High Performance Computer Architecture
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Lecture - 32
Storage Technology

Hello and welcome to today’s lecture on Storage Technology, we have already discussed about a cache memory, main memory which are used as memory devices of a computer systems. And if you look at the hierarchal memory organisation, a particularly the virtual memory systems that we have discussed in the last couple of lectures, we will find that secondary storage is the last component, in that hierarchical memory organisation. And storage technology provides that secondary storage and so our discussion will not be complete without considering storage technology.

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We shall discuss about different types of devices, which are used in secondary storage, like magnetic disks, optical disks, magnetic tapes, cache memories, and now a day’s solid state disk. And in the in another lecture we shall discuss about, how we can improve the liability by discussing multiple disks together, and different raid levels 0 to 66. And let today let us primarily focus on the different types of technologies used to build a secondary storage.

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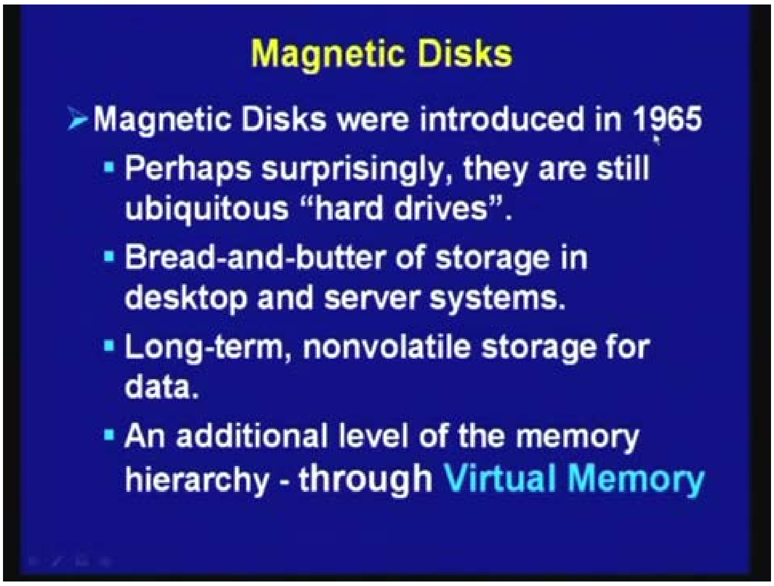

So, magnetic disks were introduced back in 1965, and perhaps surprisingly they are still ubiquitous hard drives. So, if you look at any computer system, you will find hard disk is always present and that is becoming ubiquitous as with the computer systems, and this is the bread and butter of storage in desktop and server systems. So, without magnetic disks no computer system can be built or we cannot see now a days.

And a magnetic disk are used for long term storage, non volatile storage for data, non volatile means when the power is removed information will be retained. And this has already provided, the additional level of memory hierarchy through virtual memory systems that we have already discussed.

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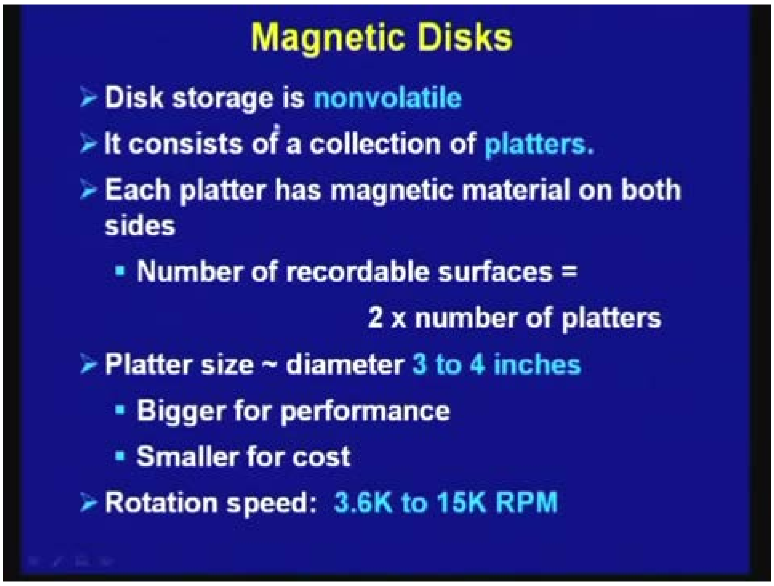

So, these are the different features of magnetic disks number one as I said, it is non volatile disk storage is non volatile and it consists of a collection of platters. So, platters means, different disks you can say with a two surfaces and each platter has magnetic material on both sides.

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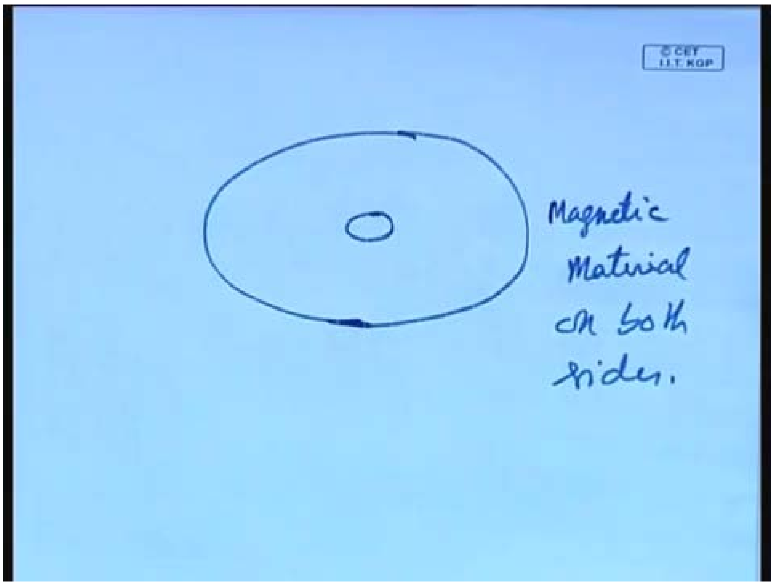

So, you can say this is a platter circular disk and a magnetic material is deposited on both sides.

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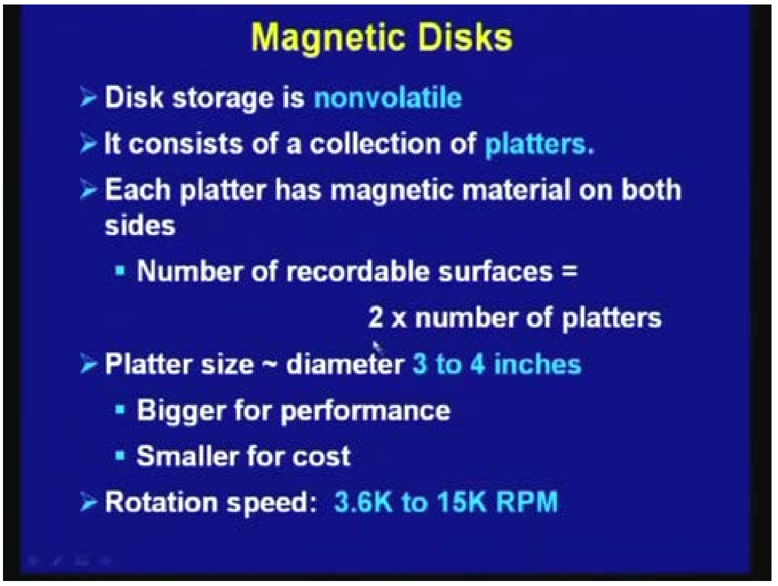

And as a consequence, the total number of recordable surfaces is 2 into number of platters. So, number of platters that you are having will decide how much information you can store, instruction of data whatever it may be, and the platter size is I mean the diameter is in the range of 3 to 4 inches, smaller sizes are also available. But, this is the common size 3 to 4 inches, normally 3.5 inches is the diameter of the magnetic disks, and bigger sizes can be used for performance and smaller for costs.

So, smaller the diameter it will be cheaper and larger the diameter it will provide you better performance. And the rotational speed is in the range of 3.6 k; that means, 36,000 revolutions per minute to 15,000 revolutions per minute, and actually the performance is gradually improving.

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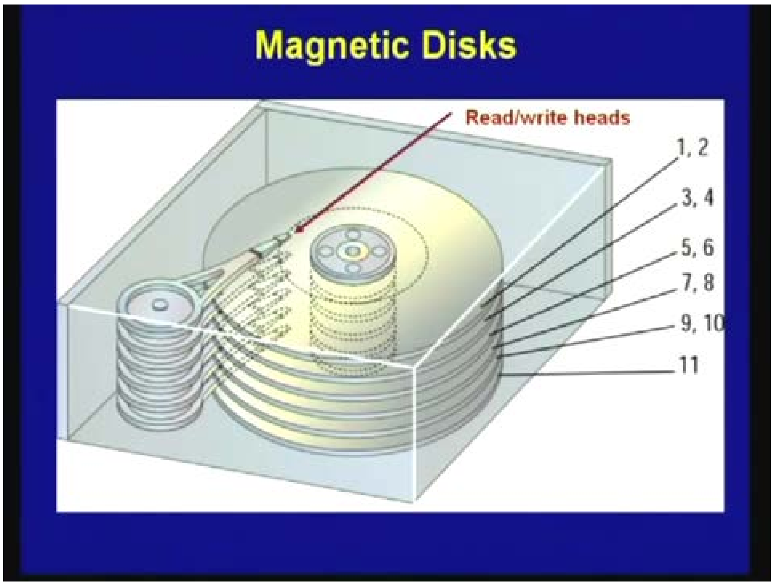

And this is a magnetic disk, as you can see you have read write heads, these are the read write heads. And each of them is representing a platter and as you can see, each plate is having 2 sides; that means, 1 and 2 corresponds to 2 sides of platter 1, 3 and 4 corresponds to 2 sides of platter 2, 5 and 6 corresponds to the 2 sides of platter 3 and so on. Of course, the last platter you cannot really access the bottom side that is why only 11 surface is shown 12'th surface is not accessible.

So, this is how I mean magnetic disk is organised, you have got a number of such platters providing you to into number of platters that is number of surfaces available.

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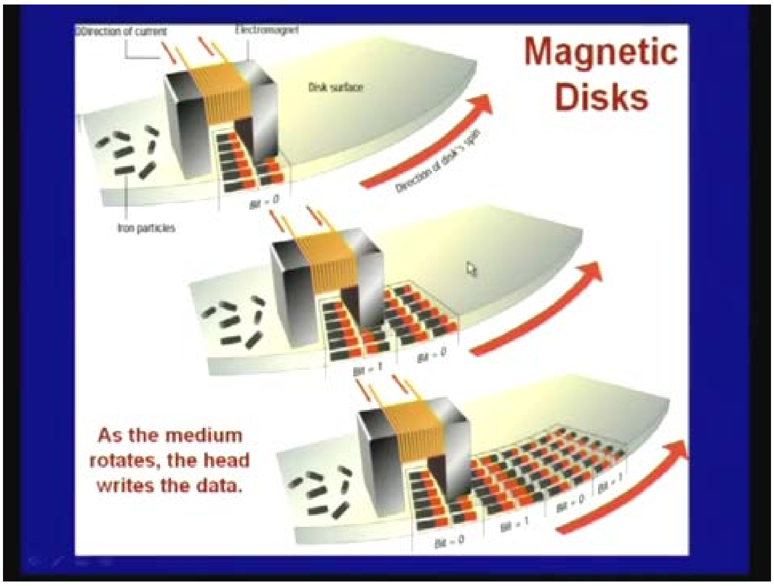

And the way information is written on magnetic disk is shown in this particular diagram, this is that disk surface which rotates at a particular speed, which we have seen it rotates and it is that disk is placed just under a read write head. So, this is that read write head, there is a coil that is a electromagnet; that means, a current passes through it, it will be magnetized in a particular direction. And because, of that magnetization the iron particles will get oriented in a particular way, depending on the current flowing in that electromagnet direction of the currently flowing in that electromagnet.

For example, before the disks surface comes under the electromagnet you can see, the iron particles are haphazardly distributed, there is no orientation of the iron particles. However, as it passes through the read write head, the iron particles gets oriented in a particular way depending on the current directions. So, this is the current directions now, so bit 0 is written and disk is moving in that direction.

Similarly, bit 1 is written when current passes in the opposite directions, so in this particular case current is passing in the opposite direction. So, bit 1 is written, so in this way as the medium rotates, the head can writes data on the surface, it can write bit 1, bit 0 and so on. One after the other on the disk surface, reading can be done in a similar way in such a case what happens, as the as the disk moves under the I mean already written data moves under the surface it induces current in this coil.

And the depending on the direction of the current in this coil you can read as 0 or 1, so this is how reading and writing take place on the magnetic surface, with the help of a read write a coil by placing it on top of the magnetic surface. So, one point you should note at this junction at this point, you can see the read write head is coming in physical contact with the magnetic surface as a consequence there is a wear and tear.

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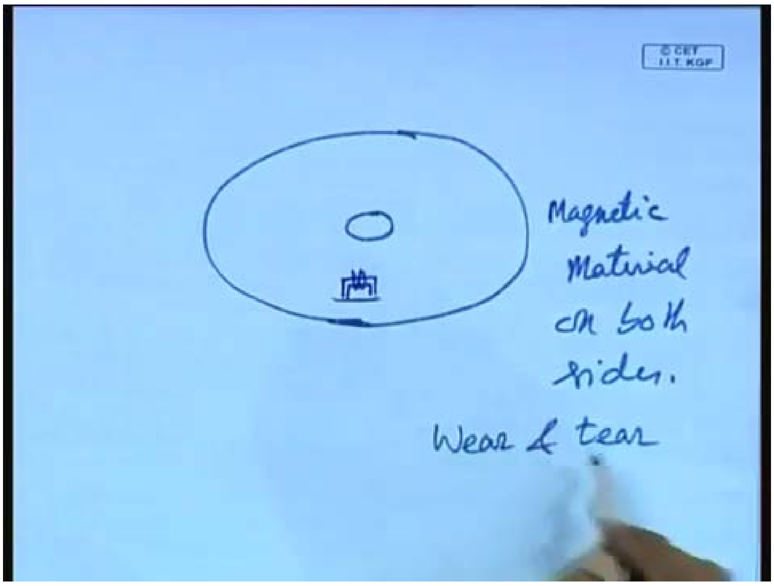

So, there will be wear and tear because, that magnetic surface is coming in close contact here for example, this is the electromagnet. So, it will come in physical contact as you can sequence with the magnetic material will get I mean eroded with time that is the reason why, the life of a magnetic disk is not very long.

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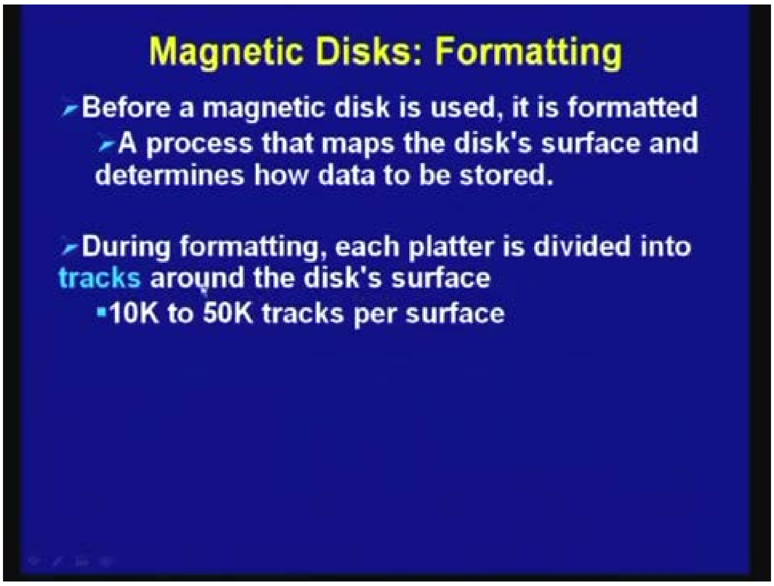

So, this is how reading and writing takes place there is a concept called formatting to make the disk I mean to for storing information on the disk, a technique known as formatting is used. That means, before a magnetic disk is used for storing data it is formatted, and formatting is a process that maps the disk surface, and determines how data can be written.

So, disks surface is earlier it is I mean it is a without any demarcation about, where you can store data, which part has to be kept free. But, as it is formatted then it identifies on which particular area you can store data and in which particular area, you have to keep blank and you have to keep gap. So, during formatting each platter is divided into tracks and around the disks surface.

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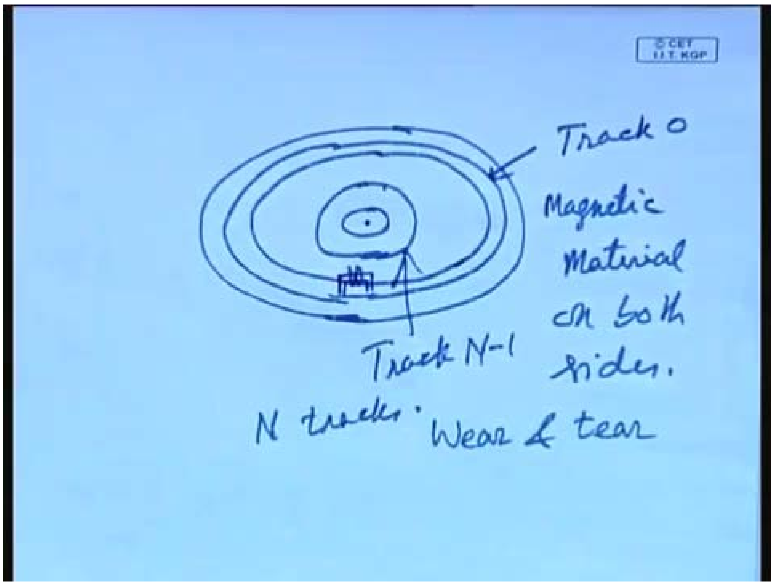

So, you will find there are tracks, so in the this is one track the circular ring, this is another track. So, in this way up to certain I mean certain distance of closer to the centre, the writing can be done, so in this way this is the track 0 and this will be the track say N. So, you can have N tracks N plus 1 tracks, so if it is N minus 1 there will be n tracks on the surface.

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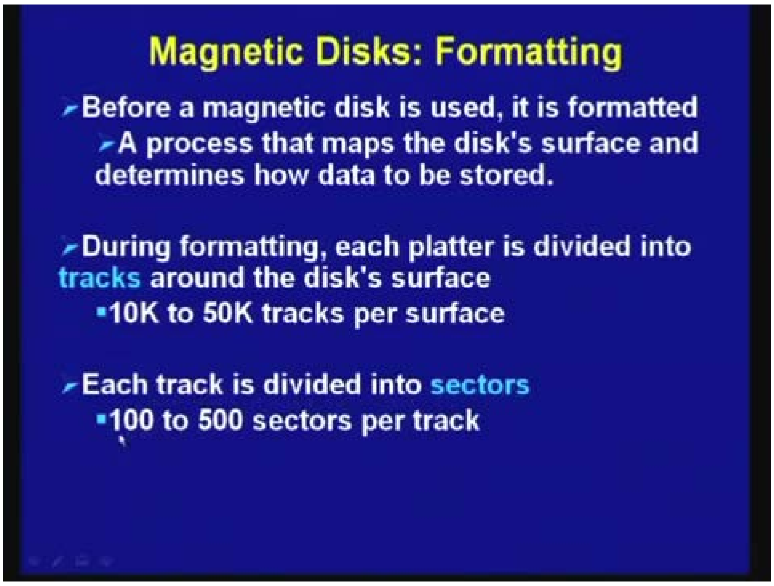

And the number of tracks is increasing with advancement of technology as you can see, it can vary from 10 K to 50 K tracks per surface, on a single surface you can have 10,000 to 50,000 tracks. So, quite a large number of surface I mean tracks you can have on the magnetic surface, actually that depends on the resolution of the read write head. Smaller it is it can store on a smaller area of the surface, then each track is divided into sectors.

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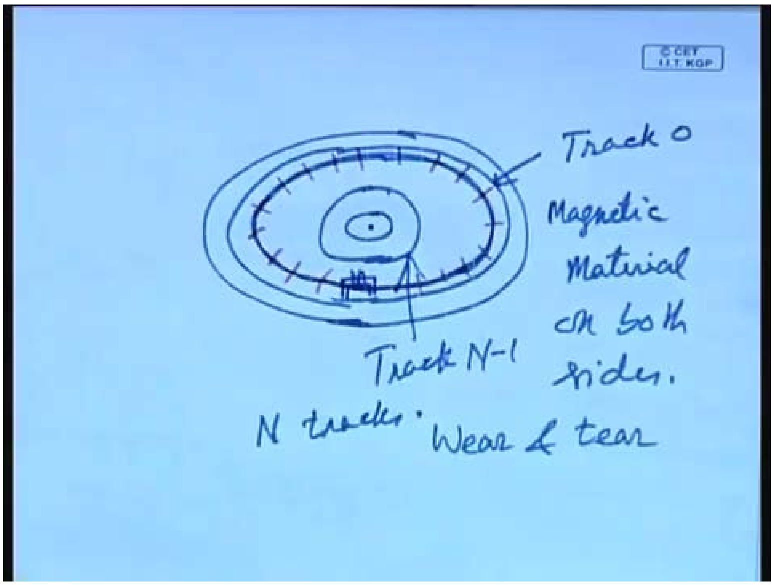

So, suppose this is one track and this track is divided into a number of sectors, so this is one sector, this is another sector, this is another sector, this is another sector and in this way you have a number of logical sectors, so you are dividing into a number of sectors.

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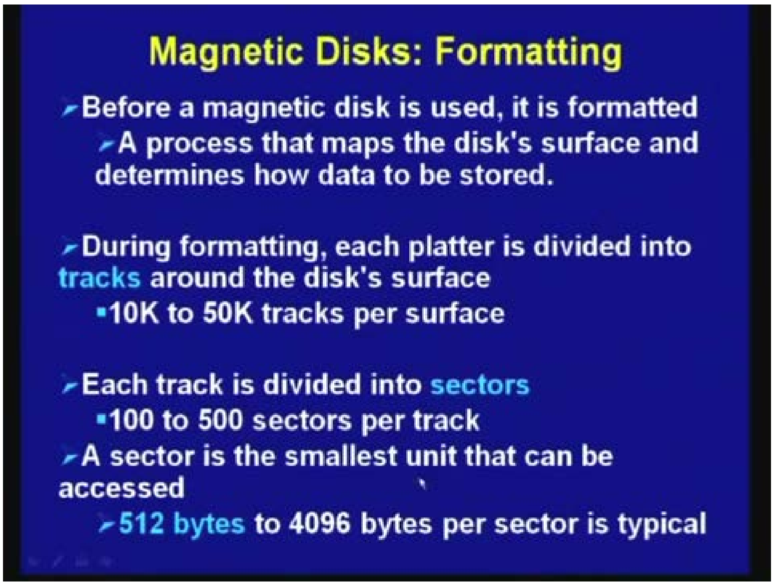

And the total number of sectors per track can vary from 100 to 500, so you have you can have 100 to 500 sectors per track. And a sector is a smallest unit that can be accessed; that means, whenever you are reading a data from disk or writing data into the disk, so minimum unit that you can access is a sector. That means, a sector can be read or more than one sectors can be read.

So, multiple of sectors can be read and on a single sector you can have 512 bytes to 4 K bytes of data per sector. So, this is a typical value the number of bytes that you can store on sectors varies from 512 bytes to 4 K bytes.

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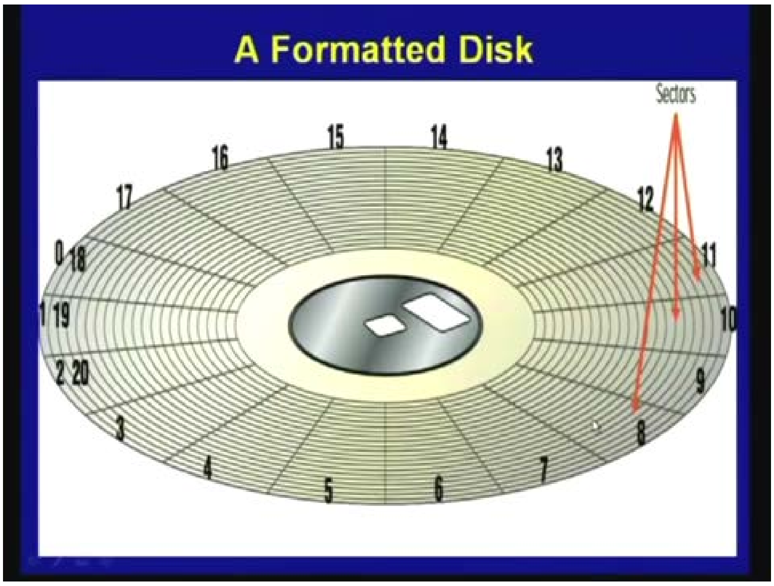

So, this gives you some information about a disk and some more and here a formatted disk is shown, you can see this is a disks surface shown and the as I said that outer track is the 0'th track. So, this is the 0'th track, and 0'th track is divided into a number of sectors 0, 1, 2, 3, so in this particular example there are 18 sectors per track and the number of sectors on each track is same irrespective of whether it is closer to the centre or; that means, it is same in the 0'th track and the n'th track.

That means, number of sectors per track is identical, so you can see various sectors on a on different tracks are shown. So, this is how logically a disk surface is I mean used and where you can store information, so this part is central part is used for holding this disk on the disk system because, you have to firmly hold it, so that it can be rotated at a particular speed.

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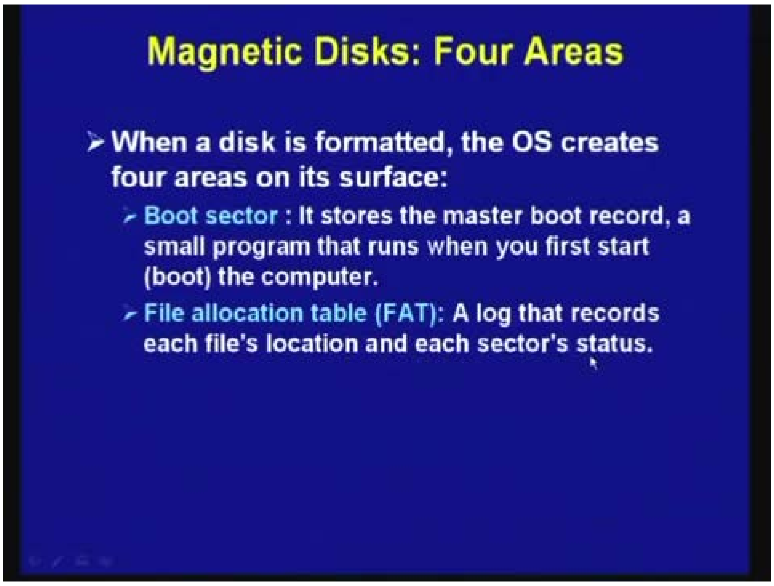

And there are four areas defined at the time of formatting that operating system creates four areas on the surface, number one area is known as a boot sector. So, it is stores the master book record, a small program that runs when you first start the computer; that means, normally you know whenever you put a disk, and start the computer the boot sector is read. And boot sector is used for the purpose of I mean bringing the system up, second is your file allocation table, so that is a log that is records each files location and each sector status.

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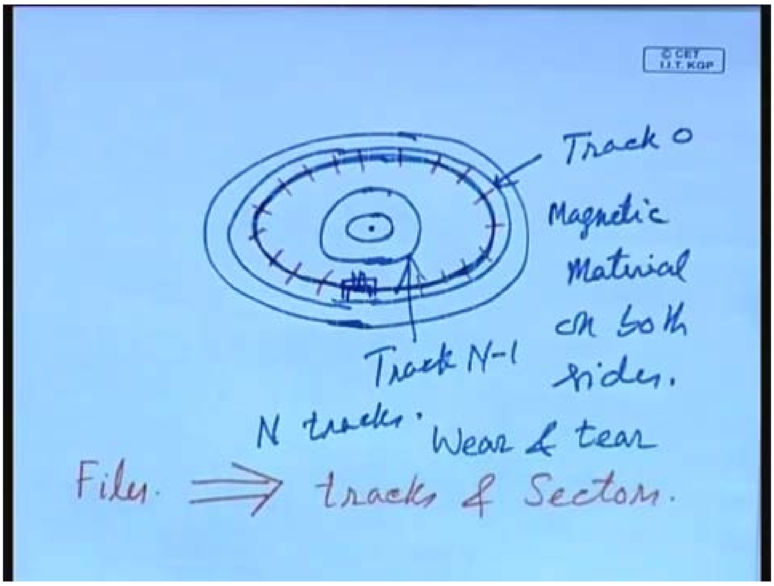

That means, in a, so far a programmer is concerned he is concerned about the files, he stored different files. And these files have to mapped to different tracks and different sectors of a track that mapping is done that information is stored in this File Allocation Tables or FAT.

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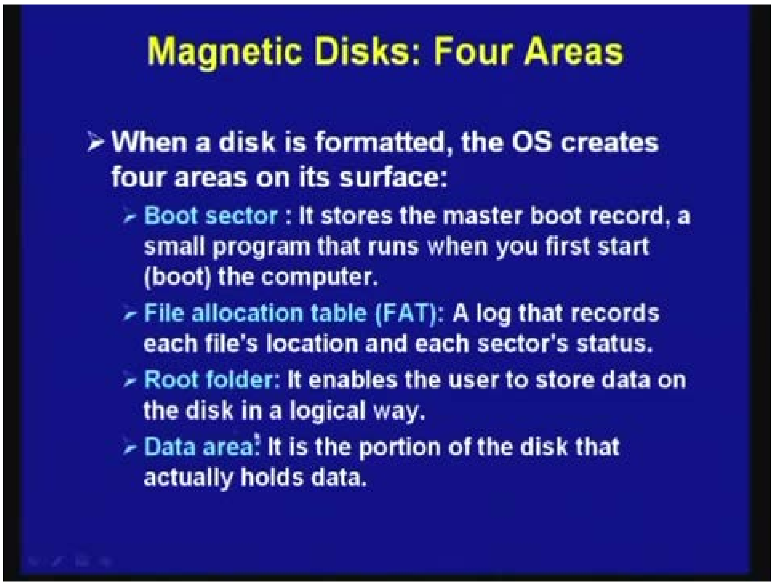

Then third area is root folder, it enables the user to store data on the disk in a logical way, and finally you have got data area. It is the portion of the disk that is that actually holds data, so you can say those boot sector file allocation table, root folder these are overhead, only area where information data can be stored is that data area.

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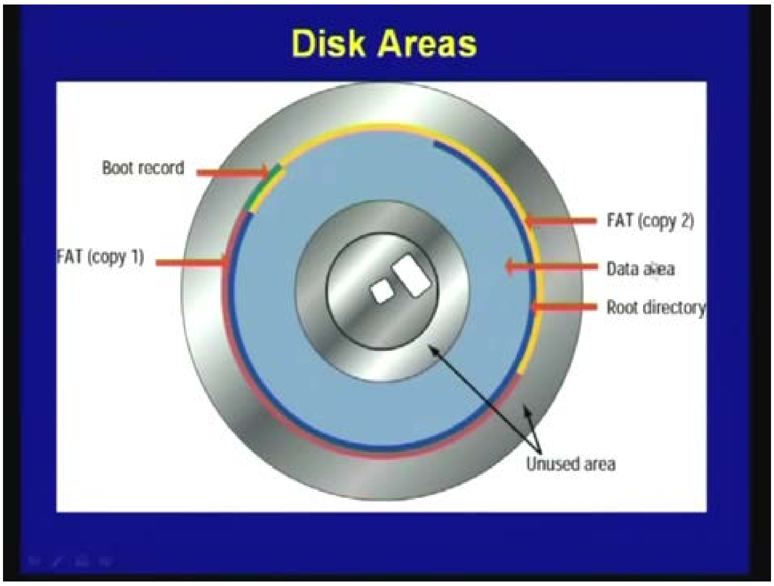

As you can see in this diagram different areas are shown, so that boot sector is that green portion is the boot sector, then is that File Allocation Table FAT that read track. And that file allocation table is duplicated for the purpose of I mean higher redundancy, so there are two file allocation tables stored as you can see two FAT, FAT copy 1, FAT copy 2. Then root directory that blue circle blue track is showing the, so you have started in this way first the boot sector, then the FAT.

Then the second copy of the FAT, then it goes to the second track where you are storing the root directory, root directory is being stored root. So, these are the components which is essentially overhead and information is stored only in this part of the hard disk.

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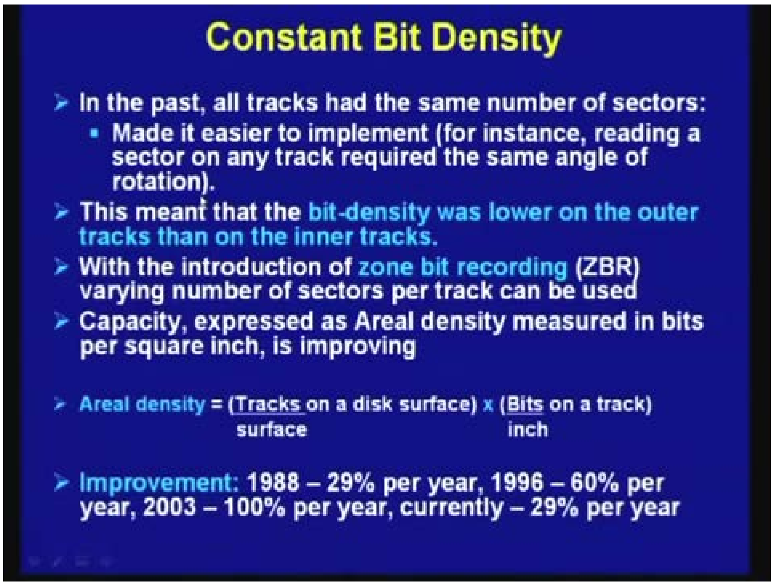

Now, in the past all tracks had the same number of sectors, as I have already mentioned, and this made it easier to implement, implement means for instance reading a sector on a track required the some angle of allocation rotation.

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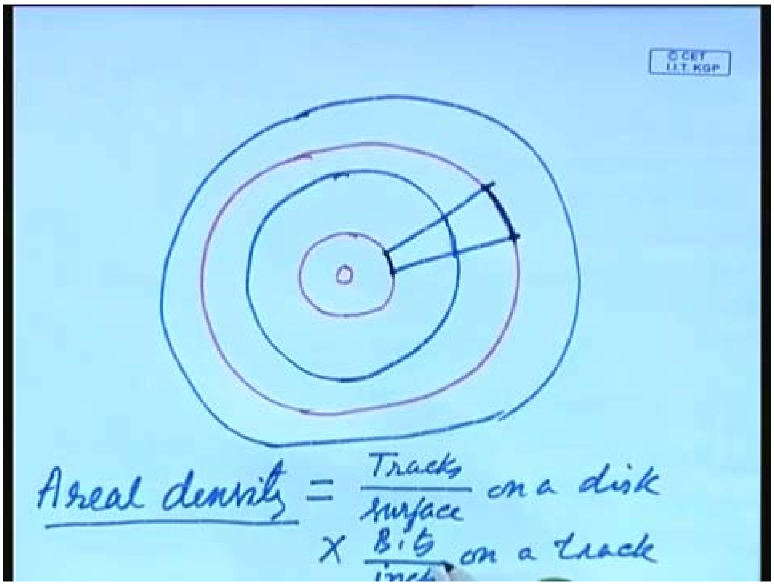

So, earlier what was being done as we have seen this is the track closer to the centre, and this is another track which is at the outmost layer of the disk. So, this is the disk, so we have seen that you have your dividing into a sector, so this is one sector, this is another sector and this one sector. You can see that length of these which is away from the centre is more than the length of this part, where which is closer to the centre.

So, the bit density is different tracks as you go away the centre, the bit density is smaller compared to the bit density which is on the track, which is closer to the centre. So, that is because of this particular technique where all tracks have the same number of this sector. So, this means that bit density was lower on the outer tracks, than that of the inner tracks as I have mentioned.

Now, subsequently with the introduction zone bit recording, varying number of sectors per track can be used. So, this is one innovation which was used to increase the capacity of a disk, so capacity expressed as the areal density measured in bits per square inch is improving. So, areal density which is representative of the capacity per unit area, unit inch that that is actually tracks per surface on a disk into bits per inch on a track. So, this gives you the parameter areal density, and actually it is specifies the number of bits that you can store per unit area.

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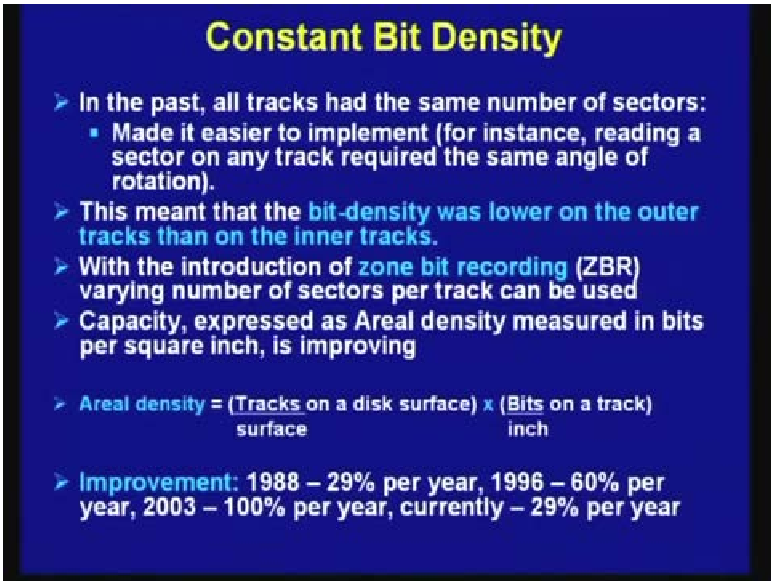

And this is improving over time and as you can see, in the starting from the year 1988 to 1996. The increase in areal density was 29 percent, then from 96 to 1996 to 2003 the improvement was 60 percent per year, and from 2003 onwards to recent years it is 100 per cent per year that is every year the areal density was doubling. So, you can say it is even better than the most law; however, currently the rate of increase has dropped, and it is only 29 percent per year then this is a rate at which the areal density is increasing.

So, you can see whenever you are using this type of innovations like john bit recording and, so on. You are able to increase the capacity of a disk, and the rate of improvement is quite high as you can see.

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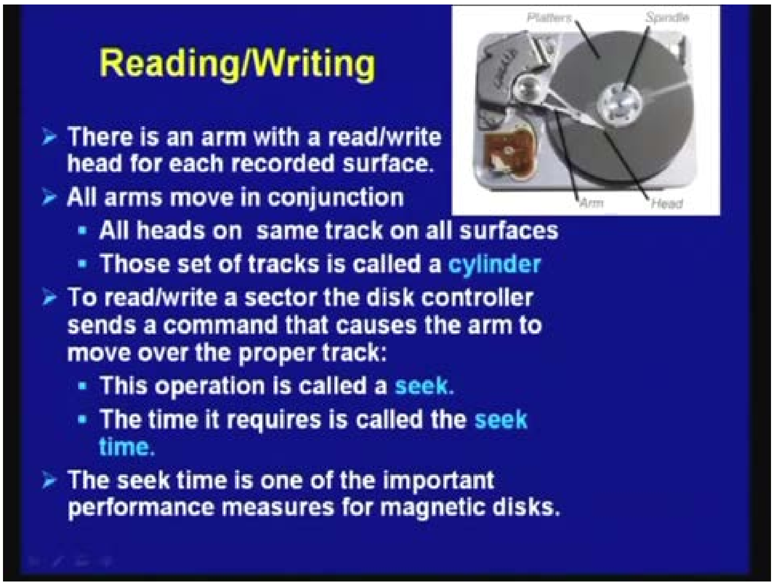

Now, how you are performing reading and writing, so there is an arm with a read/write head for each recorded surface. So, there is separate read write head you can see this is one here, separated read write head, which is available for each surface, so all heads on this same track on all surfaces, so what happens that all the heads move together.

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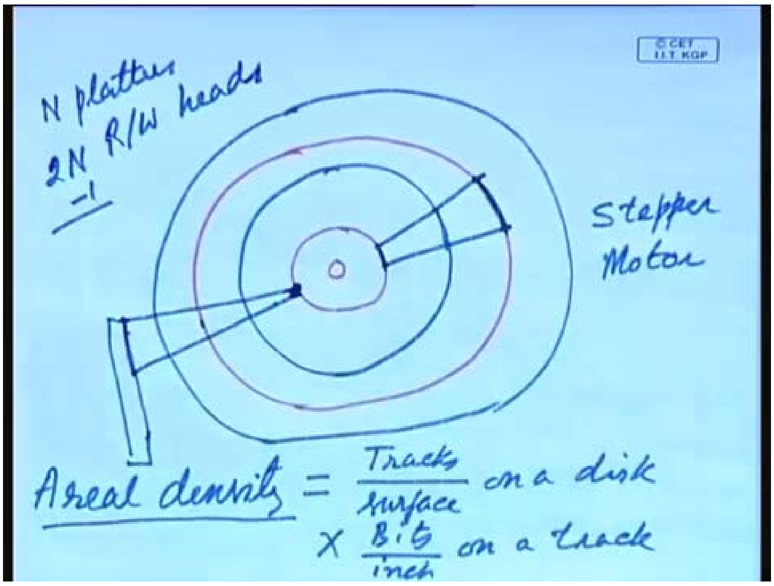

So; that means, what happens your read write head if this is read write head, if it is pointing to track number 0. So, it can move in this direction track sorry track number 0 is this 1, track 0, track 1 in this way it can move with the help of motor that is called stepper motor, with the help of a stepper motor the read write head is positioned on different tracks of a surface. And this read write head assembly, you can say all the heads on different surfaces move together.

So, if you have got say n platters you will be having a 2 N read write heads, all will move together on different surfaces. Of course, you may say 2 N minus 1 because, the last platter which is at the bottom will not have one surface will not be available. So, you will be having 2 N minus 1 read write heads which will be reading and writing on the surface.

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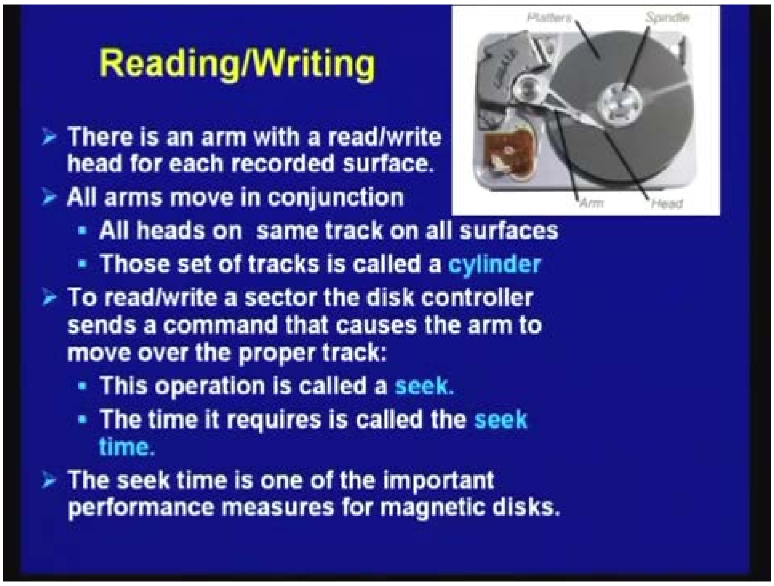

Now, those set of tracks is called cylinder what is a cylinder actually the concept of cylinder is coming in this way.

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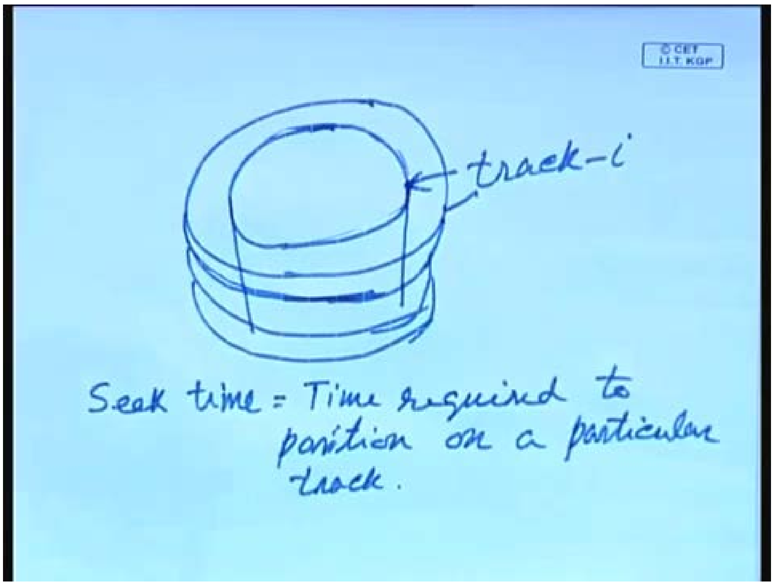

Suppose this is one platter, then at the bottom of this there is another platter, then there is another platter, then there is another platter in this way you got large number of platter. Now, let us consider the read write is positioned to track number i, so track number of i of this platter on both surfaces, than the track number i of the other platter on the same track. So, all will form a kind of cylinder, so essentially you can read from this particular track of this platter and from the platter you can also read together.

So, these are forming a kind of cylinder, so that is why the concept of cylinder has coming because, different tracks on different plates is forming a kind of cylinder. So, to read write a sector the disk controller sends a comment that causes the arm to move over the proper track. So, these operation is called seek, so there are different type of times you will encounter, the first one is known as the seek time, what is seek time, seek time is the time to position a read write head on a particular track.

So, initially you know that read write can be arbitral positioned, then it is read write is withdrawn. And whenever it reaches 0'th track from there it is starts moving towards other tracks with the help of that stepper motor, so seek times is a time required to position on a particular track.

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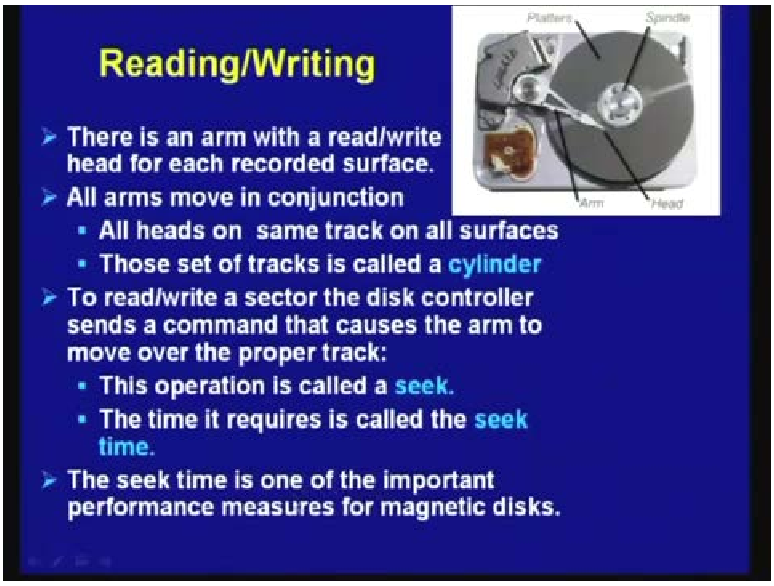

Then this seek time is one of the important performance measures for magnetic disk, since it is a very important performance measure, there is confusion about it is definition.

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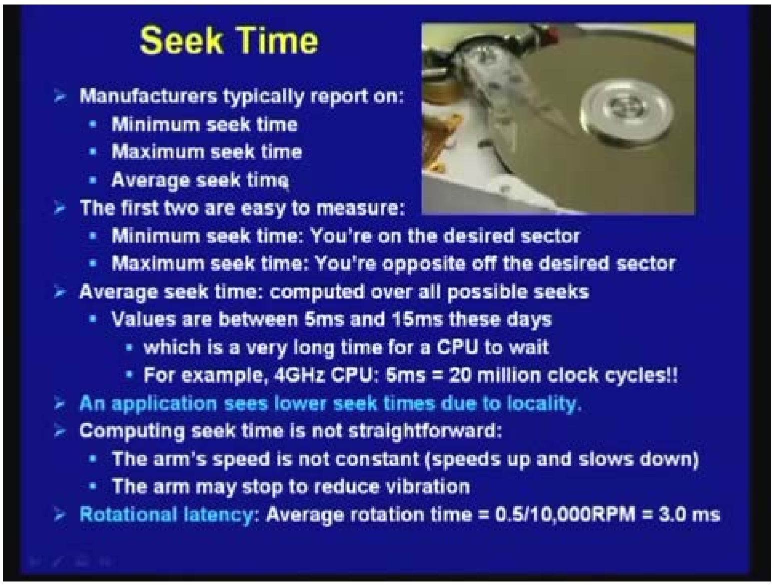

So, people will specify about minimum seek time, maximum seek time, average seek time. So, people will get confused which one you have to take because, minimum seek time means the minimum amount of time.

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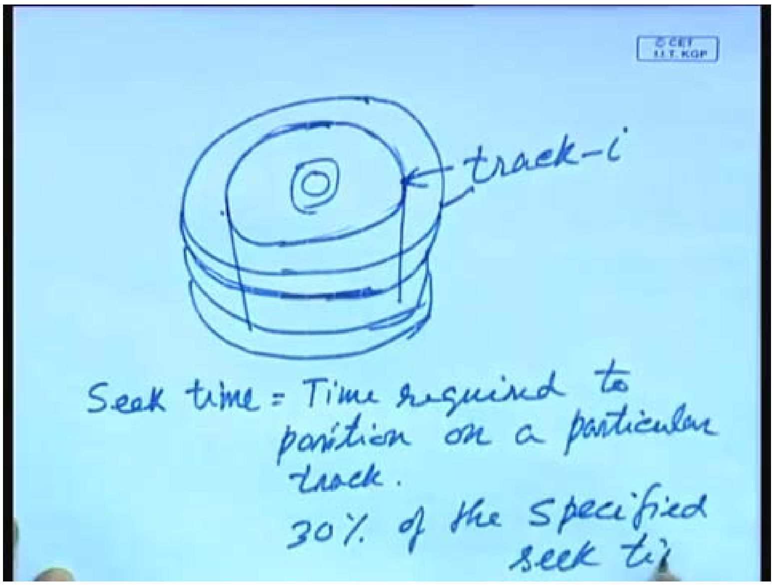

If the read write head is very close to the 0'th track then seek times will be small, if it is very close to the centre, then you have to take it back towards the 0'th track and the seek time will be longer. So, that is the reason why minimum seek time, maximum seek time and average seek time, these are deported the first one are easy to measure because, it depends on the actual position at a particular of the read write head, at a particular position.

So, here as you can see the read write head is here, so you have to move to these 0'th tracks. So, this is the 0'th track, and this is the nth track, so then it will take longer time and on the other hand if the read write head is at the 0'th track then this seek time will be smaller. So, average seek time is computed over all possible seeks, so you can the read write head can be at any one of the tracks of the end tracks, and as a consequence you have to take the average of them.

So, the seek time can vary between 5 millisecond to 15 millisecond these days, now a days the in spite of the improvement it is the order of the milliseconds. Because, mechanical motor is involved in the process of I mean placing a read write head on a particular track, and that is the reason why if the values I mean varying between 5 milliseconds to 15 milliseconds. And; obviously, this time is a very long time for a CPU, you know now a day's processors are operating at the rate of few GIGA hertz.

So, you can see this 15 milliseconds or even 5 milliseconds is too long at a times, so for example, for 5 GIGA hertz CPU, 5 millisecond means 20 million clock cycles. So, just for positioning the track, positioning the read write head on a particular track, you will take 20 million clock cycles that is too long at time. So, an application sees lower seek times due to locality of course, although this is the I mean worst case time you can say, but in practice.

Because, of the principle of locality actual seek time will be much lower it has been reported that the actual seek time is about 30 percent of the specified seek time. So, computing seek time is not straightforward, the arms speed is not constant, and another very important parameter is the read write head I mean which is holding the read write head is hold by a arm, this is called a arm that arm speed of that arm is not constant. So, it is speeds up and slows down because, in the beginning it will be having slow speed.

Then you know just like, you know you are driving a car initially speed will be low, then the speed it will pick then as you try to stop it will slow down. So, it is a motor, so the arm stop to reduce the vibration, so it may be allowed to stop without giving power, so that vibration is not present.

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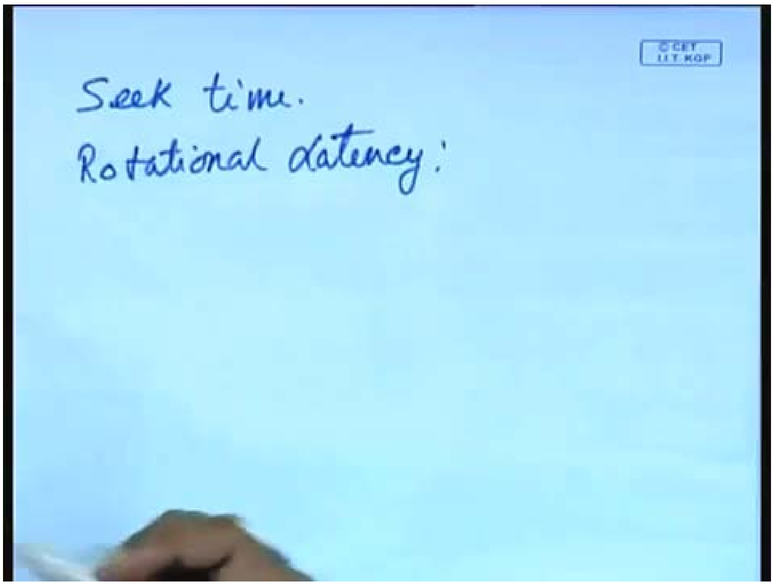

And another parameter is rotational latency, so first parameter is seek time, second is rotational latency.

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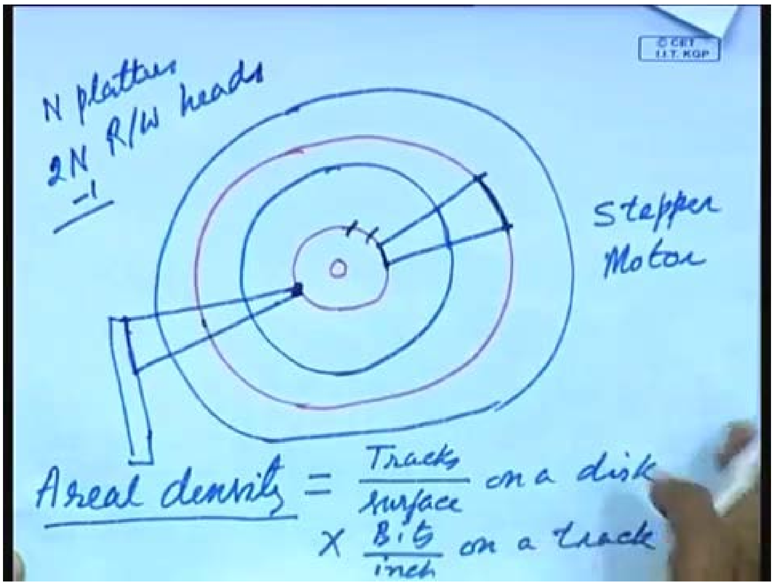

What is rotational latency, we have seen that seek time is the time required to position a read write head on a particular track, now you have to place it on a particular sector.

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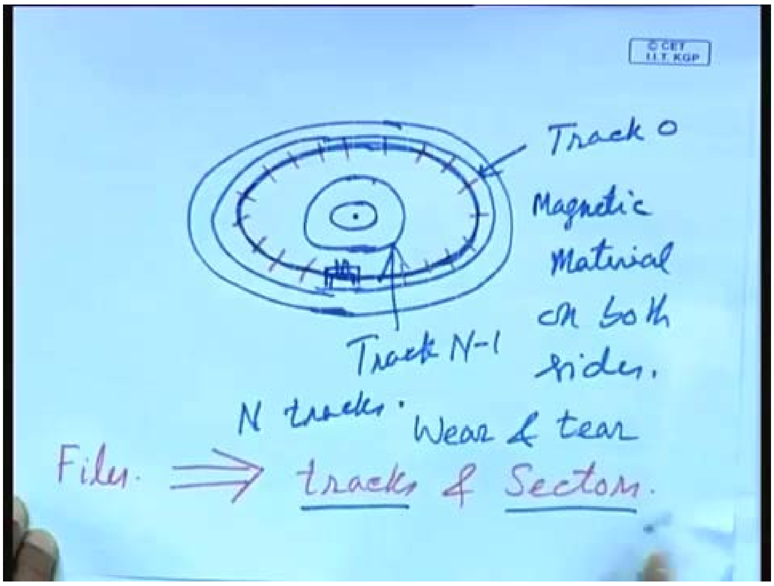

Because, that file I mean which is mapping to tracks and sectors in terms of tracks and sectors to read data, you have to position not only on a track you have to position on a particular sector.

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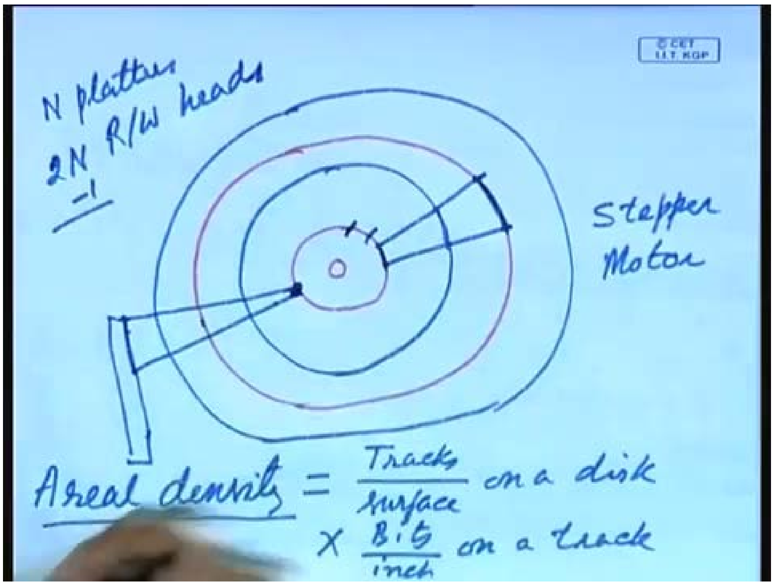

So, on a particular track you have to being read write head on a particular sector.

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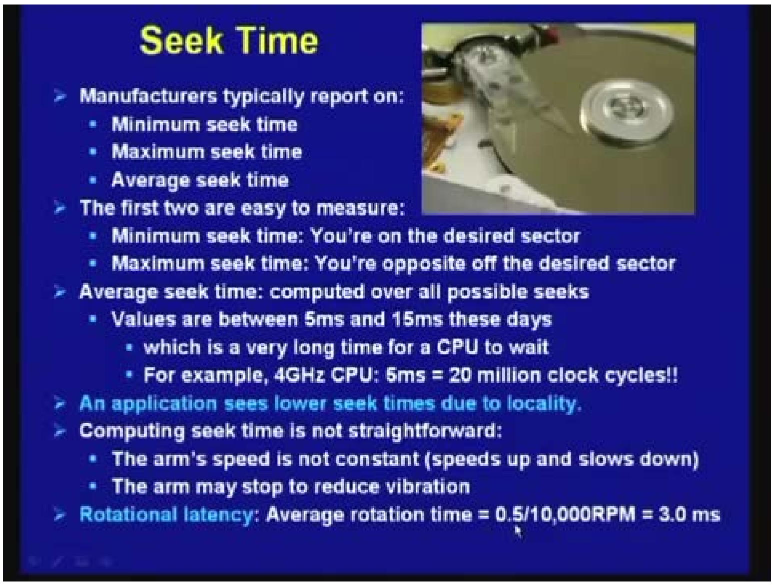

So, that is actually decided by the rotational latency, and average rotation time is roughly half of the worst case time that is your 0.5 by 10,000 RPM if this speed is 10,000 revolutions per minute. So, that is roughly equal to 3 millisecond, so you can see rotational latency is of the order of 3 millisecond.

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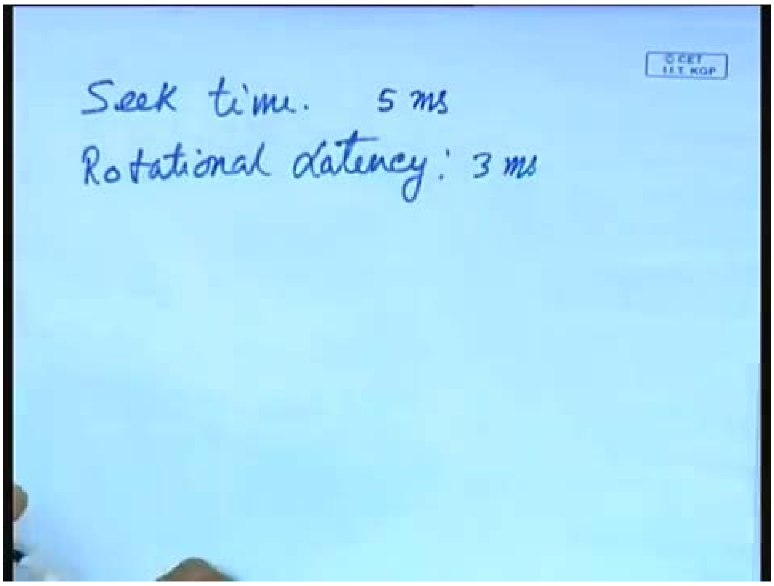

So, you may say that this is the order of 3 milliseconds, and this can vary from 5 millisecond to less, so it may be 5 millisecond or 4 millisecond like that.

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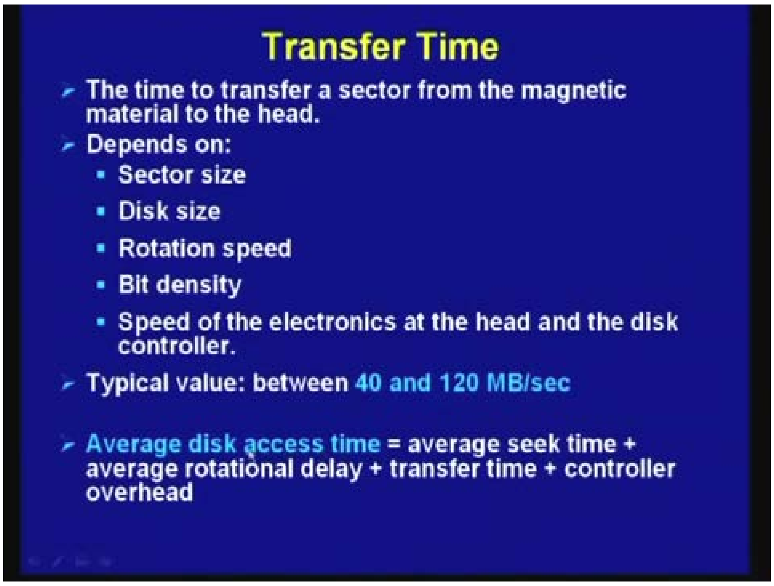

Now, comes the another parameter that is your transfer time, so the time to transfer a sector from the magnetic material to the head. So; that means, you have position a read write head on a particular sector, now you have to read it that read write head will read it, and transfer it through that there is a controller through the controller it will send to the processor. So, the transfer time is the time to transfer a sector from magnetic material to the head.

And it depends on the sector size, disk size, rotation speed, bit density, speed of the electronics at the head and the disk controller. So, you can see this transfer time is dependent on a number of parameters, and this parameters will decide the transfer time and typical value is in the range of 40 to 120 megabits per seconds. So, this is the speed at which the data transfer will take place.

After the read write head has been position on a particular track, and then on a particular sector. And after that, this is the rate at which data transfer will take place from the read write head to the processor.

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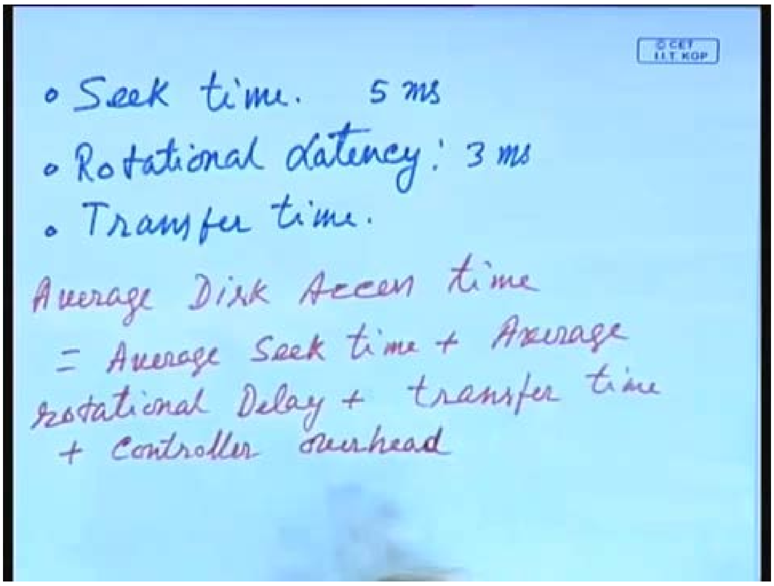

So, you can say that average access time than your transfer time, so there are three components. And you can say that average disk access time, it has got several components, one is average seek time plus average rotational delay plus transfer time and there is some overhead because, of the controller. Controller is holding some electronics, and that controller will take some time to transfer the data to the CPU. So, this is the average disk access time comprising four components, average seek time, average rotational delay, transfer time plus controller overhead.

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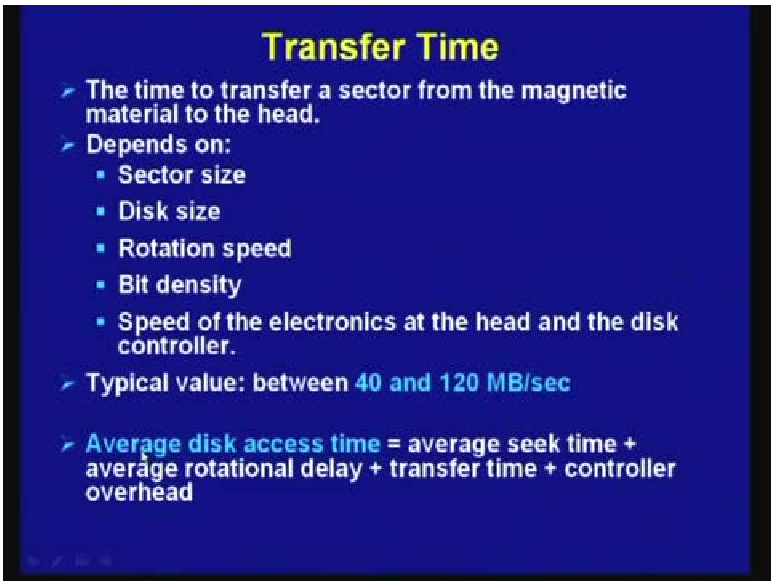

So, you have to take into account all these four components whenever you find out try to calculate the average disk access time.

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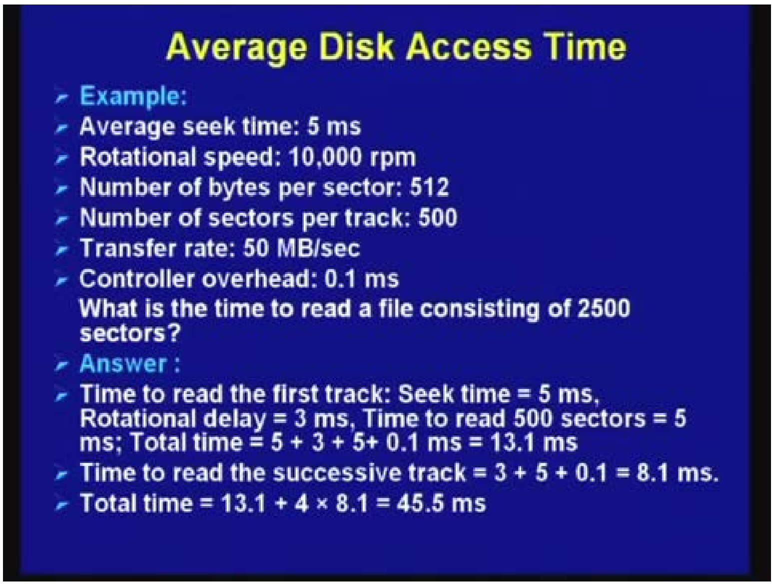

So, let us consider an example to crystallize the idea, let us assume that average seek time is 5 millisecond, rotational speed is 10,000 revolutions per minute. Number of bytes per sector is 512, number of sectors per track is 500, transfer rate is 50 mega bits per second and controller mega bytes per second everything is specified in terms of bytes. And controller overhead is quite small 0.01 millisecond, now considering I mean with the help of these parameters, you can calculate what is the time required to transfer a file from the disk to a processor.

So, question is what is the time to read a file consisting of 2500 sectors, so let us to let us try to calculate this.

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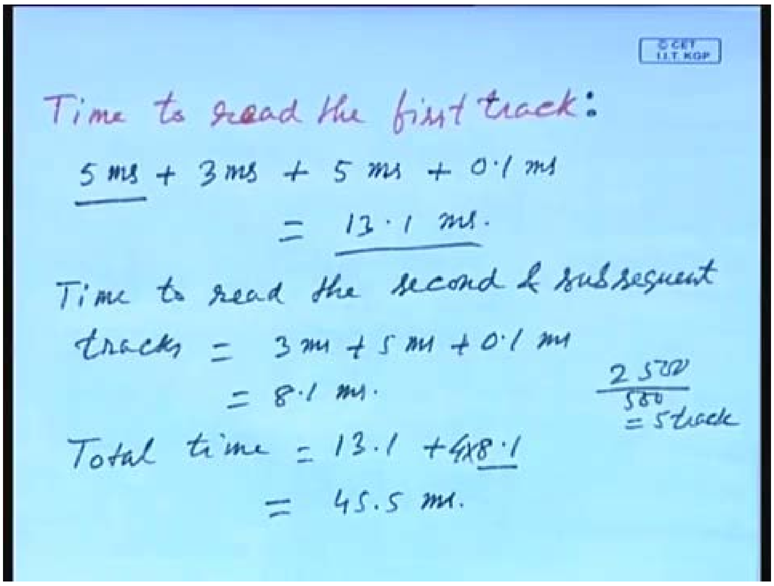

So, we can calculate in this way time to read the first track, so that it will vary from track to track. So, after it has been positioned on the first track, then subsequent tracks can be easily accessed because, seek times will be 0 for other track, so that's why time to read the first track is separately considered that will consist of 5 millisecond. As you mean that the seek time is 5 milliseconds, then the rotational delay is 3 millisecond, then the time to read say 500 sectors you know we have seen that there are 500 sectors per track.

And to calculate to time required to transfer 500 sector is will be you may calculate it and you will find that it is again 5 millisecond. And then you have got that controller overhead is which 0.1 millisecond, so this is the total time that will read, the first track comprising 500 sectors, and this is equal to 13.110 13.1 millisecond. Now, you have other four tracks, so time to read the second track, second and subsequent tracks you can say will be equal to this will no longer be present. So, this will be equal to 3 millisecond plus 5 millisecond plus 0.1 millisecond.

So; that means, this will be equal to 8.1 millisecond, so total time to transfer 2500 sectors will be equal to 13.1 plus 8.14 into 8.1 because, you have to read 5 tracks. So, 2500 tracks I mean 2500 sectors, and 500 sectors per track, so you have to read 5 tracks, so first track will take time required will be 13.1 millisecond, remaining each track will require transfer of data from each track will require 8.1. So, it will be four into 8.1 for the remaining four tracks, so the total time will be equal to 45.5 millisecond, so this is how you can find out the access time for different situations.

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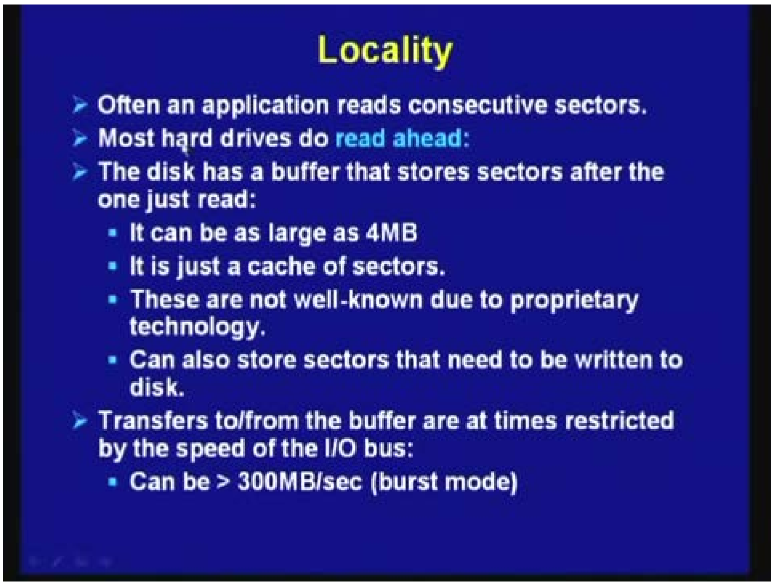

Now, we shall focus on one very important aspect that you can exploit that is the locality of the reference, often application reads consecutive sectors. You see although a particular file can map to different tracks and different sectors, but usually the a particular file is stored in consecutive sectors of a particular track. So, that locality can be exploited special locality, and that special locality can be exploited and the technique that is used is known as read ahead.

So, most hard drives used read ahead, so what is this the disk has a buffer that stores sectors after the one just read. That means, we have seen that whenever a disk is accessed minimum unit of access is 1 sector, normally one sector will be transferred then it will read another sector and, so on. But, what you are doing in this particular case, you are not only reading 1 sector you are reading another sector you are reading ahead and this can be as large as 4 mega bytes.

And it can be that buffer can be as large as 4 mega bytes, where you can store subsequent sectors, and it is just a cache of sectors. So, we have already discussed about the use of cache memory, so it acting as some kind of cache memory, a buffer where you are reading some additional sectors and storing information of those additional sectors. So, this can also store sectors that need to be written or the to the disk, so in this way here not only reading, you can also do it for writing purpose.

That means, you will be writing into the buffer, then you will be transferring into the disk. So, both for reading and writing you can use this concept of read ahead, which is aching to the concept of cache memory in the context of main memory system, so transfers to and from the buffer are at times less restricted by the speed of the I/O bus. So, here you know later on we shall discuss on that a computer system will have several busses, one is CPU memory bus which is the fastest; that means, CPU transfers data with the CPU, another is CPU I/O bus.

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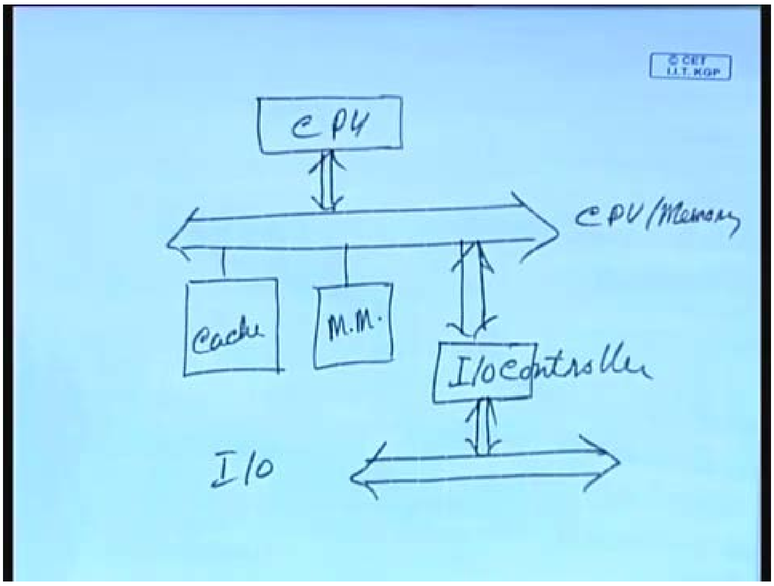

So, it is like this, so here let us assume we have got CPU and there is a bus, and this is the CPU memory bus to which the cache memory and main memory systems are connected. So, this is your cache memory and this is your main memory, now another bus you can have that is provided by with the help of a I/O controller, and this will provide another bus known as I/O bus. So, this I/O bus is relatively smaller I mean slower compared to the CPU memory bus because, rate of transfer of data that takes place to this I/O buses I mean is normally slower I/O devices connected through I/O bus.

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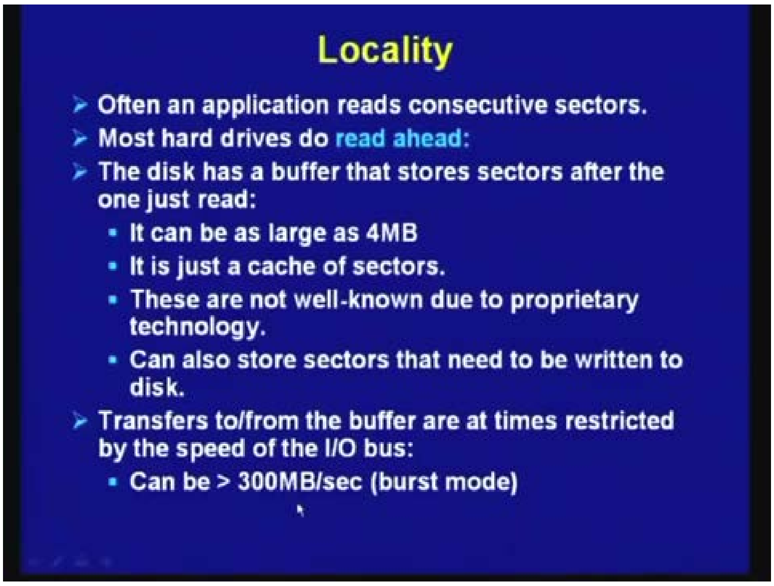

And as you can see here the data rate can be 300 mega bytes per second, so compared to few GIGA bytes per second, here the speed is 300 mega bytes per second, it is the bus mode. Bus mode means, you are transferring all the data together 4 mega bytes you are sending one after the other not you are you are not reading one sector, then another sector, another sector it is already available in the buffer, and from the buffer all the data is transferred in the bus mode. So, this is how you can exploit the locality with the help of this read ahead concept.

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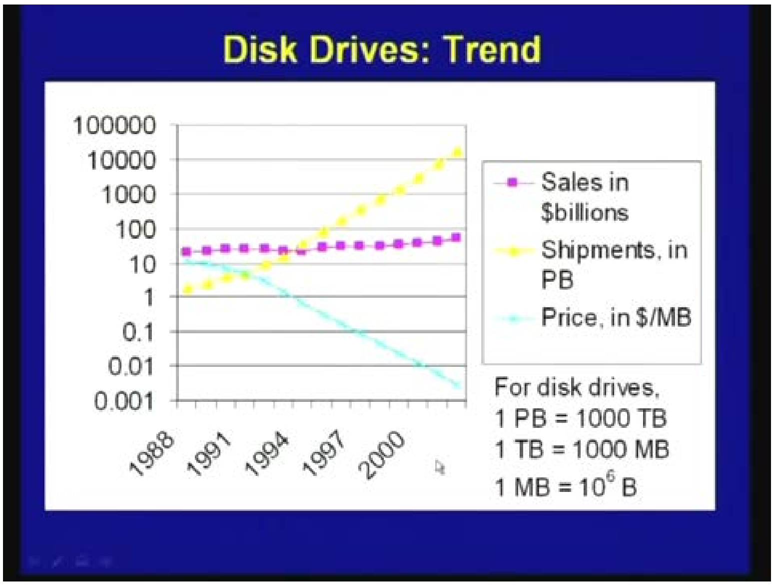

So, this gives you the a trend for bus drivers I mean disk drives, you can see here 3 parameters shown that yellow line corresponds to shipments in PB. So, the volume is increasing at a very high rate, the second the pink line corresponds to sales in billions, so you can see one very important feature I mean aspect or point you must note here, you can see although this shipment is larger shipment is increasing. Because of the drop in price, the sales in billions has remained same.

That means, the money that the transaction of money is actually taking place is more or less constant over the years. That means, the volume is increasing price is declining actual amount that is being that involved money that is involved in sales of dollars that is remaining more or less constant. So, for disk drives 1 PB corresponds to 1000 terabyte, 1 terry bytes corresponds to 1000 mega bytes, and 1 mega bytes corresponds to 10 to the power 6 bytes.

So, you can see we are considering very large numbers large volume you can see and, which is stated in terms of PB. And not in terms of terabytes or mega bytes, so this is the trend of this drives, and this trend has remained more or less same over the years.

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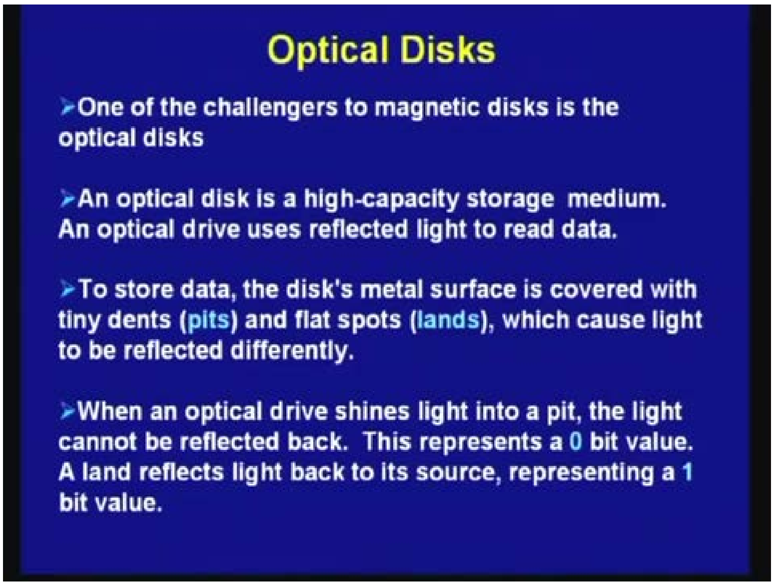

Now, we shall switch gear and consider another type of disk, so far we have considered magnetic disks. Now, we shall focus on optical disks, so many new technologies have evolved over the years particularly, but they have not become successful commercially, but this optical disk is the one of the challenges to magnetic disk is the optical disk, which has become quite success commercially. So, optical disks are quite successful, an optical disk is a high capacity storage medium.

And optical drive uses the reflected light to read data, so here reading and writing is taking place with the help of light, instead of putting the read write head on top of the magnetic surface. Here you are doing the reading and writing with the help of light, as a consequence wear and tear is not does not exist, we have seen whenever you put the read write head on top of a magnetic disk surface. And when it rotates, there is a wear and tear which does not exist, whenever you do the reading and writing with the help of light.

So, to store data the disks metal surface is covered with some tiny dents, known as pits and flat spots knows as lands. So, you have got two types of areas pits and lands, which cause light to be reflect differently, so you are trying to read with the help of light, and depending on I mean from where it is getting reflected on if it is on pits, it will reflect in one way and if it is on lands it will reflecting in another way.

So, when a optical drive shines light into a pit, the light cannot be reflected back as we shall see with the next diagram. This represents a 0 bit value, and a land reflects light back to this source representing a one value.

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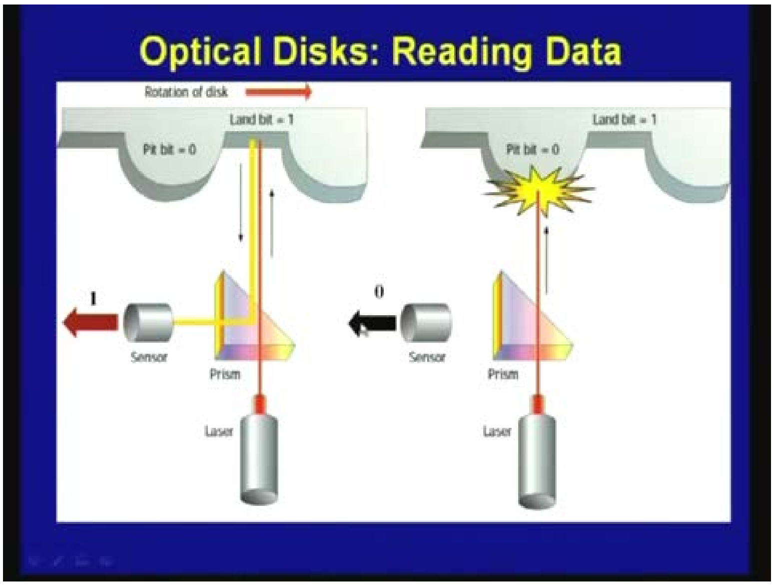

So, this is shown with the help of this diagram, so in this particular here as you can see, this is the light source, laser source. So, which is falling on the land, so which is representing one, since it is falling on a flat surface, it is reflecting the light and then there is a prism, which drivers it which I mean there is a total internal reflection. And then it goes through a censor, and that censor converts it to light to electrical signal and you get a one.

So, this is how you get a one, on the other hand whenever the light is falling on a pit, which is representing bit 0. Then what is happening the light is getting scattered in all directions, so it is not getting reflected like the previous case, and as a consequence there is no light present, then no light will pass through the censor. So, they have sense of any signal, light signal is considered is 0, this is how 1 and 0 can be read from the optical disks.

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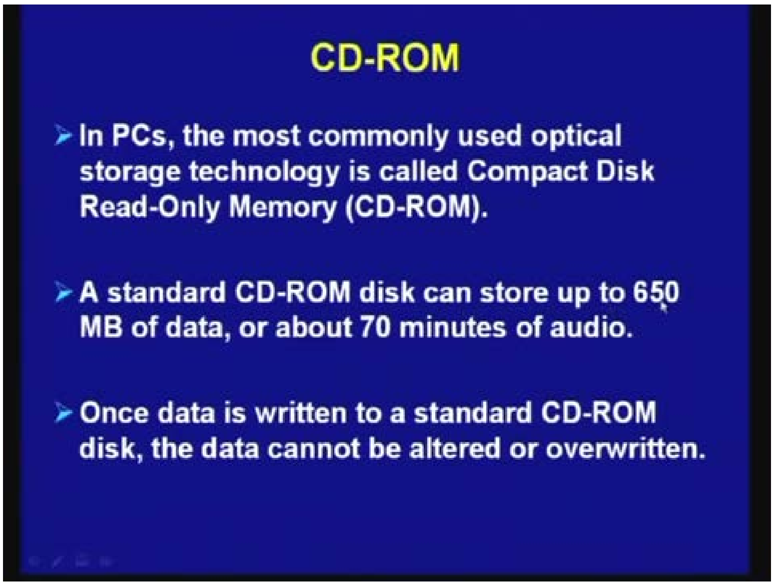

So, in PCs the most commonly used optical storage technology is called the compact disk or read only memory that is your CD-ROM. So, standard CD-ROM disk can be can store up to 650 mega byte of data or about 70 minutes of audio, now a days because of the popularity of music. And also the popularity of DC-ROM, these two it has become very common to store music on CD-ROM, so that's why, you know instead of mega bytes, we are also stating in terms of time that is the amount of audio signals or music that you can store 70 minutes of audio.

So, once data is written to a standard CD-ROM disk, the data cannot be altered or overwritten. So, this is one characteristics of CD-ROM; that means, this writing is cannot be modified, so some kind of burning has taken place in certain areas, so with the help of some special device, these pits and lands are created and it is permanent. That's why it is called CD-ROM Compact Disk ROM, stands for Read Only Memory you cannot do the writing.

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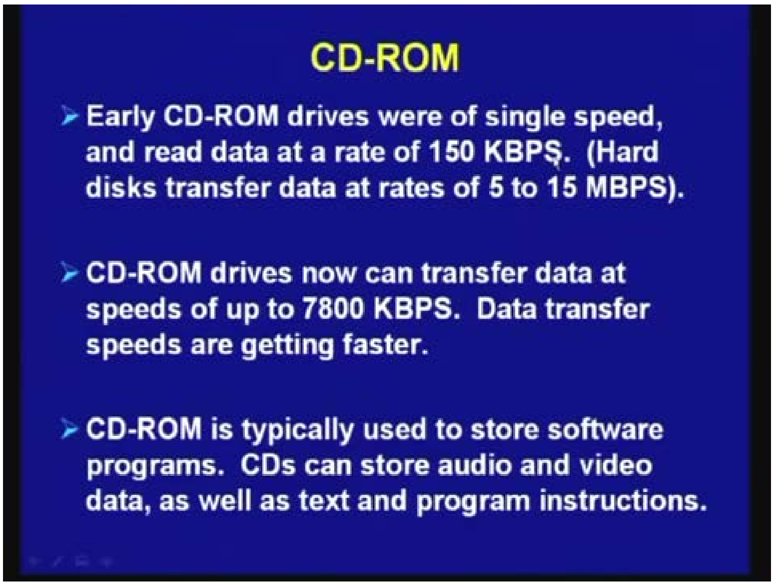

So, early CD-ROM drives were of single speed and read data at a rate of 150 kilo bytes per sec, hard disk transfer data rates is about 5 to 15 mega bytes per seconds. So, you can see there is significant difference in the rate of transfer of data, so I mean CD-ROMs are much smaller compared to hard disk in terms of data transfer rate. And CD-ROM drives now can transfer data at the rate speed of about 7800 kilo bits per second, and data transfer speeds are getting faster and faster with time.

And CD-ROM is typically used to store software programs, whenever you buy a software, and it is permanently stored in CD-ROM and that is delivered to you. On the other hand CDs can store audio and video data as well as text and program instructions, so different types of information can be stored in CD-ROMs.

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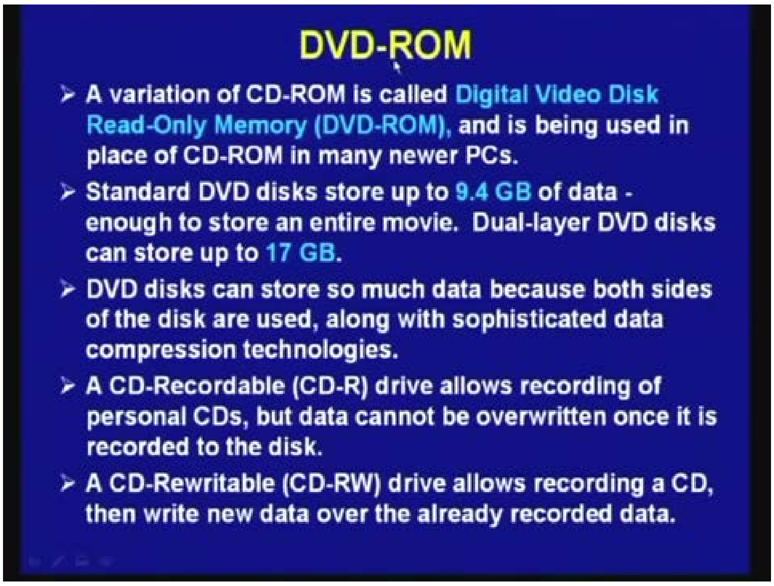

Then another variation is known as DVD-ROM, DVD stands for Digital Video Disk, so DVD-ROM stands for Digital Video Disk Read Only Memory, and it is being used in place of CD-ROM in many PCs. So, now, a days this is also become very popular, and standard DVDs disks can store up to 9.4 GIGA bytes of data, enough to store an entire movie. So, you can store an entire movie into it, and dual layered DVD disk can store up to 17 GIGA bytes.

So, DVD disk can store as much data because, both sides of the disk are used along with the sophisticated data compression technique. So, in case of CD-ROM we have seen the capacity is much smaller, but in case of DVD we are using some sophisticated technique, by which you are also doing data compression to store more data. And that is the reason why the storage capacity is much higher, and then another variation is their CD recordable, CD recordable means you can write only once.

So, with the help of a special device you can do the writing only once, so drive allows recording personal CDs, you can create your personal CDs. And conventionally which you use that is CD recordable CD-R, but data cannot be overwritten once it is recorded in data or to the disk. So, this is the most common type of disk we encountered, there is another type of DVD-ROM or CD you can say CD re writable, so this variety is very costly, and not very commercially successful.

So, CD rewritable drive allows recording of a CD re recording of a CD, you can write just like your it may be consider it as CD read write or CD-RAM, then write new data over already recorded data.

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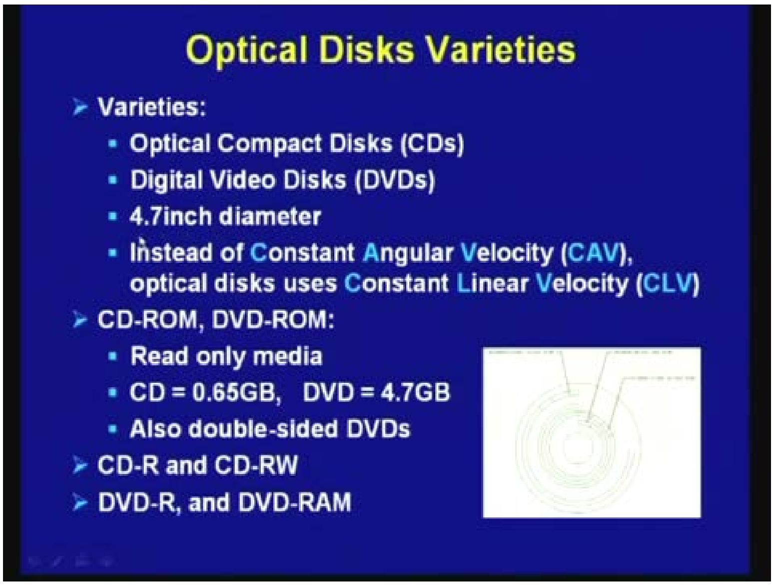

So, this gives you shows you different varieties optical compact disk, Digital Video Disks DVDs, 4.7 inch diameter. So, one new technique that is used here is instead of constant angular velocity, optical disk uses constant linear velocity.

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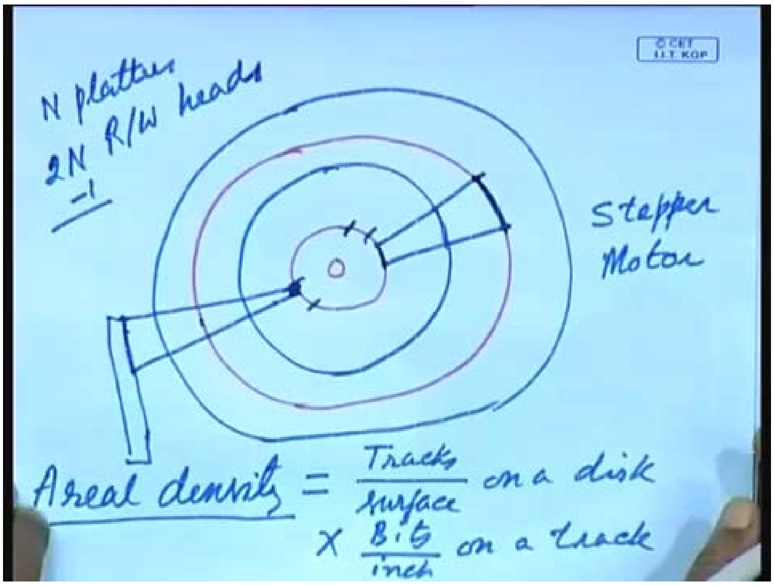

So, earlier we have seen that angular velocity is small because, you know the, so when the read write head is here, the time that is required to read for this part is same as the this part, so angular velocity is same.

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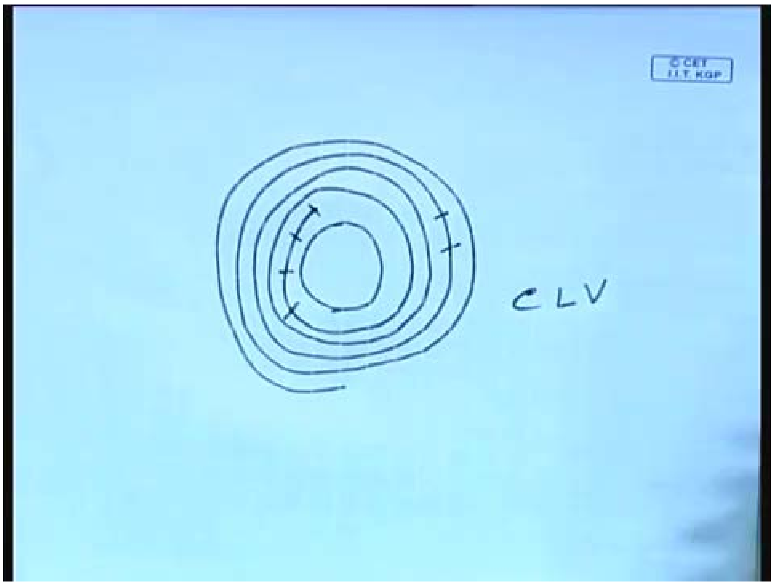

But, now what is being done in case of CD-ROM you will be, so this is the centre and it is written in this manner, in the form of a spiral. So, here since you are storing in the form of a spiral, so this is one particular sector, this is another sector, this is another sector and, so on. And, so that is and you are reading using constant linear velocity, so you have got constant linear velocity of reading, you are here time to read this part and this part is same. So, this is your constant linear velocity, so CD-ROM uses this constant linear velocity.

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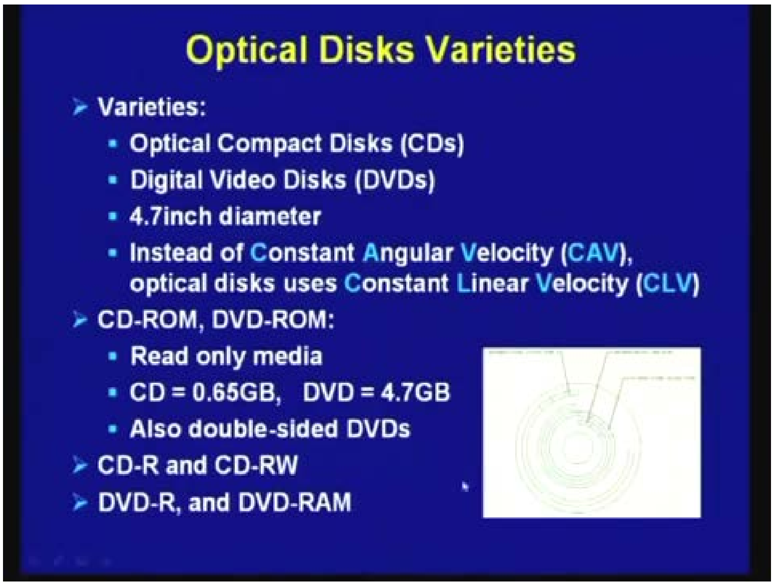

And there are different kinds of read only memory, CDs are 0.6 GIGA bytes, DVDs are 4.7 GIGA bytes, these are very common. Also double sided DVDs are available, we have already discussed about CD-R, CD-RW then DVD-R and DVD-RAM, so difference between CD-R and CD-R w is in case of CD-R you can write only once in case of CD-RW you can write many times.

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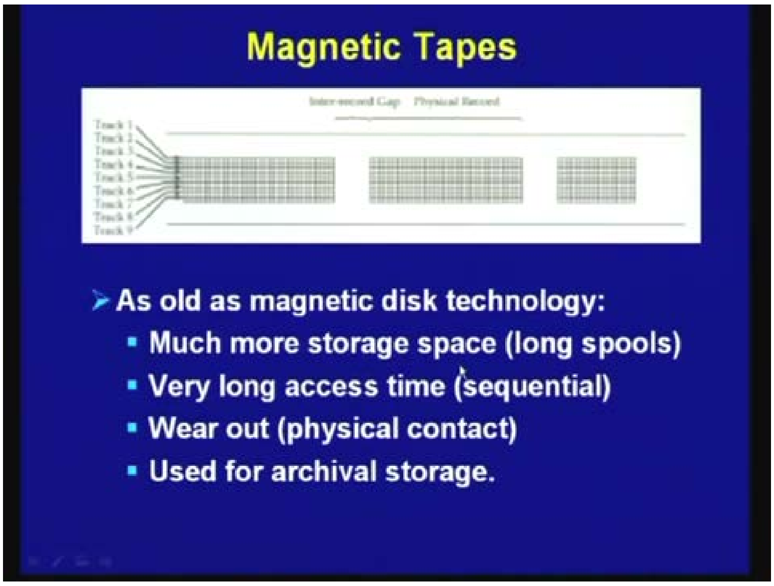

Then comes the magnetic tapes, this is as old as the magnetic disk technology, much more it has got much more storage space, very long access time. So, you can see here on a it is in the form of a tape just like your audio tapes, so on a single tape it is having a number of tracks, track 1, track 2, track 3, track 9. So, you can transfer parallelly, a number of bits different bits, so 9 bits you can transfer parallelly, whenever you are you are reading from a tape.

And unfortunately it has got long very access time because, you are reading sequentially you have to start from one end, and then you have to go ahead just like your audio tapes. And since, it is made of magnetic material it wear outs very quickly because, of the physical contact of the read write head, and primarily these magnetic tapes were used for archival purposes. So, in the early years in our computer centre we had large number of magnetic tapes, where all the various programs, and data were to be stored in magnetic tapes and primarily they are used in archival purposes.

So, with this let us come to the end of today's lecture, so in my lecture we shall discuss about some other alternatives. Because, magnetic tapes are becoming increasingly I mean becoming out of outdated, and new technology are coming in which I shall discuss in my next lecture.

Thank you.