INDIAN INSTITUTE OF TECHNOLOGY
KHARAGPUR

NPTEL
ONLINE CERTIFICATION COURSE

On Industrial Automation and
Control

By Prof. S. Mukhopadhyay
Department of Electrical Engineering
IIT Kharagpur

Topic Lecture – 46
Introduction to CNC Machines

Welcome to lesson 23 of the course on industrial automation and control today I will be talking about.

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CNC machines that are numerically computer numerically controlled machines so as usual.

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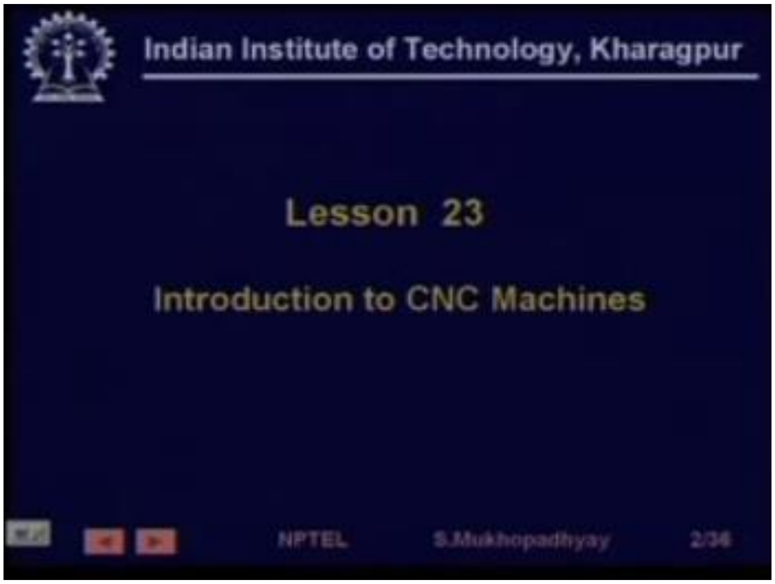

Let us look at the.

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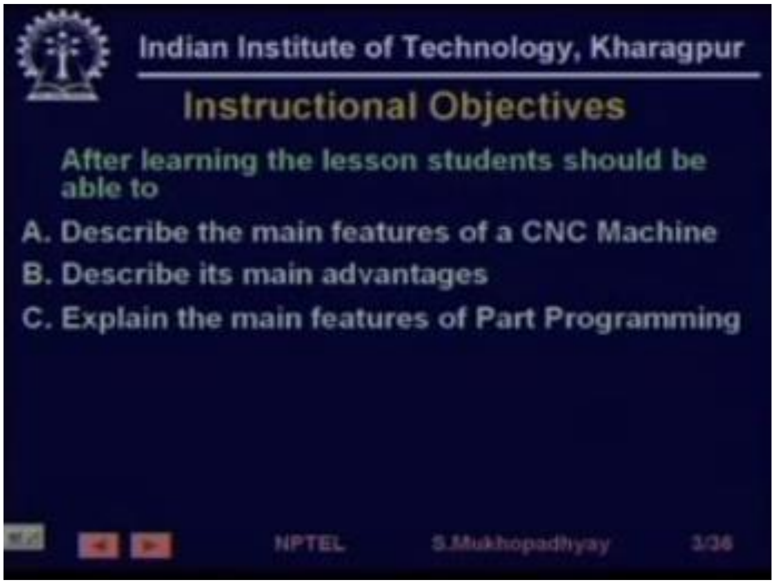

Instructional objectives of this lesson so after learning the lesson the student should be able to describe the main features of a CNC machine what makes it describe its main advantages why we should spend money to buy these machines they are very expensive explain the main features of part programming because these machines are automated they can be programmed so the programs are called part programs. So we will see some basic features of Part programming and finally the drives.

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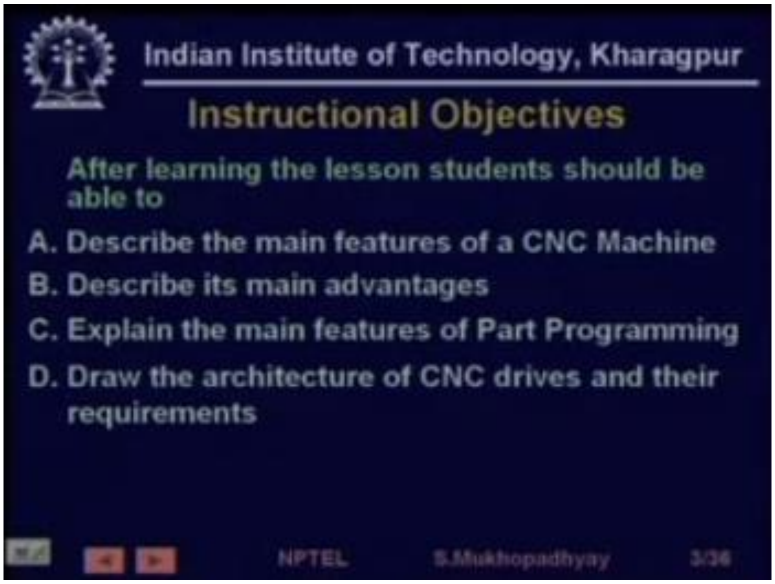

The CNC machines create motions always create motions machines especially which used for manufacturing so naturally they involve drives the technology which the generates the power and the control for creating precise motion against heavy loads so we will see their drives and we will see the requirements on the CNC drives. So that later on when we study the drive technology we can refer to that and we can we will see how these drives are actually realized using electrical machines power electronics and controls.

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So let us first look at a machining process right so basically in a machining process we are talking about manufacturing typically metal I mean metallic materials so essentially it is taking a piece of metal and removing metal from that precisely so that you get a part of a specific of specific geometric dimensions.

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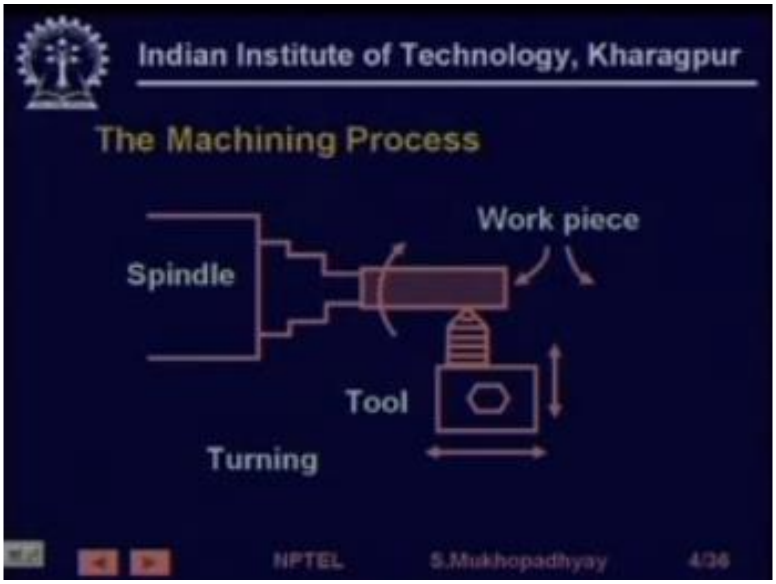

So essentially it is metal removal which means that they actually is removal by a tool which is made of very hard metal things like you know carbide diamond etcetera so essentially we have to you have to produce relative motion against off the job and the tool.

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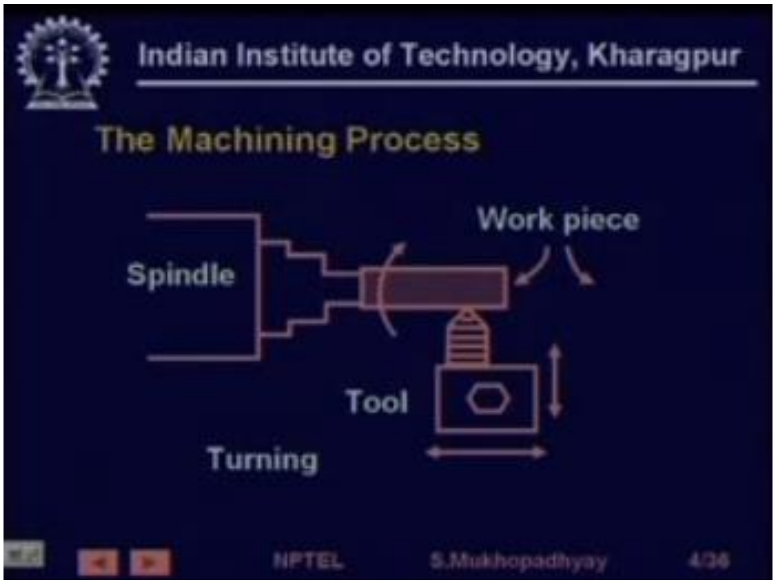

So there are various kinds of machining processes the most common is turning which we says which is seen lathes in lathe machine.

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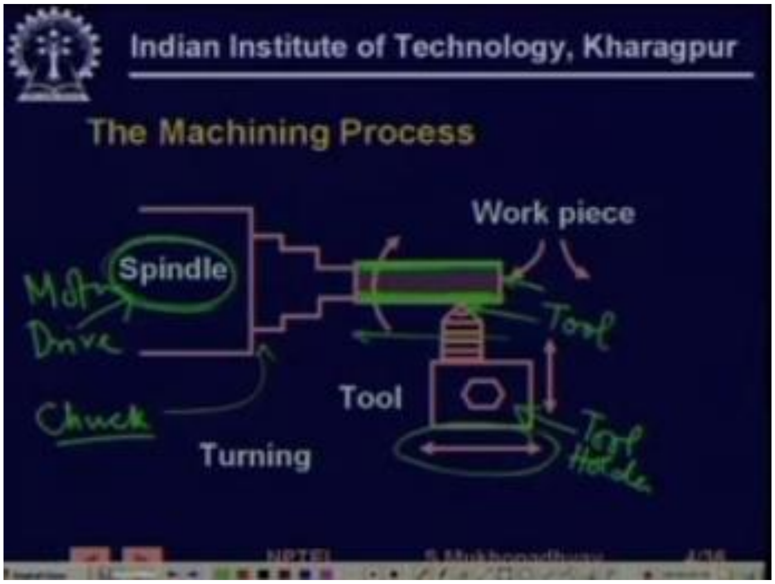

So in lathe machine what happens is that you have the this is the work piece which is held in a holding mechanism typically known as the chuck known as the chuck and the chuck is rotated by a spindle which is here there is a drive motor so you have a motor drive here and so the work piece is rotating and this is the tool holder which moves so the tool holder can move this with can move.

So therefore it for example it can be used to reduce the diameter of the work piece so as the this thing rotates and the tool moves from this end to that end with a certain degree of penetration so this much of metal will be removed from both sides so after the tool moves one cycle the diameter will get reduced to this right so this is the way turning produces.

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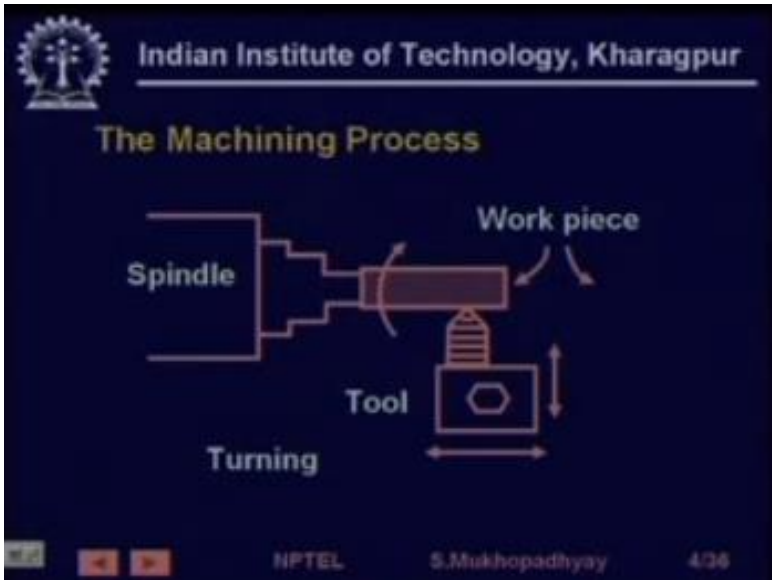

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Now then typically so in this case note that it is the work piece which is rotating driven by the spindle while it is the tool which is having rectally linear motion.

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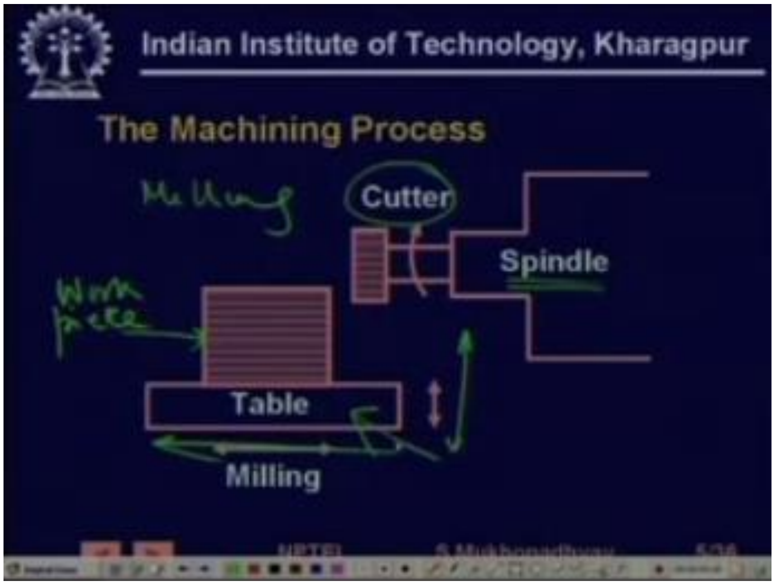

On the other hand if we take another machining process called meaning there you have a cutter so this is the milling cutter which has which has sharp teeth and which is driven by the spindle and it is the job this is the table this is the job work piece which is having rectilinear motion and generally two-dimensional rectilinear motion it can move this way that way and the table can move this way that way also.

So you can create two dimensional motion and the cutter is rotating and steady in one location so you see the compared to turning it is the interning it was the dwarf piece which was rotating here it is the tool which is rotating so it can happen both ways for example if you take another process called drilling so in a drilling also it is the work piece which is which has two dimensional motion and because you may like to drill a hole anywhere on the work piece.

On the other hand the work piece is rotating at generally at very high speed it is so it is rotating at the same time it can come down to actually drill a hole so the work piece in this case is capable of it has a high speed rotation it can also move along one axis whether the what rather the tool can move along one axis and while rotating and the and the job can move in half rectilinear motion have motion a two dimensional motion right.

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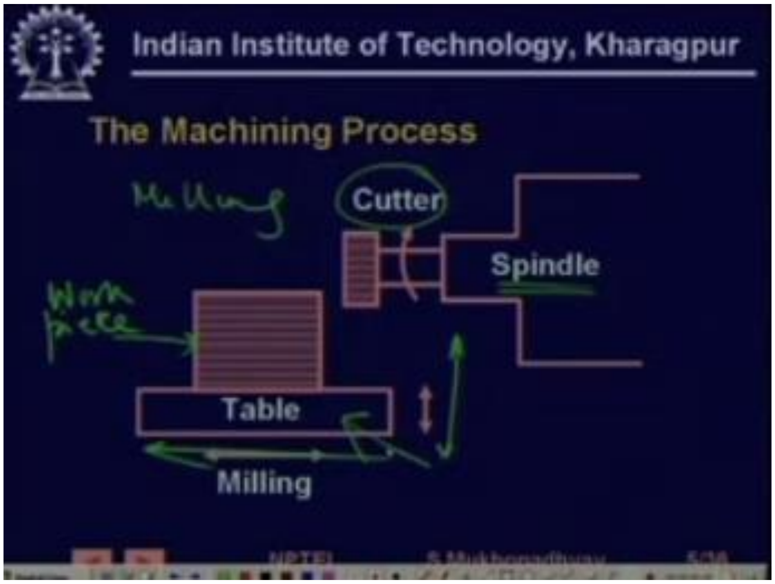

So which means so this shows that the kind that any cut metal cutting machine would require motion for the tool and would require motion for the work piece.

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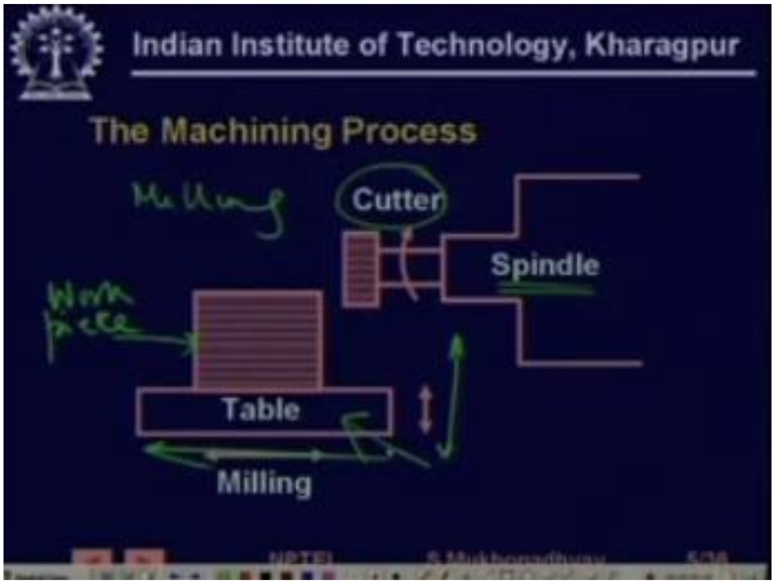

And these motions naturally have to be very sighs number two is that for quick cutting there has to be a so these are generally parameterized by you know quantities like.

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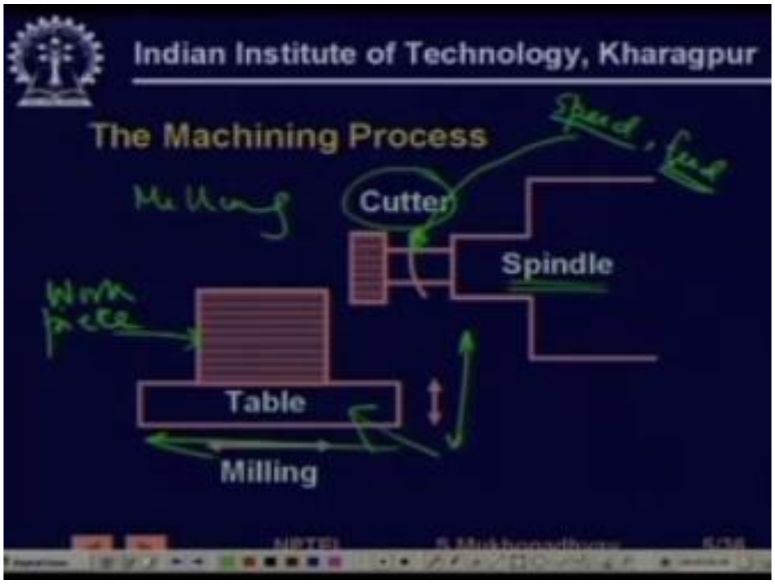

Speed which shows which is related to the cutting speed of the rotating body then it could be then there is something called feed so feed means that the stroke of the it can be the linear motion of the tool in the case of so per rotation by how much does the tool move in the case of turning or by how much does a job move in the case of milling or depth of cart.

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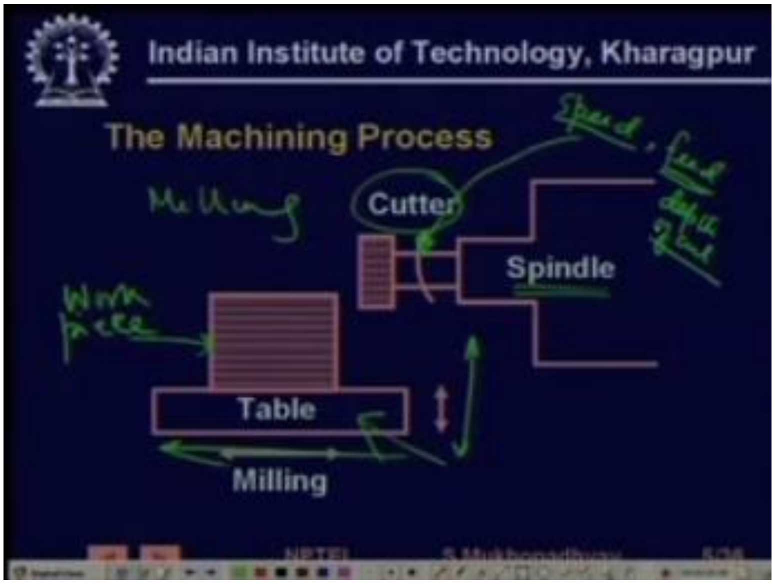

So how much in one complete cycle of motion how much material how much depth of material is removed.

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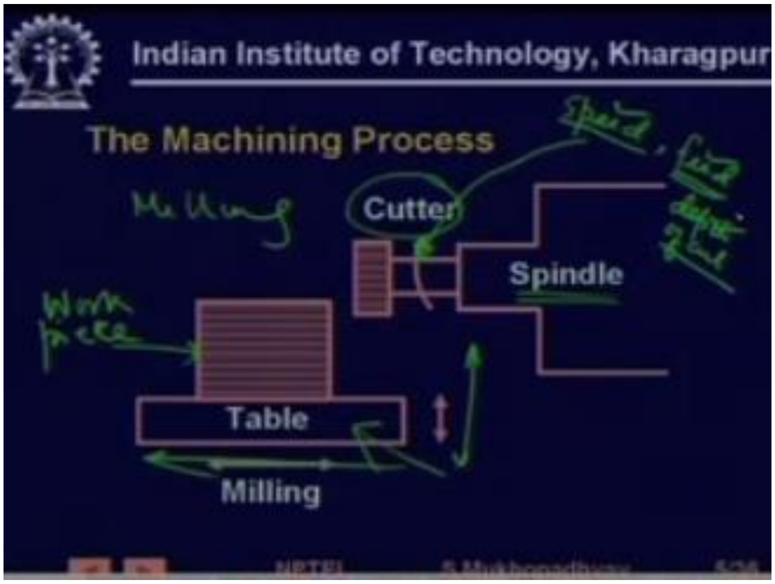

So such parameters are set typically in such machines and naturally you can understand that even if we if you want very good surface finish we generally have to we cannot give very high depth of cut but so for rough cuts we can for quick production we can give high depth of cuts and high feeds so naturally that will you are removing metal like steel so naturally it puts a lot of load on the drive. So the idea is to create con very precise motions against very high loads.

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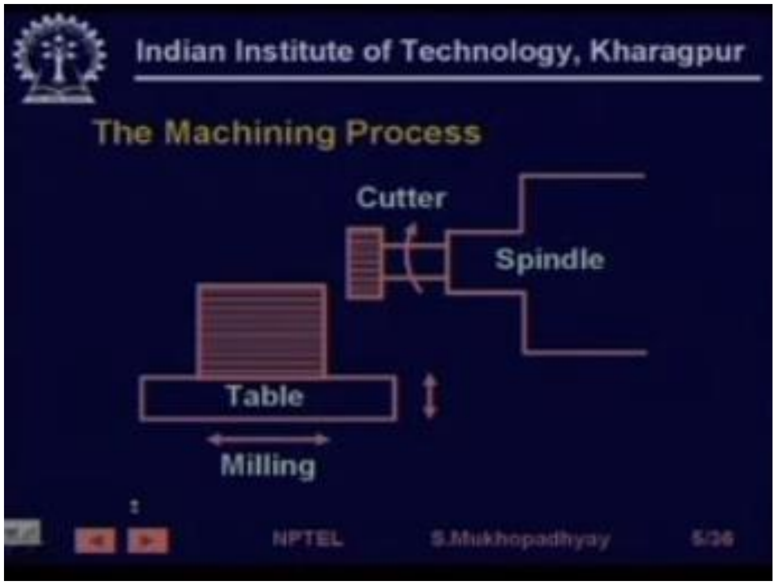

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So the work piece this shows typically show this is this shows how the movement is created so the rotating is rotation is actually very simple it is just connected to the shaft of the spindle drive motor so as the motor rotates the tool in the case of milling or the work piece in the or the chuck in the case of turning will rotate that is very simple.

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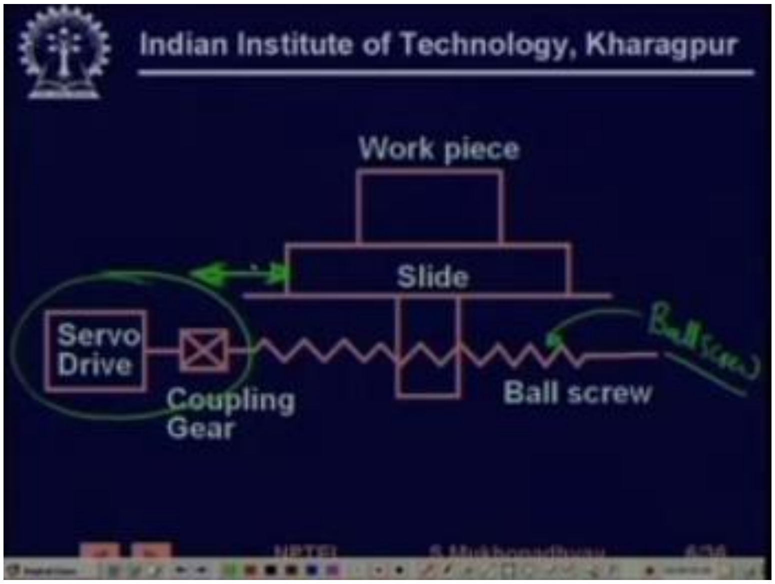

For the two for creating the two-dimensional motion of the table this kind of a mechanism is created where there is a slide so this slide can we are we are only show showing motion in one direction so this in this direction slide is slide can move along this because it is connected to what is known as a ball screw so this is a ball screw so the drive is still a motor so there is a motor which is coupled to the ball screw maybe through a gear.

So as the ball screw rotates this slide can move this where that we just like a screw motion and this wall screws are very well designed such that that is the precise motion is created and things like backlash which affect the accuracy of manufacturing are minimized and they can be minimized they are actually minimized by engineering design and whatever remains can be also mostly compensated in these machines.

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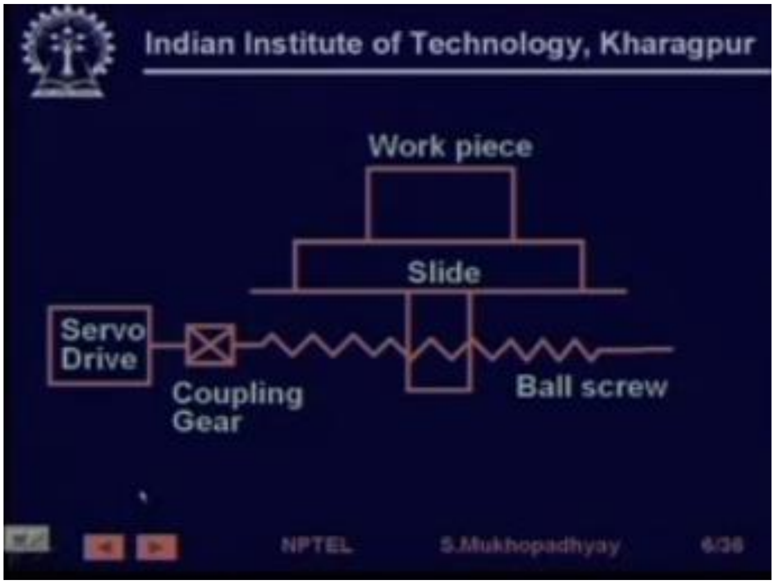

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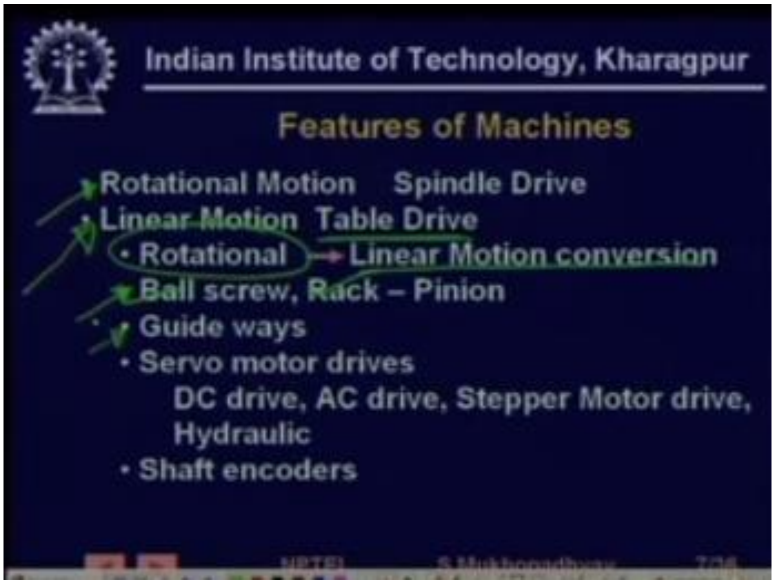

So to summarize if you look at the feature of the machine then we have to create rotational motion which is created by the spindle drive we have to create linear motion which is created by the table drive and in the table drive basically the drive is rotational there is a linear motion conversion using ball screw or rack pinion generally ball screw gives better accuracy and guide ways.

So that the there is no transverse motion motions are strictly in the direction in which the drive is provided.

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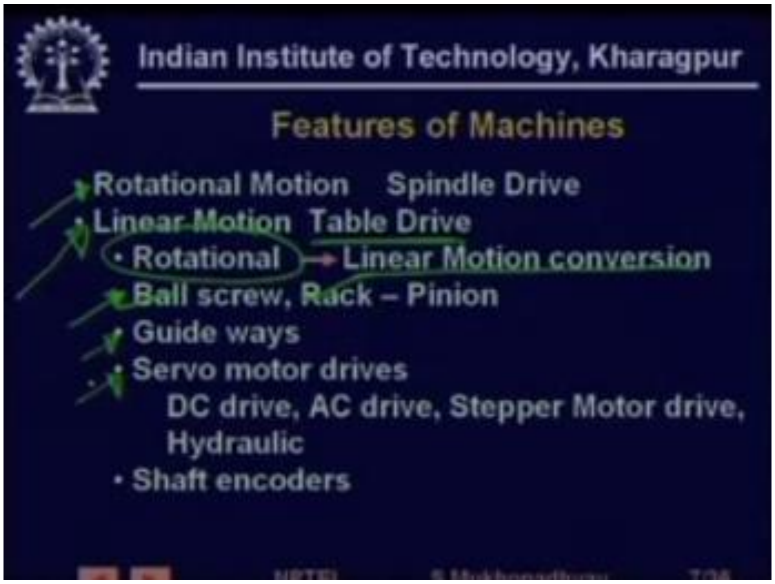

This drives that are you employed are generally servo motor drives because you need to have precise motion control and you need to have good transient response because drives have to be very precise position control is required so therefore they have to start and stop at the right moments and sometimes even speed ratios have to be maintained along the two axis for cutting you know things like surfaces says cylindrical surfaces or cutting like cutting corners.

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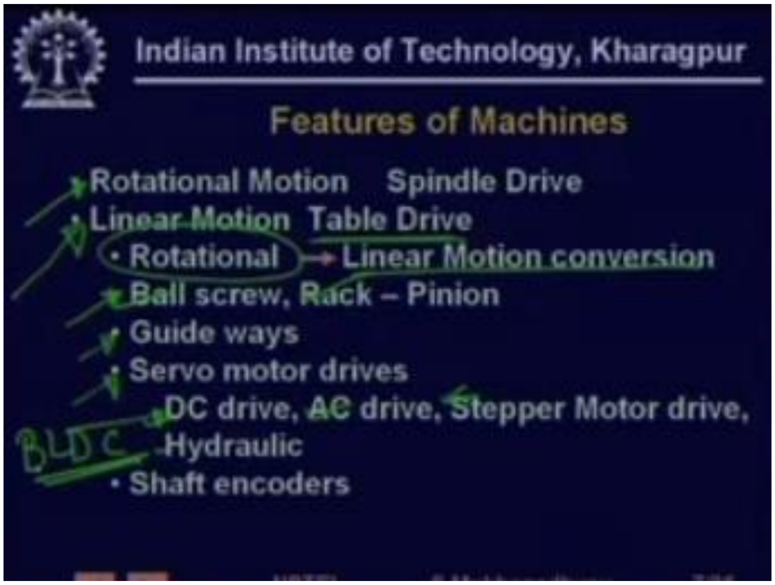

So we employ servomotor drives DC drives stepper motor or AC drives for very large machines you can have hydraulic drives also but generally we employ DC and AC drives for very small things stepper drives are used but they are generally not of that high rating so therefore DC and AC drives are generally used mostly DC drives DC and BLDC drives brushless DC so we will see these drives in detail in some more detail in our lessons on drives. Then you naturally you need feedback so you have.

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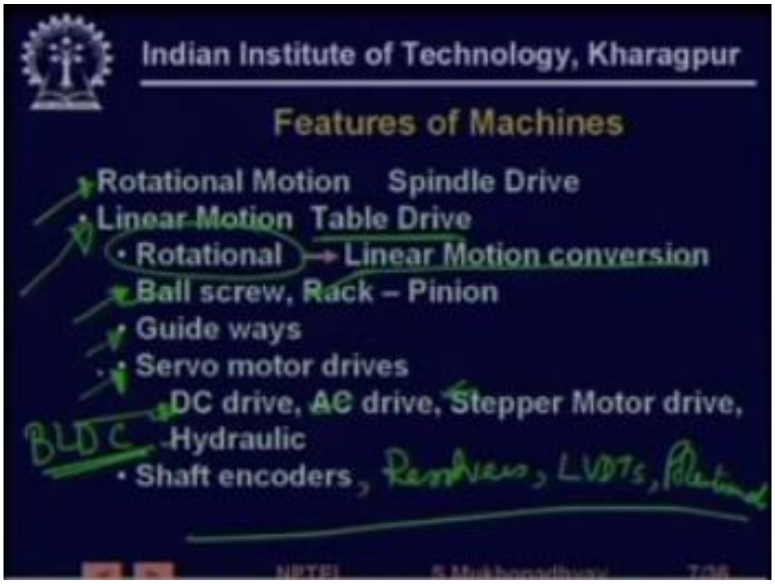

You know digital feedbacks like shaft and cad encoders or you can have resolvers sometimes you can have position sensor like LVDTs or potentiometers etcetera, so you need basically you have to create rotationally precise motion so you need precise drives to created by motors and you need speed and position feedback so they are provided by the sensors and similarly you have mechanical arrangements which create precise motion like balls crew etcetera.

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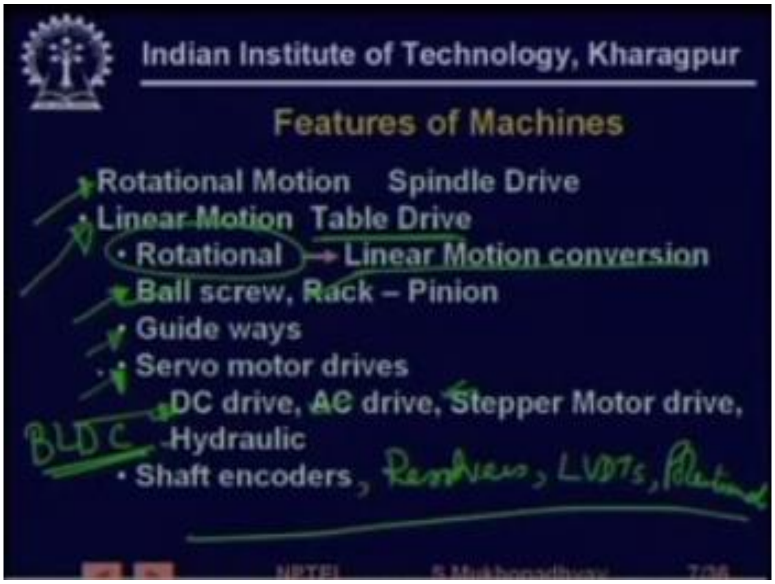

So this, these are the major parts in the machine.

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Of course there are various kinds of auxiliary parts like for example there is you know there is very high heat generation at the tool work piece interface so there so there is cooling coolant has to be applied liquid coolant has to be applied directly at the 12g of interface so that the interface does not heat up because that will affect the quality of machining, so there is a coolant + there are all kinds of other things like you know for automation there are there is whole automation setups where for somebody can enter program so there is an operator display they are all kinds of protection mechanisms so they are there the auxiliary components.

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Such as power.

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So actually these machines it was soon developed the dough soon understood that there is a lot of things to be gained if we can control the machines precisely using you know digital techniques and finally by computer like components like especially micro processors can be interfaced to it so this kind of controllers would lead to very precise control of the machine which is not possible generally not possible by a manual operator.

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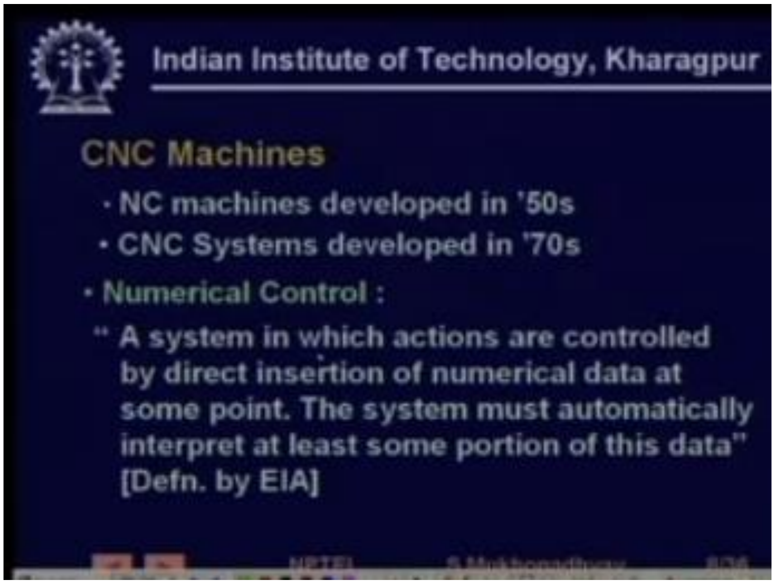

So it will soon realize that these systems can lead to very high quality engineering and also reduce unproductive time now this term numerical control has been defined by a by the EIA as a system in which actions are controlled by direct insertion of numerical data at some point so at some point numerical data must be used to control the Machine and the system must automatically interpret at least some portion of this data.

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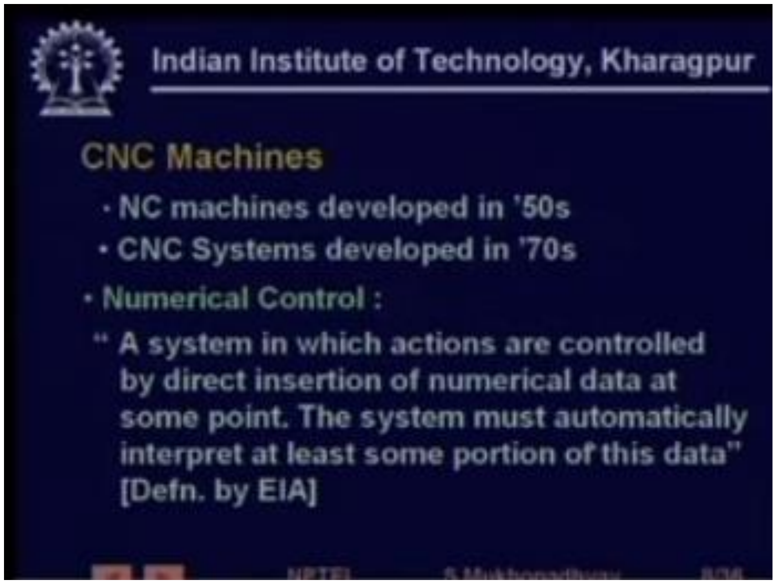

So even if you do not have a computer you can have a paper punch card reader they are there you know the ordinary they were the early versions of the CNC machines so even if you have so you have a you know paper tape which is punched and there is to be a paper tape reader and that reader is to create the motion so even if there is no explicit electronic computer here also in the paper tape you are there is some numeric data which is punched and according to that numeric data the machine was control that is why it is called numeric control.

But but in modern machines these things do not exist at all modern machines are all computer-controlled so basically computer numerically controlled means that computer control so it can be a it is generally a microprocessor it may be it may be a industrial PC sometimes it there will be a PLC so various kinds of industrial computers are used.

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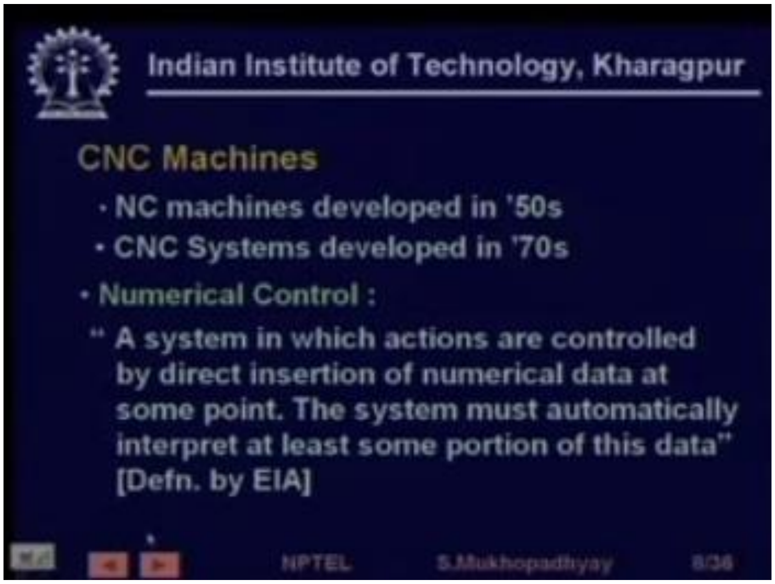

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So it basically is meant to replace manual actions of operators and so the instructions to the machine which are required for its operation are written in the form of a kind of program called part programs we describe the activities which are interpreted and executed by the machines so we will see little later what kind of things can be done using part programs.

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Typically you know this case the CNC machines are very expensive so it is not that everybody can afford it or that for every kind of manufacturing operation one has to procure a CNC so CMC will be good.

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For parts process frequently in small lots because if you process parts frequently in small lots then you will if you do not use automation then you are going to end up spending a lot of time by lot of set-up time so every time you have a new lot you will spend a good amount of time in setting up then you will manufacture since the lots are small so you are going to manufacture a little while and then again you have to spend time in setup so the actual productive time of a machine.

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Which is just the time when it cuts the metal is actually reduced so therefore the CNC machine is suitable for this because it cuts down that set of time significantly using automation.

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Whether part geometry is complex so you do not have to really rely on the operator skill you have you have to just write a, you have to just produce a correct part program and if the part program is correct then the machine being automated will absolutely correctly will produce that geometry irrespective of the operator skill.

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Tolerances are closed because the kind of controls that you apply the kind of controls that you apply are so sophisticated that it is not possible for manual operators to apply such control and therefore very high compliance to the tolerances can be realized.

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When there are several operations needed on the part again it is rated to set up time you may need to you may need to have various kinds of tools working on that so therefore again you will lose a lot of time by you know changing tools while with things like technologies like automatic tool changes and wide variety of tool magazines these this tool changing is generally achieved very efficiently in CNC machines.

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And parts are expensive because when parts are expensive you do not like to take a chance that due to faulty manufacturing some part will get wasted so that is why you take help of a machine which once it is set up properly it will go on working and producing the parts without any mistake or failure.

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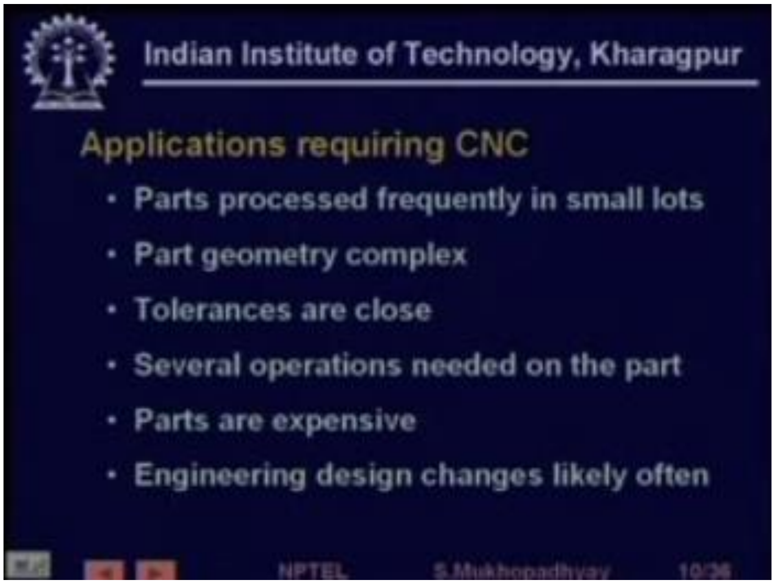

When engineering design changes are again lightly again this is also related to set-up time so you see that there are basically two points one is situations where a good amount of set-up time is required and secondly where situations have situations where very high skills took to cater to complex geometry and close tolerances are required so it is during these for these two reasons that CNCs score over non CNC machines or manually operated machines.

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So from advantages disadvantages you have flexibility is one advantage which is achieved by programming in so you can easily change up just change a program and your whole setup will get changed.

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Are you going to pre-stored programs which can we just need to be loaded which is a much faster operation disadvantages and roscoe accuracy flexibility and accuracy disadvantage corresponding disadvantages could be one is one is cost so there is a these machines are very expensive and they have very high costs and maintenance.

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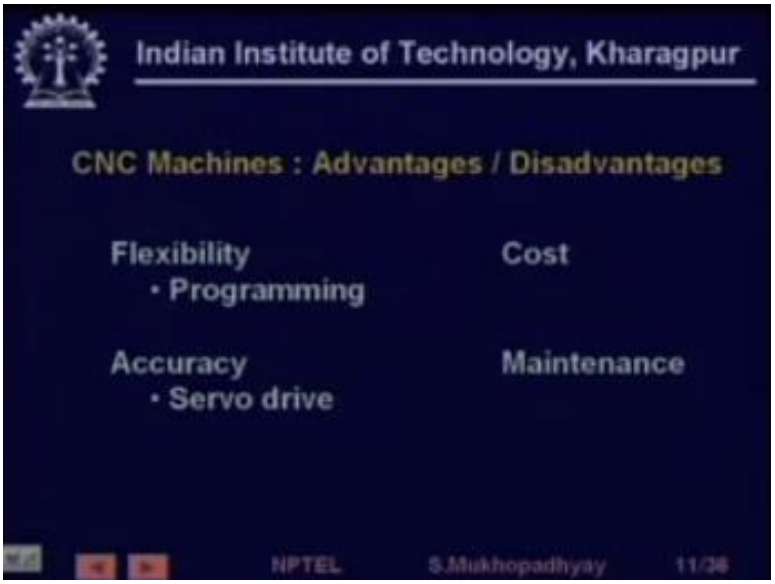

So you need very expert maintenance for this machine because if they are not maintained properly then they are going to be damaged and then finally they will lose their accuracy and things like that.

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So what all productivity is much improved we do to reduce set of time automated tool changing which is again reduce the set-up time I mean unproductive time sometimes some of these machines will have inherent material handling so if you want to change a tool the machine will stop the machine take out the tool put it in the tool bag as a zing bring out another tool so all these material handling work will be done by the machine itself.

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Scrap rate is reduced because you must have it is assumed that the part programs are written with carefully using scientific you know optimization methods so from a given piece of material because you are not going to you have much more precise operation so you can have optimal material utilization therefore scrap rate will be reduced manpower is reduced because much of it much of the work in these machines can done automatically.

Sometimes you know you program a machine for a day and feed it with enough work material once at a time and then run it whole day without any kind of supervision or any kind of operating personal this these machines can go on manufacturing one of one after the other the parts they have reduced downtime because they are these are the benefits that you get by paying that high sum of money for its cost.

So downtime is reduced because these machines are very well made their engineering is very strong on the other hand the disadvantage is that their operation of these machines and maintenance required very highly skilled operator not only just skilled in operation but in various other kinds of technologies for example part program writing etcetera they may require skilled operators.

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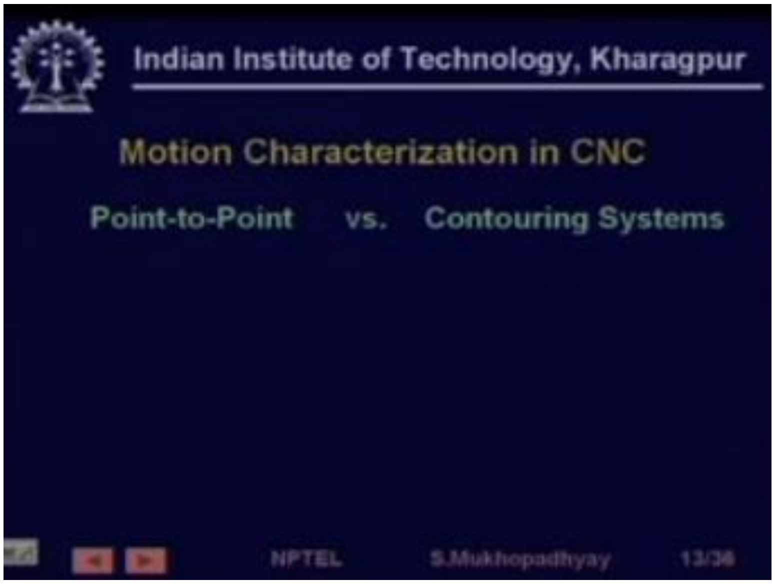

So these are the so we have seen that CNC machines in many situations are amply justified so now we will see that what kind of motions these CNCs can be created such that you know automatically parts can be manufacture there are generally two kinds of machines one kind of machines are.

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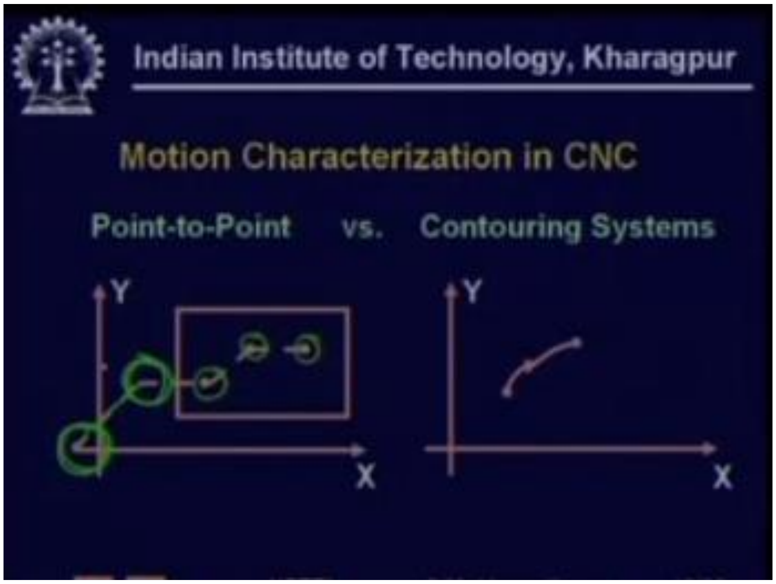

Capable of having making point-to-point motions so typically used in drilling so you say that drill a hole here then I hold here then a hole here, here and here so this is so you are just specifying certain points so the machine is coming to a point bring a certain operation then again going to another point and go doing another operation so the operation that the machines are doing are essentially point operations like drilling. On the other hand you can have systems where you can specify the.

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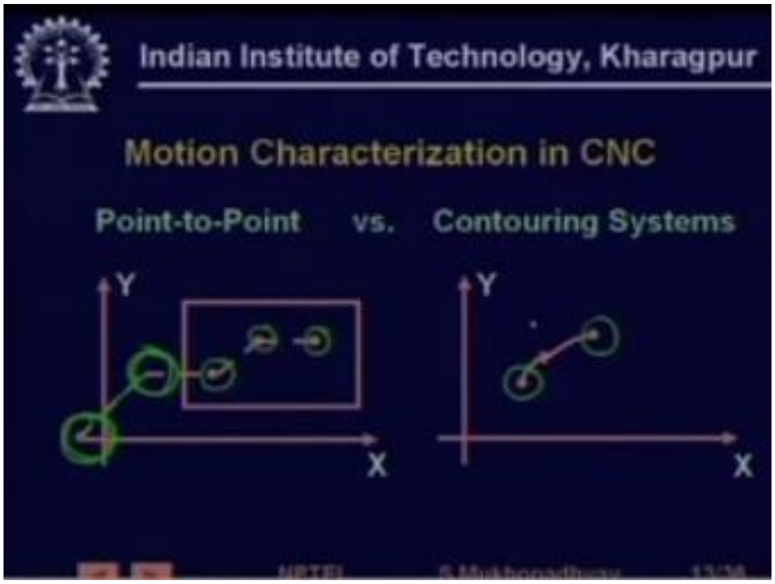

Start points in the coordinate space the endpoint and then specify some kind of interpolation let us say a circular interpolation.

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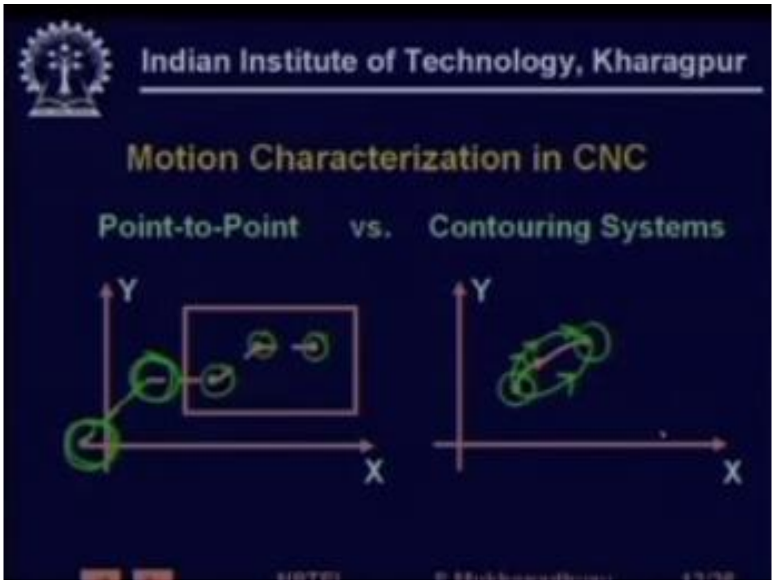

So the machine will start from here and depending on your instruction will cut an arc suppose you are talking about circular interpolation will cut an arc from here to here or it could also cut an arc it could also cut an arc between these two points so that depends on what you have specified.

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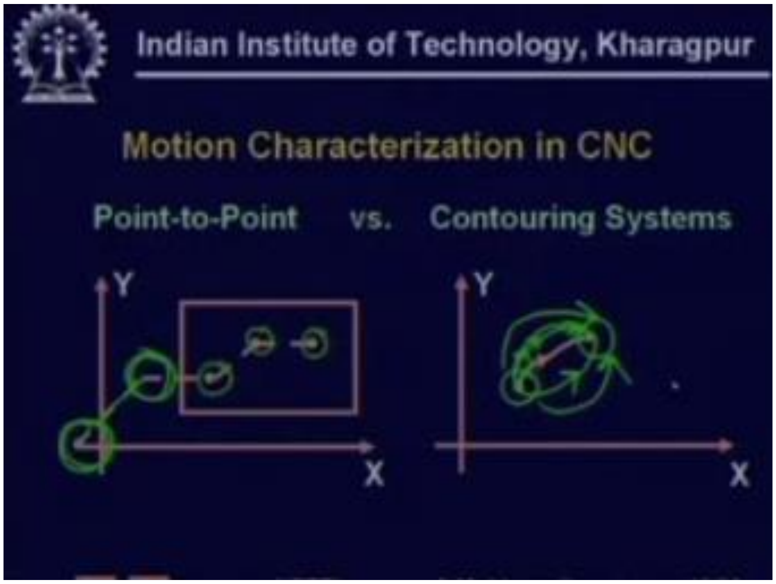

If you are specified if you are specified a clockwise arc then this will be drawn if you are specified an anti-clockwise arc then this will be this will be cut so these are called contouring systems you can note that here the controlled cutting goes on throughout the journey and to be able to achieve certain kinds of profiles like a circle the X and Y axis drives for the table has to be very coordinated to be able to get that cannot do it.

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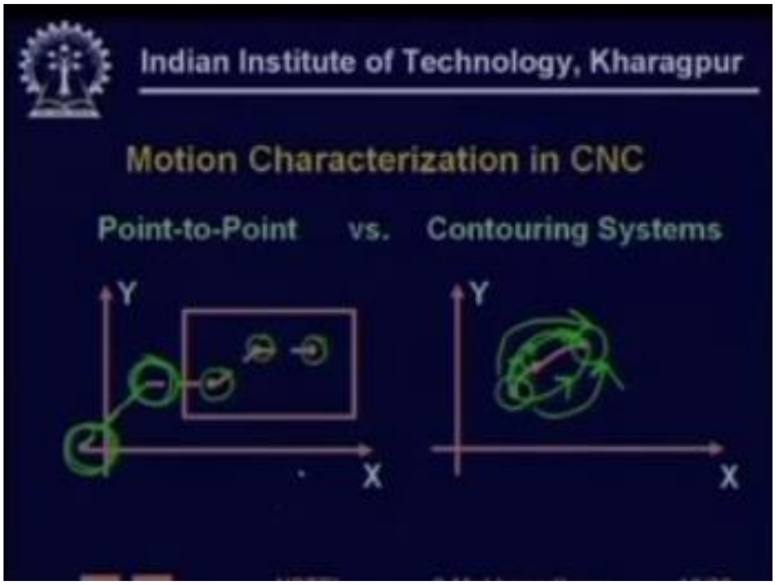

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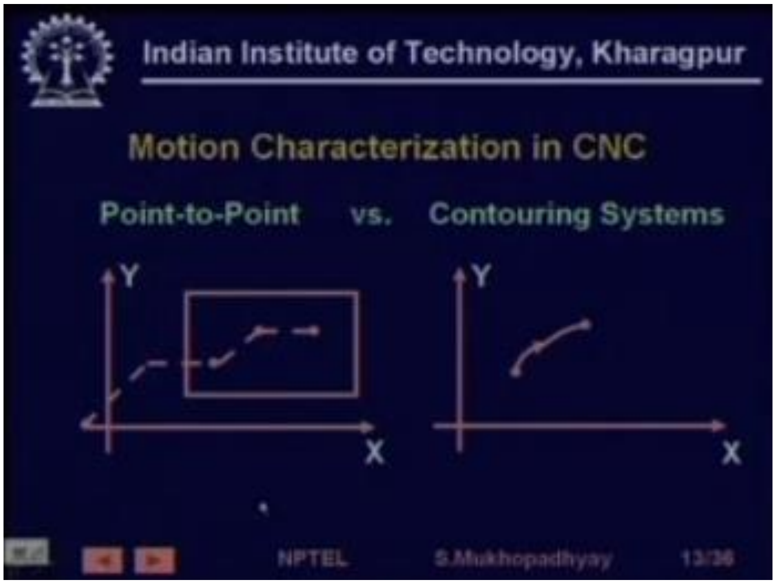

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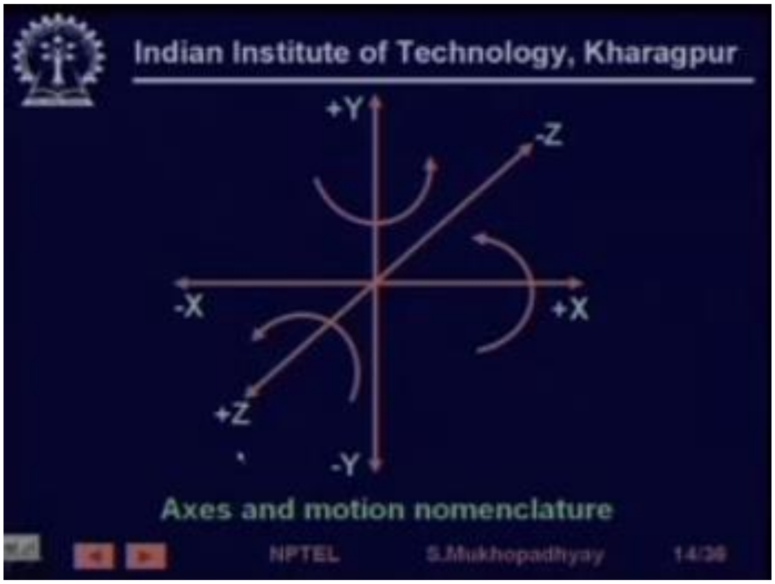

So it is fundamental to define coordinate systems because all the part program instructions are given most of them are involved especially the main cutting instructions part program instruction all involved you know various coordinate so the coordinate space is actually very simple.

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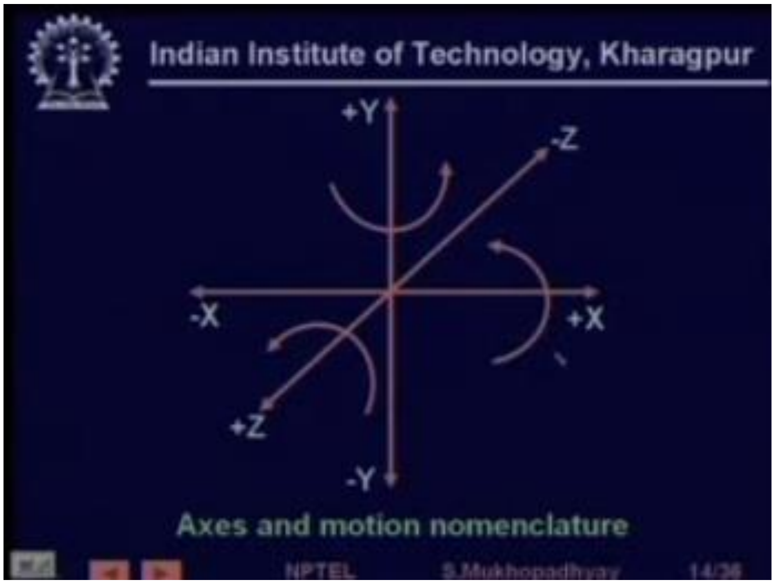

So this is like a no x I am sorry.

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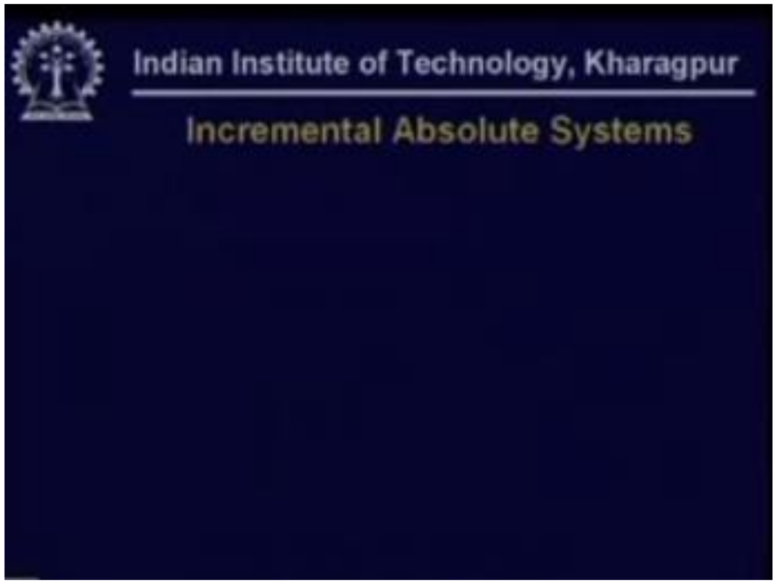

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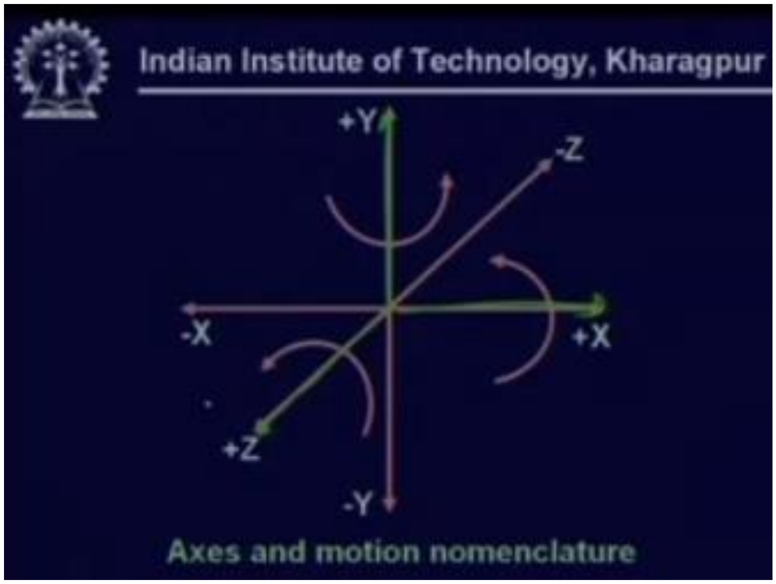

So it is like X in this direction Y in this direction a right handed coordinate system so therefore Z will be the vertical direction and therefore you can also have you can also similarly define rotational direction so if you take again a right-handed system.

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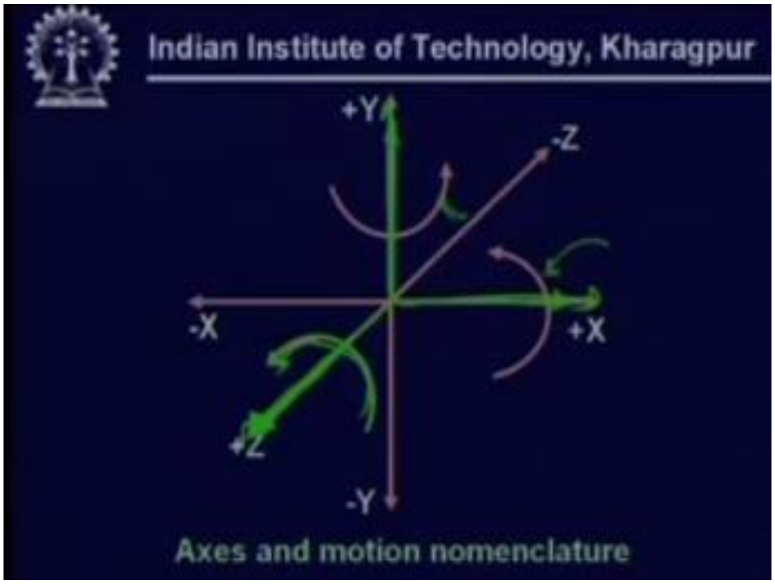

Then if you curl your fingers around this then the positive direction this direction is positive which where the thumb will point towards the positive their axis so these are given according to that so these will be positive rotations and these will be positive translations.

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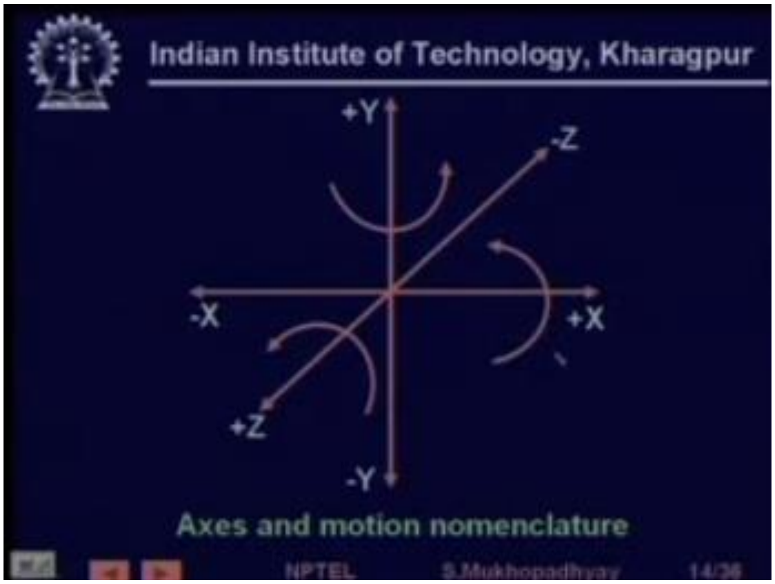

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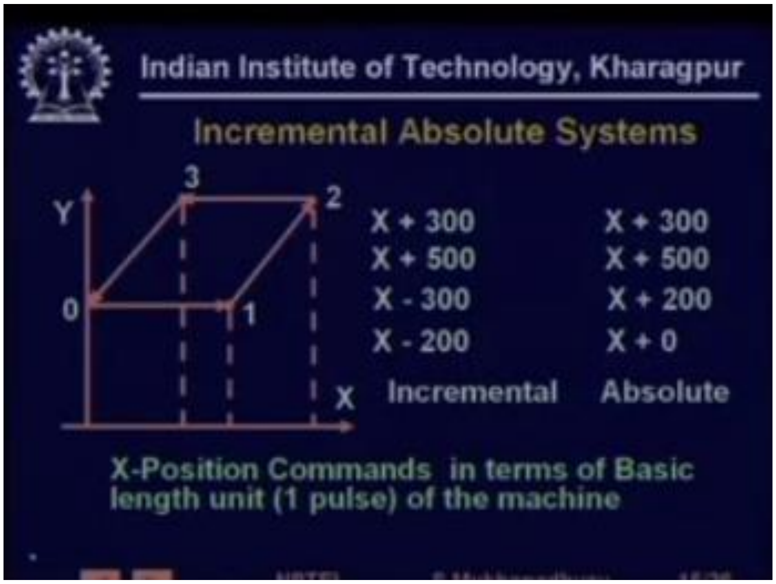

Then all these you know points and coordinates which are mentioned are can be mentioned in two ways one is an incremental or an absolute system.

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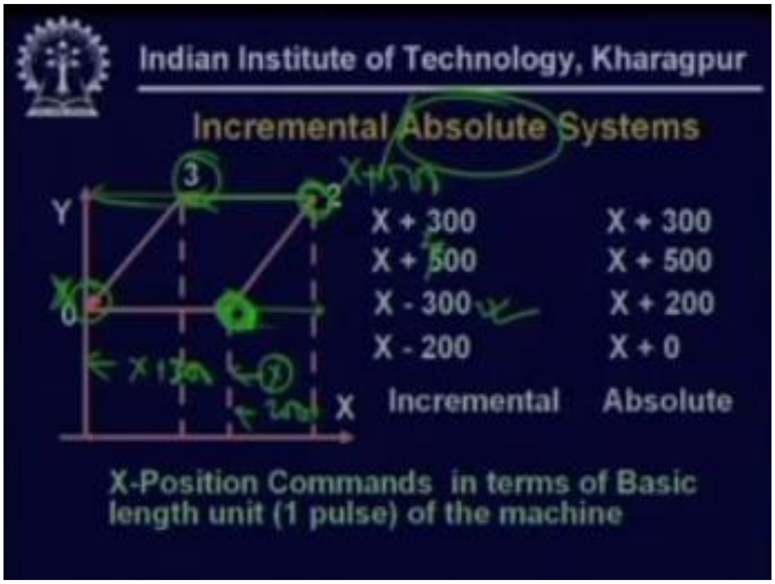

Generally the absolute system is preferred so you see that if you want to specify the x axis coordinates of these four points then in the incremental system you will say suppose this is X here the x coordinate is X so this is going to be say X + 300 similarly this is going to be and once you have done X + 300 now your current position is at one so now X is the X coordinate of this point in X + 300and the coordinate of this point is X + 500.

So in the incremental system you always do it from the current point so the current point is here so this is going to be 200 so therefore the next instruction to the machine will be X + 300 actually this should have been200 so X + 300 X + 200 then X then you have come to this point and then if you want to go to three then you have to do X minus 300 and then from three to one you have to do X minus 200 so you have to go this way.

On the other hand if you are using absolute then you just always do it from a stationary origin that you have assumed in the coordinate space of the machine.

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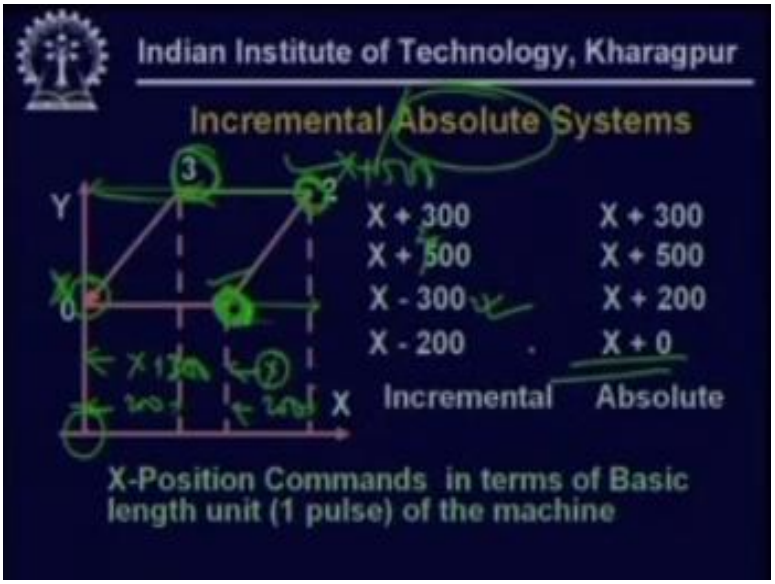

So this is going to be so the four coordinates are going to be X + 300 x + 500, 300 + 200 is 500 and then this is again X + 200because this is 200 and then finally X, now why the absolute system is preferred because suppose you are trying to hold a drill at these locations.

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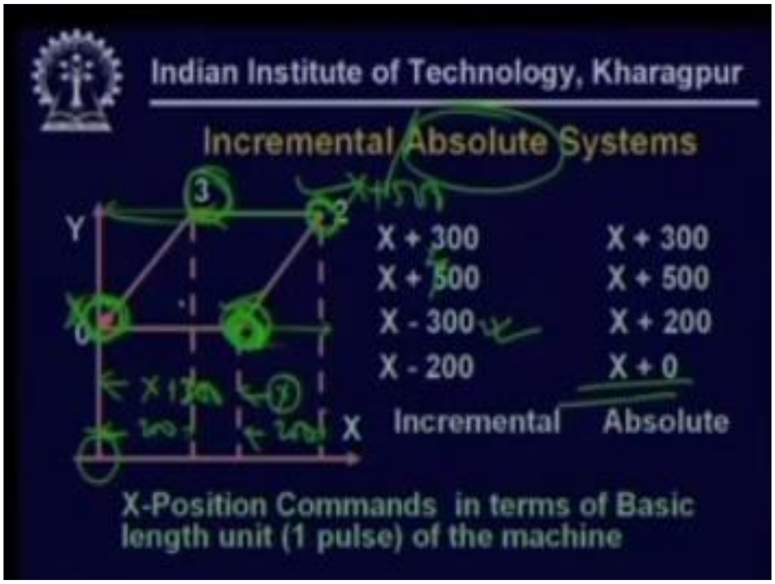

So even if this location is in error this location will not be if it is an absolute system but if it is an incremental system then if at one point the geometric coordinates are not the same then there is a high chance that all other geometric coordinates will also get affected if the system of providing coordinates is incremental and this exposition.

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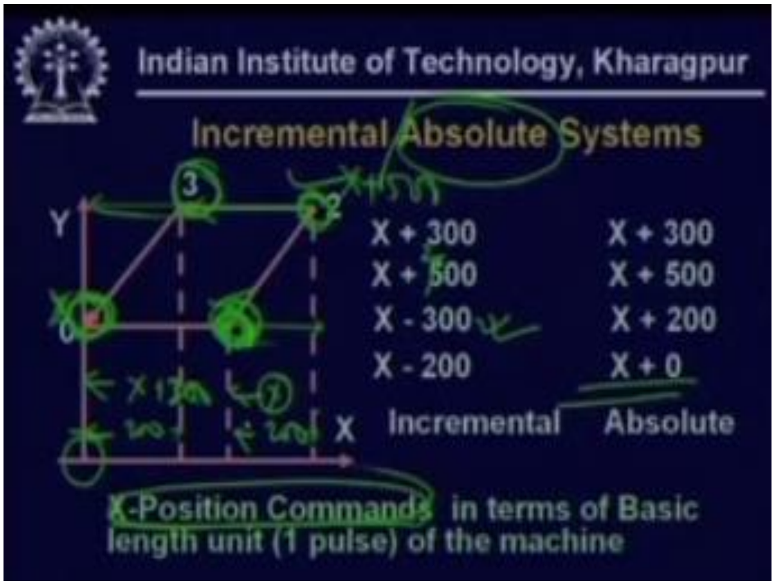

There will also be a unit so the expositions that are meant that will be typically mentioned are generally mentioned in terms of what is known as a basic length unit.

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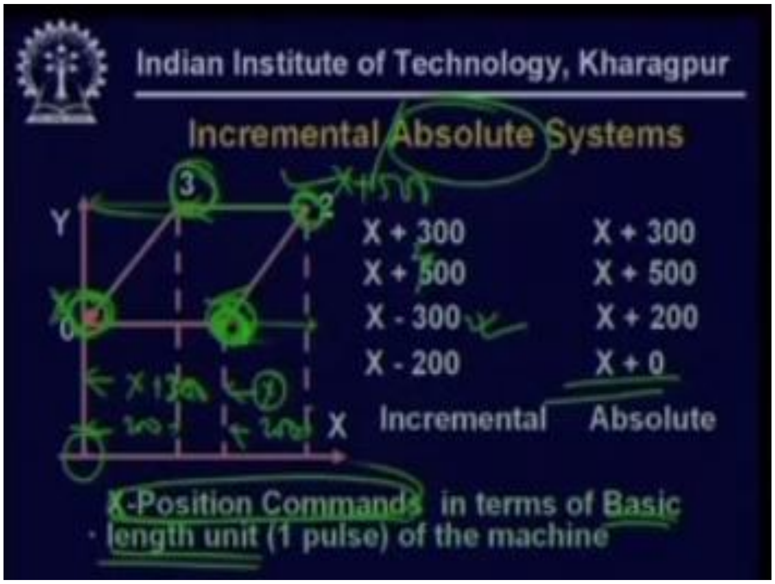

So a basic you length unit is the suppose you have a shaft encoder so the shaft encoder gives say.

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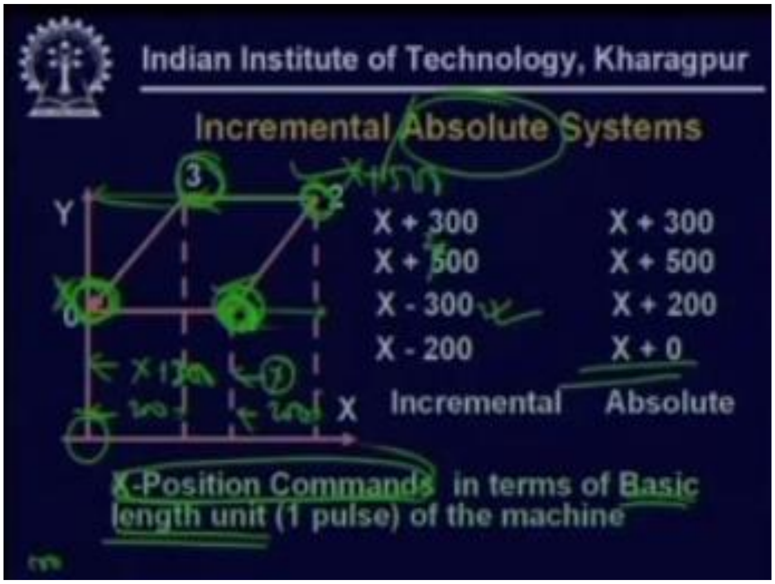

500 pulses per revolution let us do this.

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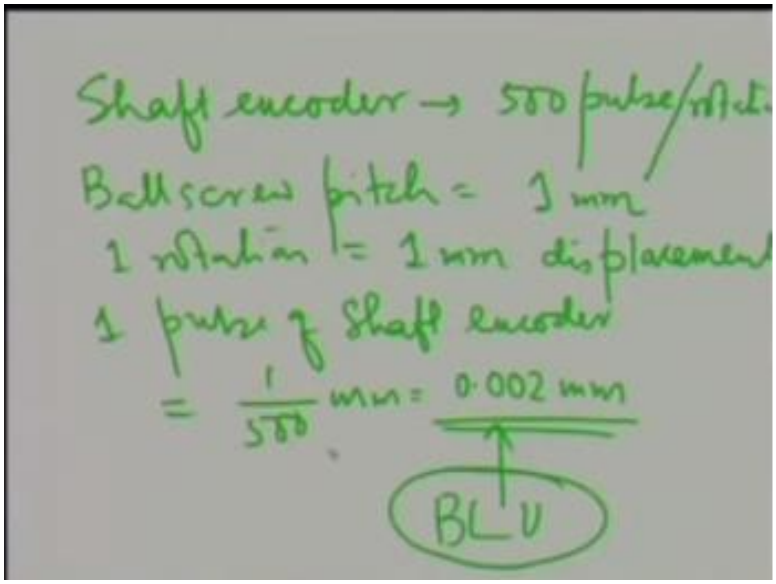

To understand what is the basic length unit so suppose shaft encoder gives 500 pulses per revel rotation on the other hand the ball screw or the ball screw pitch is say 1 mm so one rotation is equal to1 mm advancement 1 mm displacement so now one pulse of shaft encoder is equal to 1/500mm = 0.002mm right, so this is the basic length unit this is the smallest unit of displacement that this is the smallest displacement that the machine can be aware of because this will be one pulse.

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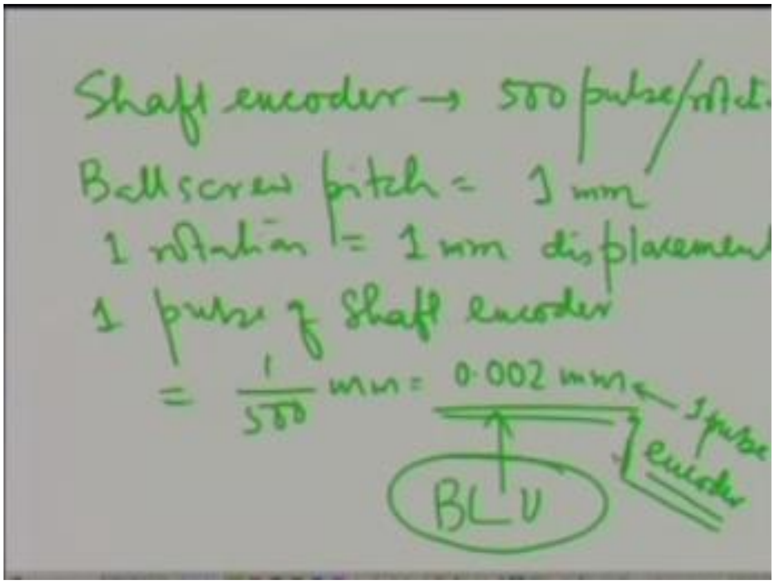

Of encoder so that is the smallest and that is called the basic length units all these can generally stated in terms of the basic length unit.

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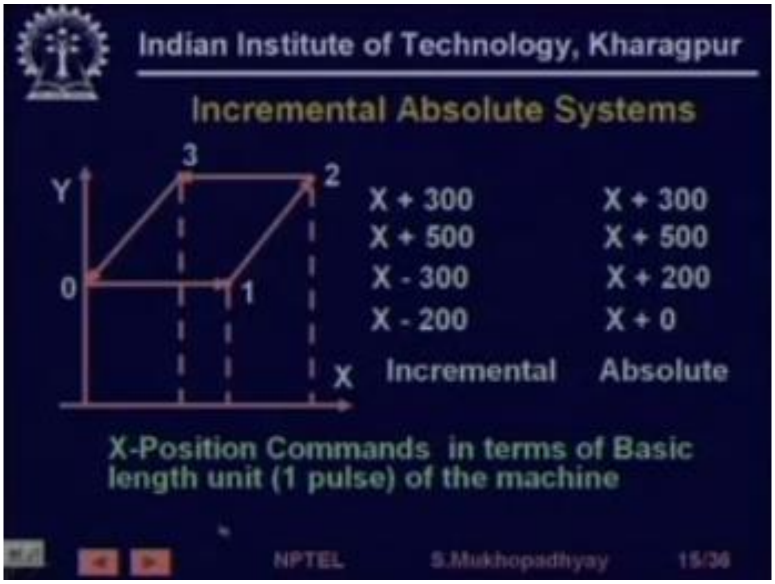

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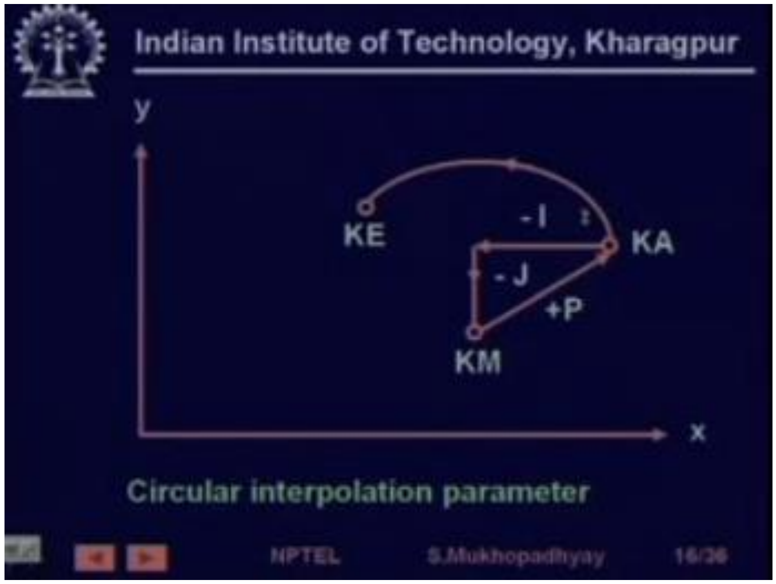

Similarly if you have circular interpolation then you have to ask give the start time and sorry.

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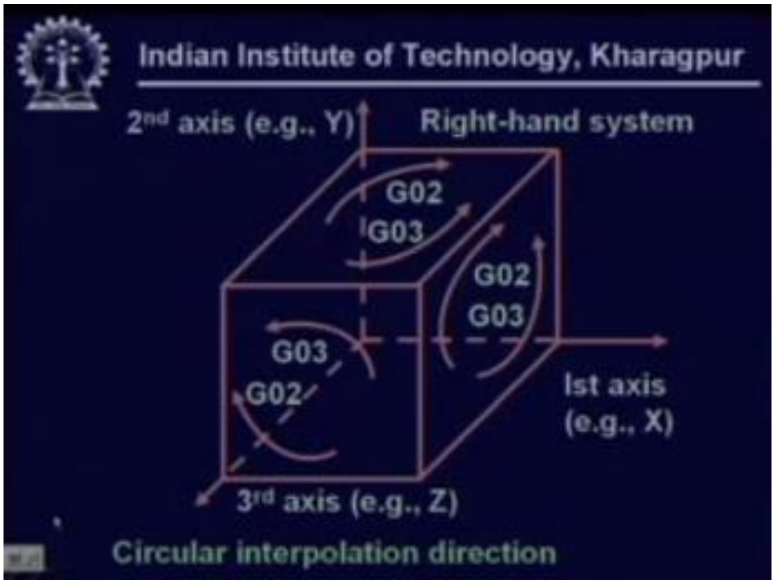

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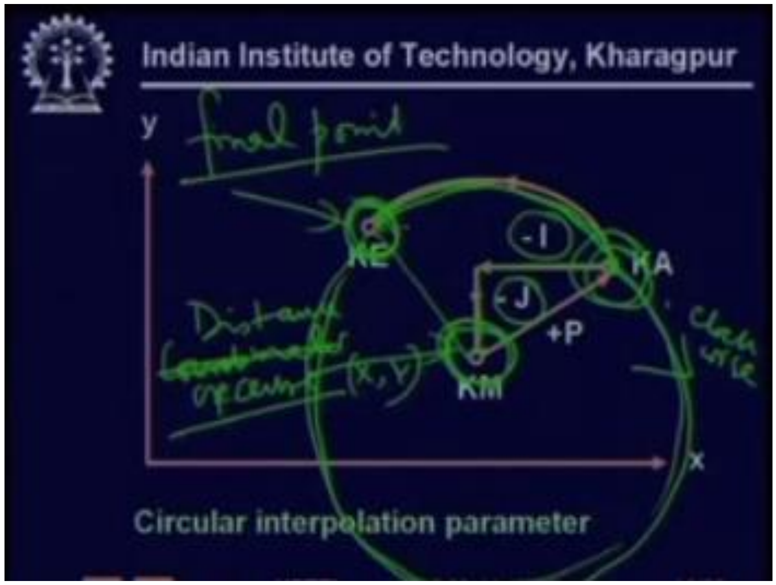

So you have to give the start coordinate you have to give the end coordinate and you have to give that this is going to be a circular arc so you have to give the coordinate of the center of center or rather the distance not coordinate distance of off center of X and Y and you can sometimes you are also given if this is given you should be able to draw the circle sometimes you know the final point is given so this is the final point.

So given these you can try to and taking this as center we have to draw a circular arc and take the tool along this circular arc so this is the way typically the circle parameters are specified so this I and J will give the coordinate of the circle this K and KE will give the two endpoints and then you know you can either you can draw the circle like this also so whether you will this is start so if you want to draw this circle then you will go this way which is clockwise if you wanted to draw this circle then you will go anti-clockwise.

So it needs to be mentioned whether the circle has to be drawn in clockwise or anti-clock wise direction accordingly.

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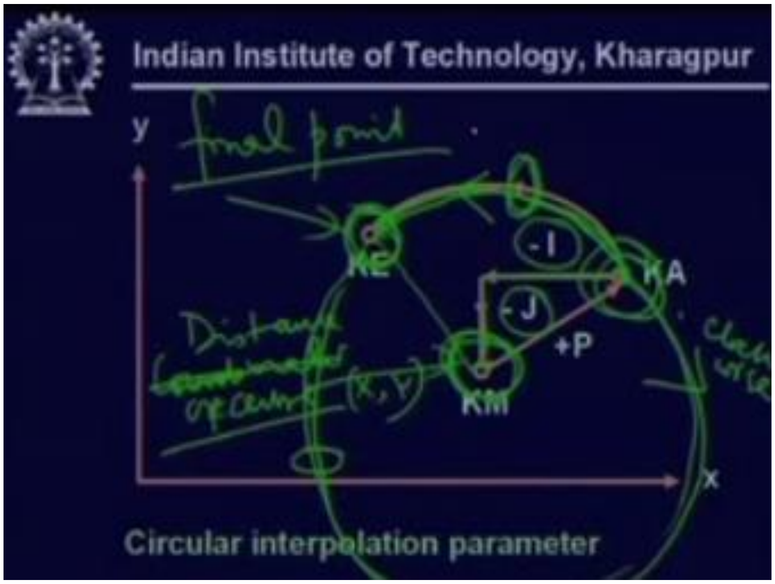

Either this one or this one will be manufactured.

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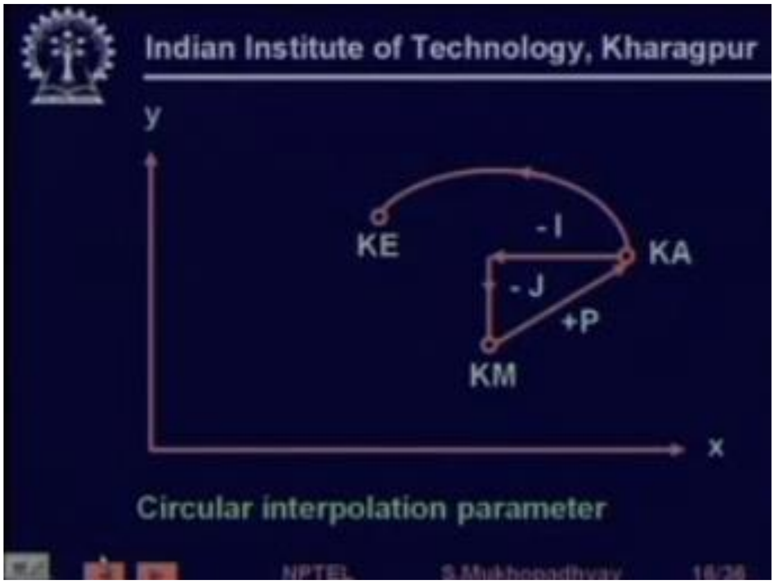

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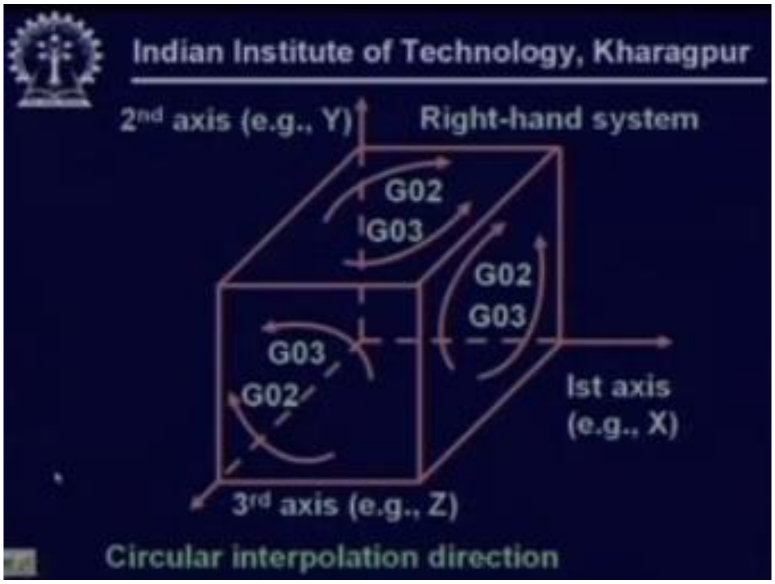

So these are the various you know circular interpolation directions, so along the various axis.