II

THE CASE OF THE FLOPPY DISK DRIVE

We are trying here to establish design principles or rules through reverse engineering, i.e.- by analyzing a pre-existing artifact, taking it apart and looking at how it is put together.

By disassembling the floppy disk drive and studying the techniques involved in its fabrication, we are starting with a final product and attempting to reconstruct the decision process that led to its design. In doing so, it soon becomes apparent that the design process reduces itself to three fundamental questions which constantly interact with each other. Interestingly, it is also found that these same fundamental questions exist at every level of the design process, form the overall conceptual design down to the last seemingly insignificant detail.

These three fundamental questions may be formulated as:

First: **What is it for? i.e.- What is the function of this artifact?** What does it do? In other words, what are the *functional requirements* for this artifact?

Second: **How is it done?** i.e.- How are the functional requirements realized, or translated into actual identifiable physical parameters? How did they do it? "They" here refers to the designers, never to assumed to be a single individual since any artifact is always the result of the work of many: engineering personnel, manufacturing, marketing, service, clients collaborating in the context of a given culture and history, however parochial. The "how" in this operation endeavors to establish the *Design Parameters* chosen by the design team, i.e.-how did they physically embody the functions that the artifact is supposed to fulfill? How are they physically realized?

Third: **Why did they do it THAT way?**
There are often many ways of doing a certain thing. Some are more clever, simpler, cheaper, more elegant, or cumbersome than others. What is the logic or at least the reasons the design team chose this particular way of doing things, why have they *chosen* these particular Design Parameters in the present instance?

Our analysis might proceed from a general overall level to very specific ones. These three kinds of fundamental questions should be asked *hierarchically*, i.e.- at various levels of the analysis. At each level they will lead, of course, to ancillary questions adapted to the specificity of the device and of the function examined; *but it is important to keep asking the questions and to never be satisfied with the answer that comes to mind.* The essence of the method is the **sustained questioning** that, eventually, **penetrates to the core of the design.**

Throughout the analysis of the design process, it is important to recognize that certain constraints delimit the design space, i.e.- frame the possibilities of the design. These constraints vary from the availability of materials, manufacturing processes, assembly and disassembly requirements, fabrication, space and weight limitation, costs, recycling and effect on the environments, rules, and regulations regarding safety, ease or difficulty of communication with clients and customers, etc. Some constraints may be obvious, some may require considerable research to be clarified. Very often it is consideration of these constraints that will lead to answers to our third fundamental question, namely--why did they do it THAT way? To guide our search for these constraints, we can classify them in three categories: extrinsic, intrinsic and human.

The extrinsic constraints are those which are exterior to the product itself. They pertain to the conditions in which the design is evolved, e.g.- physical scientific laws, rules and regulations regarding safety and the environment, economic conditions, laws, etc.

The intrinsic constraints are inherent to the product. They depend directly on the design parameters, e.g.- choice of materials, assembly or disassembly requirements, weight, etc.

The human constraints are the limits imposed by the human nature of those involved with the design such as the degree of ingenuity of the designer, the understanding of the problem to be solved by the client, the ease of the communication between client and designer, etc.

As a finished product, understanding the design of the disk drive, let alone designing the drive from the beginning, appears to be a formidable task. Once we start applying our three fundamental questions, the process soon becomes manageable.

We ask the *first question*: **What is the disk drive for?** What are the functional requirements of such a device? An answer might be, at the general level:

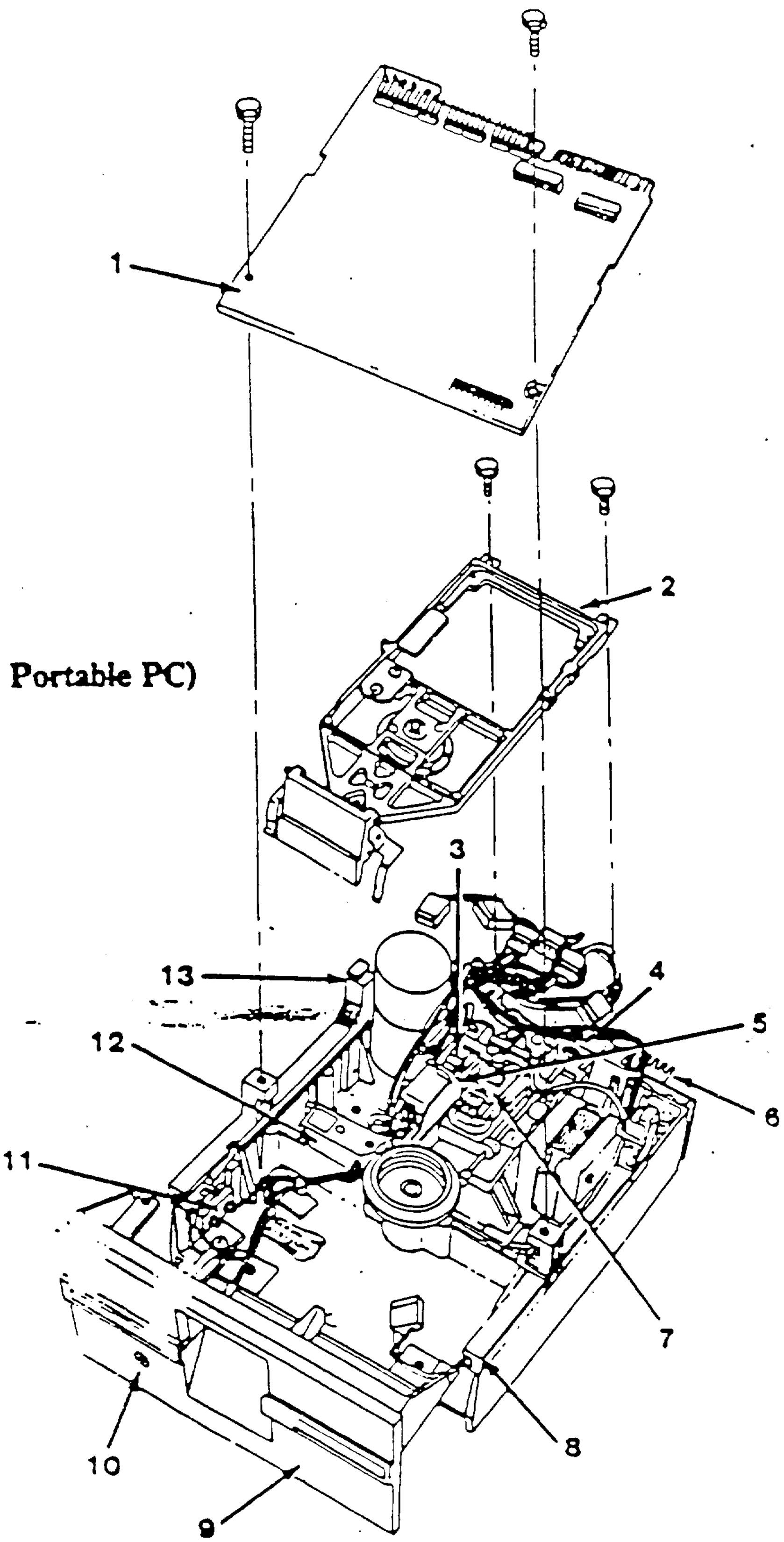
"It is a device that permits the storage, retrieval and erasure of computer information."

This then, would be the first hierarchical level of functional requirements. We may thing of *constraints* associated with this level. For instance, the time needed for writing one bit of information should be less than or equal to a certain number, the price of the disk should not exceed a certain value, etc....Asking now the *second fundamental question:* **How is it done?** An answer might be: by use of a magnetic substance. This, in turn, leads us to consider the reason for the use of that particular material; have other materials or other methods been used? Why were they abandoned or not even tried? What is the specific material used in the present case? How is it made? How expensive is it? Is there any environmental hazard connected with its use? What about its machinability, malleability, mechanical, magnetic and electrical properties?

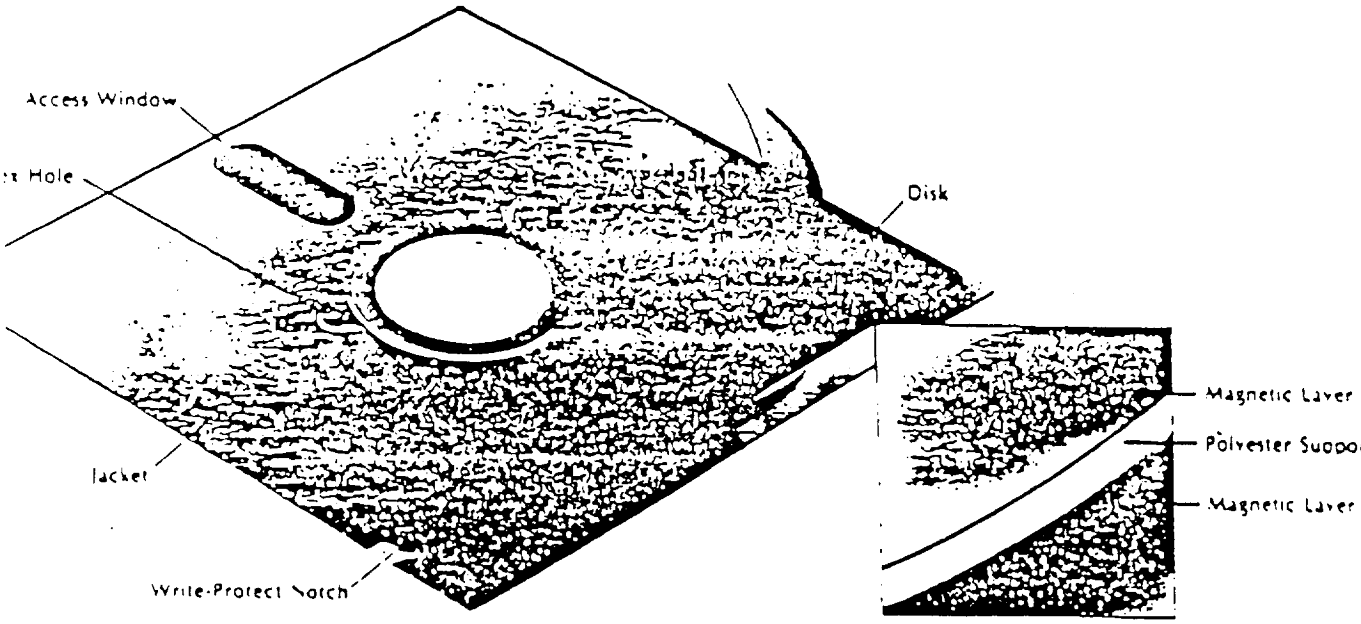
Of course we are not going to be able to answer all these questions on the spot, but we should duly *note them down and find answer through diligent research* in the library, catalogs, and/or whatever data banks, artificial or human, are available to us.
Putting these questions aside for further clarification for the time being, we now *return to the main question along another line of inquiry*: Given the fact that we have indeed a disk of magnetized substance for information storage, retrieval and erasure, how is this done?

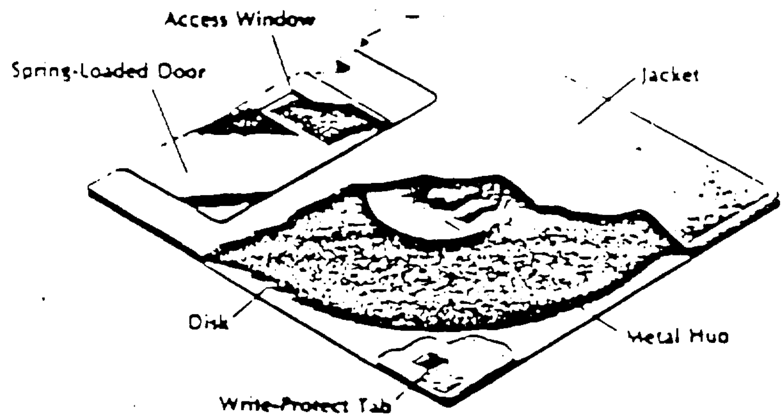
Let us begin by looking at a sketch of a 5 1/4" disk drive.

Parts (PC, XT, Portable PC)

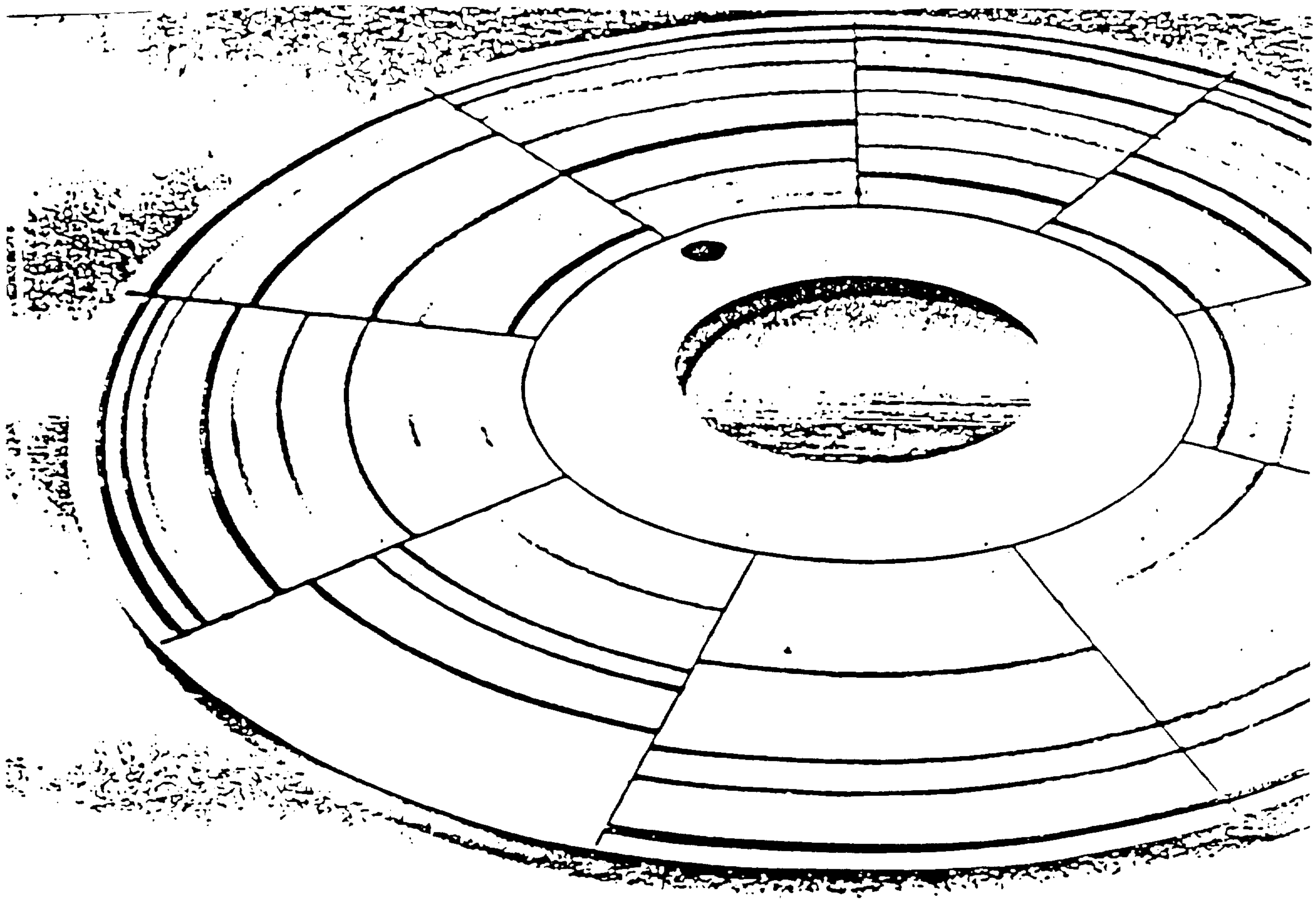


Now let us take a closer look at the disk itself.





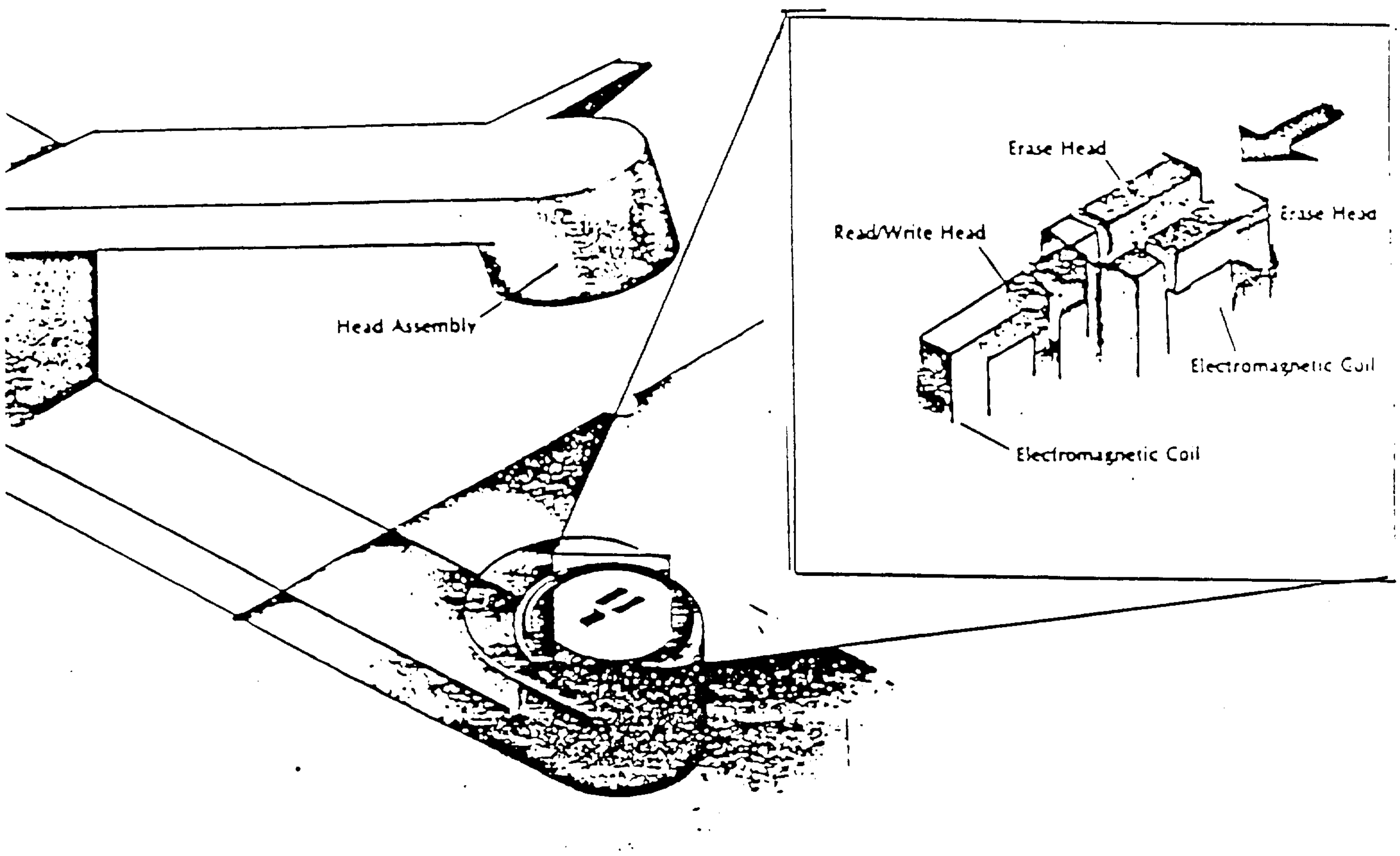
Although the disk placed into the disk drive is square, upon disassembly it is found to contain a thin circular sheet of magnetic material. Although not obvious by looking at it, the disk is divided into sectors like slices of a pie and tracks arranged on concentric circles. The tracks differ from that of a long playing record (LP) where a groove starts at the outer edge and spirals toward the center.



So the question naturally arises: *Why is it done in this way?* What exactly are they trying to do? Looking at the device, we infer that the problem is to rapidly imprint or retrieve information under the form of a magnetic field from a flat circular surface.

More questions arise: Why a surface? Why not a volume: a cube or a sphere for example? Why a circular form? Would it not be simpler to have a fixed surface with a head moving over it in a specified pattern, or in a random way, or in such a way as to always find the shortest distance between where the head is and where it ought to be in order to find the information requested, or the "slot" where the information will be stored?

The next Fundamental Question to ask is "How" does the disk drive read and write information onto the magnetic disk. The answer to the "How" question is the Design Parameter (DP) which determines the physical product itself. Data is transferred to and from the disk by means of a "read/write head" according to the principles of magnetic recording. Computers exploit binary mathematics which is the combination of "ones" and "zeros." The presence of a small magnetic field represents "one," the absence of the field is a "zero."

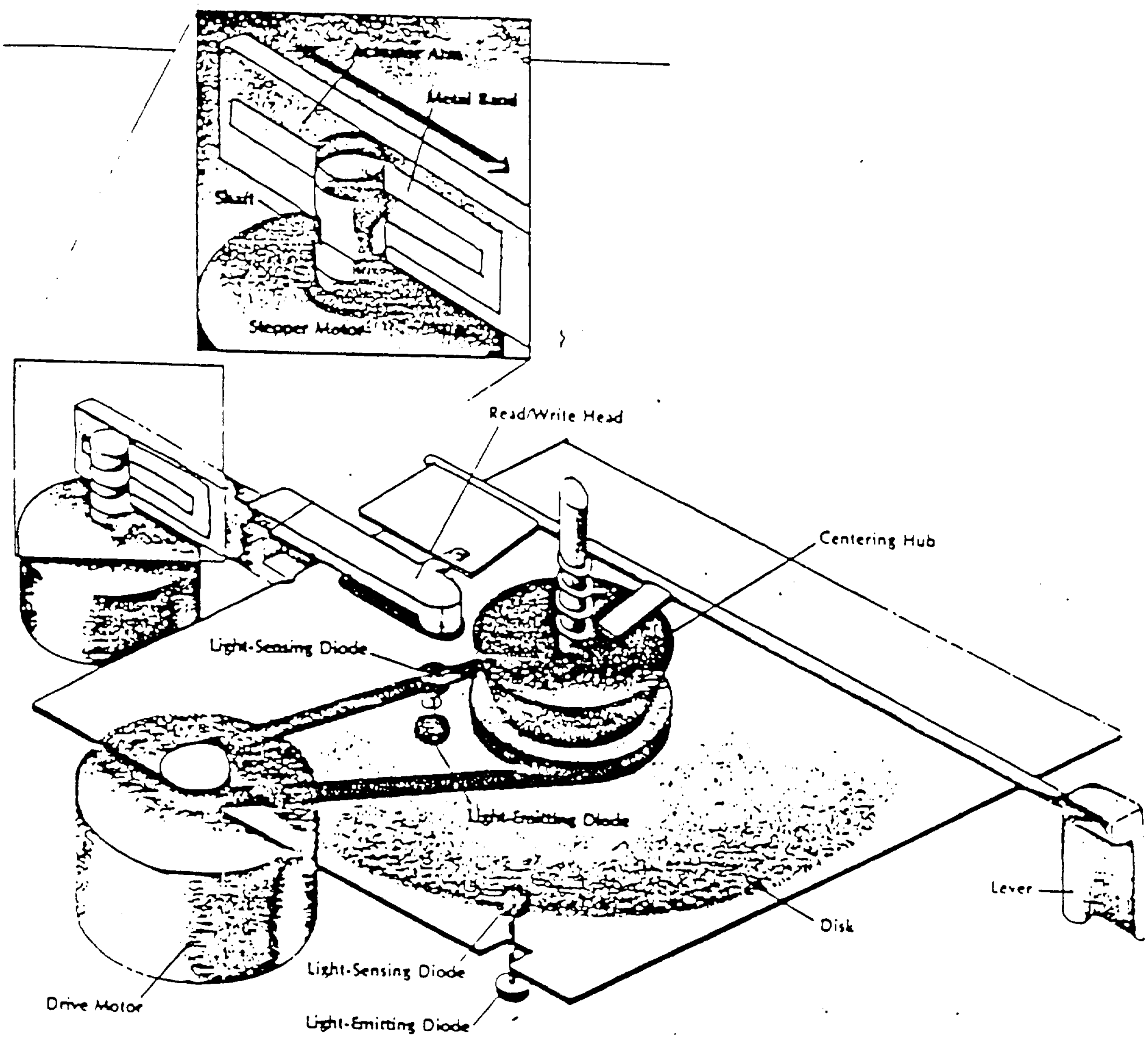


It is also noted that a read/write head is really three heads in one, the third is an erasing head. Before writing, any old information must first be erased and stray magnetic signals from the space between data tracks must be removed.

We can now state that the floppy disk drive has three Fundamental Requirements (FR), to read, write and erase data. This will be done by three Design Parameters (DP), namely the read head, write head and the erase head.

It is apparent that the design should be simpler and easier to control, if somehow, changing a particular design parameter affects only one functional requirement and does not interfere with other functional requirements. For instance, in the case of the disk drive, if modifying the read time (FR_1) by changing the read head characteristic (DP_1) does not affect the erase time (FR_3).

The next question is how do we physically place the read/write head at a specific location on the magnetized disk so that the head can transmit data. The basic operation of the drive is shown in the following sketches:



The manual lever centers the disk while closing the read/write head against the disk surface. The heads are positioned at a selected track by the combination of a DC drive motor that turns the disk and a stepper motor that moves the head assembly radially toward the disc center. Sensors, consisting of light emitting diodes (LED) and light sensing diodes verify sector position and write-protect capability.

As we proceed in our analysis, the order of the questions may change and we may move from level to level, backtracking, iterating as well as moving forward. It is part of the process of discovery. The essential thing is to realize that the questions apply at all levels of analysis, from that of the artifact as a whole to that of every part of it, be it as simple as a level or a screw. *The fundamental idea* in this process, in order to derive the maximum benefit from it, *is for the student to take nothing for granted and to question relentlessly over and over what, at first may seem either obvious or trivial,* check references, handbooks, textbooks, catalogs and whatever source material is available.

It is obvious that if no clue is to be lost and no work done in vain, it is essential to maintain a *logbook or journal recording observations systematically* as in done in a lab experiment. As the three fundamental questions arise together and feed back upon one another, it is useful to clarify the analysis, to divide the log book page vertically in *three columns; one for each question*; and horizontally, level by level. It is also useful to add the fourth column for Remarks and Benchmarks where the order in which disassembly takes place is recorded so that reassembly may proceed readily and design changes or improvements may be noted. The opposite page should be reserved for sketches and other design notes (dimensions, materials, number of pieces, etc....)

Returning to our disk drive, the task now involves breaking the Functional Requirements and Design *Parameters* into as many levels as required to explain each component of the disk drive down to the last detail. As suggested above, we make a chart with four columns labeled, "What" (FR), "How" (DP), "Why" (Logic and Reasons), and "Remarks and Benchmarks." This chart should be coordinated with a multi-level hierarchy.

WHAT	HOW	WHY	REMARKS &BENCHMARKS
LEVEL I			
FR_1 read data	DP_1 read head	Principles of Magnetic Recording Convenient; proven technology	The 3 heads can be located on one assembly
FR_2 write data	DP_2 write head	"	
FR_3 erase data	DP_3 erase head	"	
LEVEL II			
1) Place a combined assembly on a particular track	1) DC motor 2) Stepper motor 3) Disc centering clamp	Combination of circular and radial motion can access any point on a disk	Disk needs to be centered, motors need a fixed location
LEVEL III			
DC motor 1) speed 2) size 3) voltage	etc.		

At the end of the procedure, we therefore have a series of functional levels each with their requirements and their design parameters. We can then ascertain the goodness of the design by studying the relationship between FR's and DP's, to see whether changing a functional requirement affects other FR's or whether they are independent of one another.

From the answers to the various questions, particularly those of the third type: *Why was it done this way?* We can obtain at least a qualitive indication of the economy of the design, i.e. whether the design is "minimalist" in the sense of maximum economy, minimum interference with the environment through the choice made for the materials and their recyclability, maximum storage of information in a given space, maximum speed of information writing, reading or erasing compatible with the technology used, minimum power consumed for fulfilling the given task, adequate heat dissipation, etc....

Through reverse engineering, principles of good design can therefore be elicited from existing systems.

To guide us in this approach, let us look at a Teacher/Student discussion during the disassemble of a 5 1/4 inch floppy disk drive.

5 1/4 Inch Floppy Disk Drive Disassembly
Teacher/Student Dialogue

T = Teacher
S = Student

T: Before we begin to disassemble the drive, let's establish the functional requirements, or in other words, what is it that we expect the floppy disk drive to do?

S: Well, when I make a report for class using the computer I have to write down words and numbers, and other times I have to read information from the floppy disk that I already have. I suppose that's what the disk drive is doing.

T: That's right. The drive also erases information from old data before it can write over it. So we can say then that the purpose of the drive is to read information, write information and to erase information.

S: What does information actually look like to the drive?

T: Surprisingly, all information is stored according to binary mathematics which means combinations of "ones" and "zeros." By the principle of magnetic recording, the presence of a magnetic field on a "bit" is a "one," and the absence is a "zero."

S: And somehow all of this data is put on the disk that I can take with me when I turn off the computer?

T: That's right. But what do you think is inside of the disk itself?

S: I don't know. I never thought of it.

T: Let's take the disk apart.

S: That's curious. Although the floppy disk is square, there is a circular disk inside.

T: The disk is made of magnetic material which is divided into sectors and tracks. The sectors are like slices of a pie and the tracks are concentric circles. This is different from an LP record where the track is a spiral that starts on the outside and moves toward the center. All information on a disk is located at a particular address consisting of its track and sector.

S: How does the drive know how to get to the address?

T: To find out, we have to get a look at the mechanism itself. Let's start by removing the logic circuit board that covers the drive. The board itself as we see consists of integrated chips, transistors, resistors, capacitors and diodes. The board will instruct a displacement device to move to precise address locations.

S: Now that the circuit board is removed, we have a good view of the inside, but I'm not quite sure what I'm looking at.

T: Let's go one step at a time. Sliding a disk in and closing the door shows that the door engages a frame which then closes on the disk.

S: The frame is held down at one end by these two screws and flat springs.

T: The frame is acting like a spring loaded first class lever that centers and holds the disk while enabling it spin. The frame also pops up when the door is opened.

S: What material is that centering hub made of?

T: Plastic. We'll see why later.

S: I notice that there is another part clamping on the disk.

T: That's the read/write head. It is connected to a displacement device that moves the head rapidly to any location on the disk. At this point we can define the floppy disk drive's principle Design Parameters. Design Parameters are the physical characteristics that accomplish the Functional Requirements of the device. We can say that if *"Functional Requirements" answers to the question "What," then Design Parameters answers the question "How."*

S: Before, we said that the functional requirements were to read, write and erase information. So the Design Parameters must be a Read-head, a Write-head and an Erase-head.

T: That's right.

S: But I only see one part.

T: If we take a closer look at this disassembled part, you will notice that it has three small separate sections located near each other, even though it is usually called just the read/write head.

S: I guess whoever designed the drive thought it would be easier to move the three sensors on a single displacement device that slides on these two rails. It seems like that makes the drive more compact.

T: Can you see what moves the read/write head assembly?

S: If I turn the drive over and look through the plastic window, I can see a metal band that unrolls from a shaft when this motor turns.

T: That's a stepper motor, which moves in increments of 1.8°. It's the only type of motor that is truly driven by a computer.

S: But how does it move the read/write assembly?

T: If we take out the rail assembly with the stepper motor, you can see that the band is attached to the slider. As the band winds or unwinds, rotational motion is transformed into linear motion. The linear motion moves the read/write head radially toward the center of the disk.

S: The last part left is this cylinder.

T: This is a vertically mounted DC motor. The output shaft is on the other side.

S: There is a band of metal that goes around another wheel.

T: It is called a belt drive, and acts as a speed reducer.

S: How much slower does the larger wheel turn?

T: Output speed is inversely proportional to the diameters. Since the output pulley is about 6 times larger than the input pulley, that means it turns at one sixth the number of revolutions per minute of the DC motor.

S: What about the black lines on the pulley? It looks like two circles.

T: Those are timing lines that have a strobe light effect. If the spinning disk drive is placed under fluorescent lighting which in the U.S. has a frequency of 60 cycles per second, the outer circle will look like it is standing still if it rotates at a multiple or submultiple of that frequency. In Europe or other parts of the world operating at 50 cycles per second, the inner circle would stand still.

S: But how fast is the pulley actually spinning?

T: As long as a circle appears stationary, the pulley is turning at 300 revolutions per minute.

S: I see that the pulley is on the same shaft as the disk clamping device. What is it for?

T: To turn the magnetic disk. Now different sectors of the disk can be reached by the read/write head. The combination of a spinning disk and the radial displacement of the read/write head provides access to every address or location on the disk.

S: There are a few more small parts inside. What are they for?

T: Most of them are sensors. This is a light emitting diode or an "LED" and this is a light sensor. They work with the small hole in the disk. This LED is on when the DC motors turning. And this sensor checks on the condition of the write protect. This other part is a limit switch that sets the stepper motor to the zero track position, and back here is a mechanical stop.

S: What about the materials that were used?

T: With the exception of the motors, the rails and some screws, everything is made of plastic or non-ferrous materials like aluminum.

S: Is that to save on weight?

T: Weight is one factor. Another consideration is magnetism. Since information on the disk is stored magnetically, stray magnetic fields close to the disk would corrupt the data.

S: What about the overall shape of the floppy disk drive? Why was that chosen?

T: The designers were operating under "constraints" such as overall length, width, depth, weight and ventilation considerations.

S: It seems like a very complicated process. I would not know where to begin.

T: The idea is to work with the concept of *Functional Requirements,* the **"What"** of the design, and.....

S: And the *Design Parameters,* that's the **"How"** of the design that we talked about before.

T: We can call that Level 1 of the design and start by listing as many Functional Requirements as we can. Then, we create one Design Parameter for each Functional Requirement in such a way that the Functional Requirements always remain independent of one another.

S: That way, if we change the design on the read head, for example, we shouldn't have to redo the design of the write head or erase head.

T: That's the idea. Then we go to Level 2 of the design. Every Design Parameter is now considered to be a new Functional Requirement, and we have to come up with another set of Design Parameters. All the while this has to be done so that Functional Requirements remain independent.

S: And then?

T: To Level 3. The latest Design Parameters become a new set of Functional Requirements and we are off to find suitable Design Parameters for them.

S: And then?

T: We continue the process to lower and lower levels until the smallest design component such as the screw holding down the circuit board is accounted for.

Another example of the method, here is the result of the analysis of the design of a Super Armatron Robotic Arm.

Functional Requirements and Design Parameters of the Super Armatron

Functional Requirements	***Design Parameters***	***Remarks***
Pick up small objects	-Grip/Release -Rotation -Vertical Movement -Horizontal Movement	These allow the Super Armatron to move like a human arm or better...
Controls/Operation	Two Joysticks	More freedom for easier control than one joystick
Fun/Challenging	Energy level count down meter for two player games	Time restrictions make the "game" challenging and fun

Functional Requirements	***Design Parameters***	***Remarks***
Grip/Release	Four bar linkage/pincher/ fingers	These are attributes and characteristics of the human hand and arm
Rotation	Wrist	
Vertical Movement	Shoulder	
Horizontal Movement	Elbow	

Level III

Functional Requirements	*Design Parameters*	*Remarks*
Gripping and Releasing for fingers Rotation in vertical planes for wrist and in horizonal planes for elbow	Rotate knob clockwise to close/ open pinchers	Simulates the gripping and and releasing of fingers
	Push left joystick up/down to move left pinchers up/down	Simulate the vertical movement of the wrist
	Push left joystick left/right to move forearm left/right	Simulate the horizonal movement of the elbow
Wrist Rotation Rotation in horizonal and vertical planes of shoulder articulation	Rotating knob turns hand Clockwise or counterclockwise	Simulates the rotational movement of the wrist, but better (360°)
	Push right joystick left/right to pivot arm left/right	Simulates the horizonal movement of the shoulders
	Push right joystick up/down to move arm up/down	Simulates the vertical movement of the shoulder