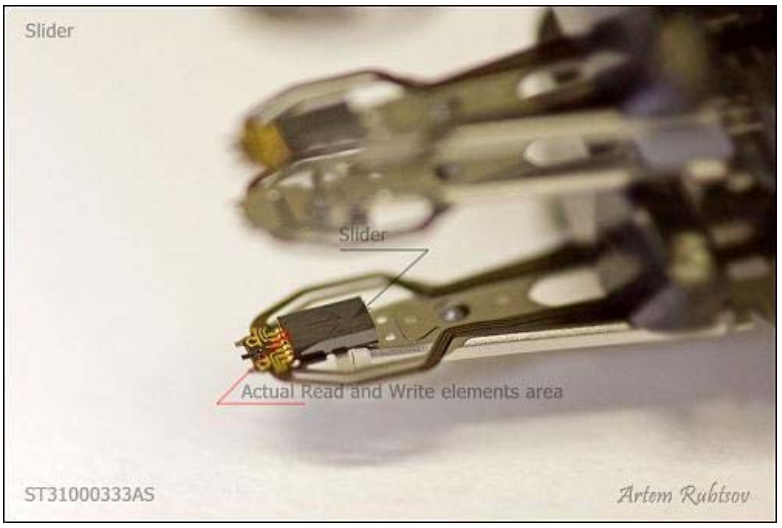

Figure 4. The sliders of the read/write head [2].

One very important part of HAS is the *preamplifier*, a chip that controls the heads and amplifies the signals from/towards it The preamplifier is situated in the interior of the HAD because the signals are very weak in the modern HDDs, which have a band bigger than 1GHz, and if you eliminate the preamplifier from the HAD such weak signals wouldn't survive, they will disappear in their way towards the PCB.

The preamplifier has several links that go to the read/write element. This type of HDD has six contacts per head:

– One contact is for ground;

– Two for reading/writing;

– Two for *micro actuator* (special piezoelectric or magnetic devices that can move or rotate the slider) which helps the position adjustment;

– The last contact is for a heating source of the thermocouple (two blades of different alloys with different coefficient of thermo dilatation) which helps adjusting the height of the heads. Once the *gimbal* has been heated, it curves towards the platter surface; this action reduces the "fly" height. After cooling, the *gimbal* straightens, returns to the initial curvature.

The preamplifier has more links that go to the heads (right side) than to the HAD (lateral left) because the HDD can only work with one "head" (writing/reading pairs).The HDD sends control signals to the preamplifier: the preamplifier selects the HDD head which it needs at the actual time.

Printed circuit board

The electronic components and the HDD connectors are mounted on a board with printed circuits called PCB – Printed Circuit Board. In Figure 5 is a photo of these electronic components for a Seagate HDD (ST31000333AS1 de 1TB), taken from the official site of the manufacturer http:// www.seagate.com/as/en/: [2]

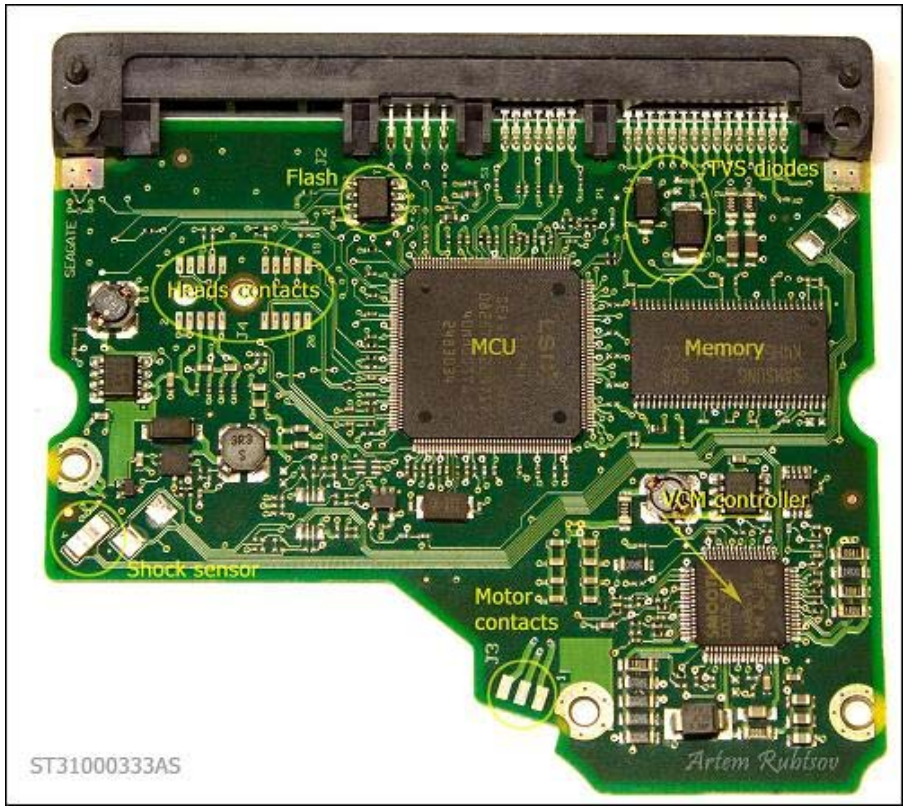

Figure 5. Printed circuit board components [2].

a. The biggest chip which can be seen in the figure is the *Micro Unit Controller* (MCU). The MCU contains a processing unit that makes all the arithmetical and logical operations and a special reading/writing unity which converts the analogical signals in digital information during the writing process. MCU has input/output ports to control PCB and to send data through SATA interface.

b. The memory chip is a *buffer memory, cachè* type. The dimension of this memory defines the dimension of HDD memory and it is a performance indicator. Cachè memory allows high speed acquisition of data. The data that have already been accessed are disposed in buffer memory; the moment a new access is required they are directly obtained from cachè, reducing the searching time.

c. Another chip from the board is *Voice Coil Motor Controller*, or the controller of the coil mobile, a *VCM controller* which controls the rotary movements of the engine and of the head arm.

d. *Flash* (flash memory chip) is a component part of the HDD firmware. When the unit is feed, the MCU chip reads the content of the flash memory and starts the execution of the code. Without this code, the unit cannot start the rotary movement of the platters. For some HDDs, the content of the Flash chip is positioned inside the MCU.

e. The *Shock sensor* can detect excessive shocks towards the HDD and sends signals to VCM controller which has the role to protect the unity from possible shock caused damage.

f. *Diode TVS – Transient Voltage Suppression* protects the PCB from brownout from the external feeding source. When the TVS detect energy leaks, it burns and creates a short circuit between the feeding connector and ground, preventing the system from deterioration.

All these components are located in an enclosed space, with very well pressurized air; which is maintained clean and dry during HDD operations. The air quality inside the HDA is very important because only one particle that passes through the slider could instantly overheat the heads, destroying them.

The seal makes the connections hermetical. The only way the air can get into the HDA interior is through the breather hole. Because the exterior air has impurities, the breather hole has many filtration layers and it is much thicker than the recirculation filter; to reduce the humidity of the air can present silica gel.

4. HDD failure modes

HDD fails can be logical, electronic, electric, mechanic, firmware corrupt failures. Fails can be immediate and total, progressive or limited, minor or catastrophic. Data from the HDD can be totally or partially destroyed. The important thing is that data can be totally or partially recovered.

As described in chapter 3, data writing is made on sectors. *Logic failure* means that on certain sections, data can no longer be read or recovered. These sectors are usually called "*bad sectors*" and mean that some sectors on platters deteriorate: some magnetic sectors may become faulty without rendering the whole drive unusable. On modern HDD as long as many bad sectors aren't formed in a short period of time, this failure isn't visible to the user. There are techniques through which bad sectors are deleted automatically through SMART technology that monitoring and solve these problems. On older versions of HDD this option was not available and the identification and marking of bad sector had to be made through the operating system tools.

Electronic failures are the ones that happen due to any electronic component, including those from the printed circuit board whether it's about cachè or flash memory, unit controller, preamplifier, shock sensor or TVS diode. These components can fail, as any VLSI circuit, whether it operates in HDD or in other part of the computer. These failures can render the HDD inoperable, but fortunately, data can be totally recovered as the magnetic storage area is unaffected.

Electric failures can happen to HDD, as well as to devices that are charged electrically, circuit interruptions from various reasons, interruptions of electrical power or shortage, grounding failure.

The most frequent failures are *mechanic failures*, generated by the mobile parts that move with very high speed, sensitive joints that can fail during normal HDD operating. Engines can fail or burn, bearing can wear so much so that it prevents HDD operating.

Most mechanic failures can generate fragments that damage the platters' surface destroying the data.

The most specific failure of HDD is the failure of the reading head. As mentioned in chapter 2 of this study, the reading head is an extremely sensitive system composed from even more sensitive components, composed with special technologies, complex and which pose special functioning and parameters maintenance problems. As we previously mentioned, the Slider floats at a very small distance over the platters. If the Slider gets too close to the platters it can scratch the platter's surface the

data can no longer be read not even after the replacement of the write/read head.

Head crash can be triggered by physical shocks, sudden feeding disruption, electronic failure, internal HDD's contamination, tear, corrosion, or even manufacture defects.

If the air's pressure from where the HDD is encapsulated is not maintained at the designed value, the sliders cannot fly over the platters at an optimum distance; can get too close and damage the platters or can distance itself too much and cannot properly read the data on the platters.

Temperature is another factor that can influence the distance at which the sliders float over the platters. As mentioned in chapter 2, the thermocouple from the HGA modifies the sliders blades' curve, depending on the temperature changing the distance at which the sliders float. Such problem can lead to temporary altered data reading till the head's temperature stabilizes (the so-called "thermal asperity")

If the air is contaminated, from internal or external causes, these contaminants would influence the reading head's floating. For this reason, the air from the interior is not replaced with exterior air, so it is re-circulated after filtration, with special filters, as shown in chapter 2.

Another failure is called by the experts Stiction; Stiction means that the head doesn't "take-off" as fast as it would be necessary, failure blamed to the inadequate lubrication of the platter's surface and also to the wear of these surfaces.

5. Conclusions

HDD is the external memory most extensively used, as it is the main solution used in the PC`s. It allows to safely storage vast data, to storage in maximum safety conditions for a very long time, fast information reading of storage data. The manufacture technologies are complex and have been developed in time, special component have been designed, miniaturized, with high reliability. The most delicate component is the slider from the read/write head, and the most frequent failure is at the writing head; with serious efforts made by all producers to increase HDD reliability.

A series of upgrades for HDD have been designed so that the smallest anomaly in the head doesn't generate the catastrophic failure. For example, the safe parking of the platters in the designated zones, landing zones. All actual HDDs are equipped with temperature sensors that the moment in which the temperature exceeds the foreseen limits from various reasons, parks the reading head. They are also equipped with shock sensors to

reduce the head crash probability. The air inside the enclosure is not replaced with exterior, but re-circulated and filtered with upgraded filter. Also, measures for humidity growth avoidance are taken.

All electronic components are chosen so that their reliability allows the manufacture of high reliability HDD, sending data in optimum conditions, intact.

The mechanic part poses the biggest problems so that engine and bearings' improvement has improved the HDD's reliability.

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