Mechanics of Machining

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Lecture – 19
CNC Machines and CNC Programming

Hello students, welcome to the course on Mechanics of Machining. Till now we have understood many basic fundamentals of machining. And in this 19th lecture, we are going to a study about CNC machines and CNC programming. CNC means Computer Numerical Control.

What is computer numerical control? See, earlier you know that in machine tools, there is operator, who does everything, he decides that how the tools should move from one place to another place alright, the job rotation etcetera is done by motors. Even the feed motion may also take by reading motor, but operator will control. He decides that when machine should be started, when it should be stopped at how much distance after traveling, how much distance I should stop it, he selects the feed and everything.

And naturally, he should be always present on the machine that usually if the even if there is a provision for automatic feed, usually the operator is there. Once the tool movement tool may move automatically, because he has engaged automatic feed, but at certain distance, it will it has to be stopped. So, operator will stop it, and then only the machine will be ready for the next operation. So, all these operations are controlled by human beings.

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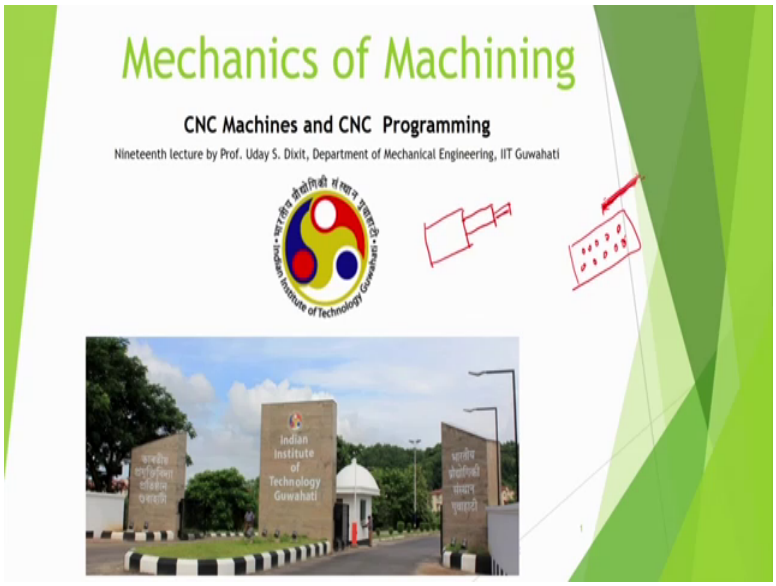

Now, people started thinking of removing the need of the where is skilled operator, so numerical control came in beginning around 50s. Now, in that around 1950 we developed numerical control; in numerical control, motions already take place with some programming.

In the beginning of course, there use to be the punched card system in which there were cards, in which there will be these were punched cards, and that time they may have various type of holes, and these where inserted. And through these holes, light can pass, and the whole control direction can be taken, but those days are now gone, because the computer has come. So, initially we had NC systems numerical control system. Numerical control means, control by number.

Here I have to make even if I have to make some complicated shape, say I have to make this type of shaft, and here there may be steps. If this type of thing I have to made make, I can program it. And after programming, this operation can be done, and that programming that instructions can be given in the form of punched card or through tapes, there are various means.

Now, many of these things are obsolete, and there is not much point in discussing that. But, after numerical control, when computer was did and everything is control by computer we are write a program in computer may be in English like language that is higher level language, then that type of thing was called computer numerical control.

So, basic machining process is same, cutting tool is same. Of course, these machines have many other features. Say for example, these machines may have different type of tools, there may be a tool magazine, and which I can mount different type of tools. And even tool changing can be done automatically, I will program it once that at this movement you have to change the tool, then the machine will automatically change the tool. And after that it will do select this speed, feed and everything is done automatically.

In other machines, if you might have seen in the workshop that if I want to select any speed, I can select the speed, but then that by means of some lever, I have to change the speed to appropriate value. Now, in these computer numerical controlled, speed changing is done automatically. Even during the operation also, speed can be continuously varied.

So, these are the various type of advantages. And then these machines are of course very precise. They have got even instead of lead screw, they have got a ball screw, which will have very low coefficient of friction. And, even the guide wage also, their movement is by means of some bar bearing type things, so that the friction is less the they are very precise can be operated at high speed.

There is work area enclosure. Inside the work area enclosure, everything is happening. And after has operator has once programmed it, and he is seeing maybe he can go somewhere. And after sometime, he can come usually may he may be still present, and may be controlling 4-5 machines simultaneously just seeing that how it is being done.

And so, these machines are very safe, and they functioned, and because everything is inside a work area enclosure the cutting a speed etcetera can be very high. And operator is protected, even from the harmful effect of the coolant, because everything is inside the work area enclosure. So, these type of things are there.

So, we will talk about something about these type of CNC machines, and also about CNC programming that how you will program that. Naturally, you have to practice it, there are lot of open source material in the Google etcetera, you can download, and kind study that programming yourself. But, in one lecture, I will introduce you, so that now the task will become very easy for you, and naturally confidence in programming comes only by practice.

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So, this is I am showing you that one computer numerical control that means, CNC machine in my workshop. It is just a milling machine, there are number of suppliers, this typical machine is from Kirloskar, but there are naturally other supplier. Here I am not intending to recommend any machine by any particular supplier, only just this is a simple photograph, which I have taken from my own workshop.

Now, here it is basically typically you can identify, it is a vertical milling machine. And this part if you see everything is there, there are motors, this is a bulb by which you can see, and then there are other control size usual, other portion little bit portion is hidden. But, on the right hand side, you are seeing basically a control panel, and there is a screen, we can write program, we can put it there or we can write a program somewhere else. And by means of some pen-drive or some other type of device, you can just insert the program here.

At the same time, you can do some small modification from here. There are these this is a key board, and then the you have got a emergency stop. Naturally, there should be one red colored emergency stop, if there is any problem, immediately press it, it should be easily pressed. And these are indicators ok. We have various type of things. Even if you in program, you have retain some feed. But, by means of the feed over ride, you can override the feed that means, you increase the feed, and you can do all these type of things here.

So, this is basically a control panel, and it is connected here. And these are the motors. Usually the salvo motors, they are getting controlled by this control panel, and that is how that this operation goes. In this machine, I think there is no tool magazine, but in generally, you can have tool magazine also. Usually in that case, we call it a machining center. So, this is a typical milling type of CNC milling machine you can say.

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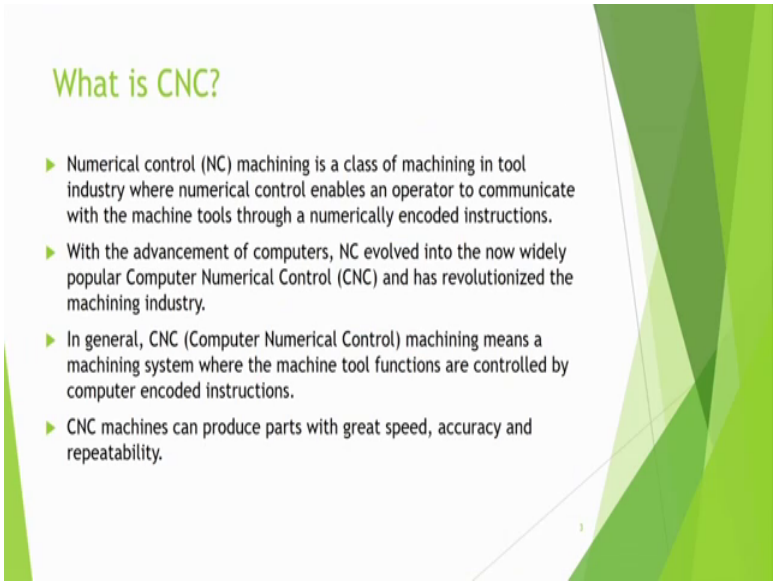

Now, question is that what is CNC? So, numerical control machining is a class of machining in tool industry where are machine tool industry, where numerical control enables and operator to communicate with the machine tools through numerically encoded instructions. That means, you know basically instructions are usually given in the form of 0 and 1. 0 means something is not there, 1 means it is there.

So, an after I think, so 0 1 so binary system, most of the computers, they follow binary system. But, with 0 1, you can get lot of combination, and you can make lot of instructions. These basic things you know. So, basically we are giving those type of instructions, they are coded instructions, and that is why they are called a numerical control machine.

With advancement of computers, NC evolved into the new widely popular Computer Numerical Control, which revolutionized the machining industry, because after the advent of this type of numerical control machine, lot of development took place

simultaneously. And after that in the computer technology, so computers you are attached, and then it became CNC.

In general, CNC that means, computer numerical control machining means, a machining system where the machine tools functions are controlled by computer encoded instructions. Computer will give instructions, and it will be interphase with the machine depending on the command, computer will naturally can send the signal that on off. Suppose, the signal is that a on, so that one particular valve can be on. And if it is off, then it can be off.

CNC machines can produce parts with great speed, accuracy and repeatability. So, three main advantages are there, it can be done at great speed, operator cannot do in that much speed, he may get scared. And suppose he that feed speed that very high speed, and may be that if you forgets to stop it in time, then the tool may hit these tuple and there may be problem. But, here that you know computer will automatically stop, so there is no need to worry.

So, it can have a great speed, accuracy, it can be very-very accurate, and then repeatability that means, even if I make hundred components, everything will be basically similar type of same almost same, because computer will not get fatigued. So, these are the various advantages of the CNC machine.

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And I am showing some other typical CNC machine. This machine we have taken from MTAB, and I took the photographs see that it is a table top mini CNC lathe, it is only used in my workshop, for training the students. And it is a type of CNC lathe machine. Here the tools have been mounted here, and they are doing the operation.

And we are there is a computer, computer has been interface with this. Here the students study the part programming etcetera, they makes some component. And before actually machining something, in this small machine aluminum can be machined. But, before machining, they first see on the screen, how the simulation takes place means how the part will look like. These operations, they can do before.

And then similarly this is table top CNC milling machine. So, one is turning machine lathe machine, other is the CNC milling machine. Here also the same type of programming can be done. So, advantage is that since everything is done in this in computer, so naturally you can see the virtual simulation that how the actual cutting process will take place. And if there is any mistake in the program that can be rectified, and finally the correct program can be fed put into the machine, and then the machining can take place.

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Then this is now in the bigger size production type of thing. This is a CNC lathe machine in which there involves seeing I think probably in the photograph, you can identify this is a round type of tool magazine in which many tools have been mounted. And depending

on the need, they will be taken by some means usually you may have some tool (Refer Time: 14:41) all which can take or otherwise sometimes the tool directly go into the spindle, and they are taken by the tool magazine. There are various types of variants.

This is also a CNC lathe machine, and everything is enclosed in the work area enclosure, you cannot see much. But, it is essentially you only lathe machine, it has a tool linear magazine, and all these type of operations are there. Usually in the work area enclosure, there is a limit switch that as soon as I open it that limit switch get opens, and then all the functions will stop; only when I close the work area enclosure, then the machine will start that type of safety inter locking is there. So, this I have shown you some photographs of our CNC lathe machines.

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And then I am showing now the photograph of CNC milling machine. Here also see there is a work area enclosure of course, it is transparent. Through these windows, you can see what is going on. And coolant is also there inside. And here there is a control panel outside, you can do all the controls.

So, this is a typical CNC milling machine. And it is showing that one machining operation in CNC milling machine. See the tools is cutting, and lot of fluid coolant is there through this flexible hoses, it is coming, and it is flooding the area, so that heat is removed. The chips are carried away, and it provides neat and clean working

environment, and that is one provides lubrication. These type of things are happening here.

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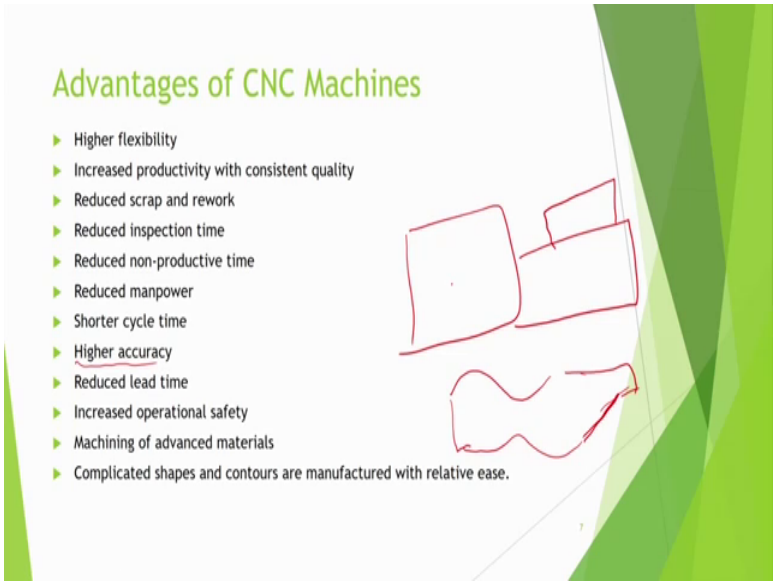

So, let us see what are the various type of advantages of CNC machine once again. First of all that it is providing you higher flexibility; if I take any automatic special purpose machine, then I am I have to do only that type of operation. But, here if I am having computer numerical machine, then there is a flexibility, say in same machine, I can do variety of job.

Even if I have hundred types of different product variety, there is no problem, because I need to have do only some small changes in the program. Initially there used to be hard wired system that means, hard wired system there instead of the program, physically we will connect the wire. But, now there is no need of any hard wired system, it is only in the software I have to make changes in the software, and I can produce this one any product that is why there is a higher flexibility.

Then increased productivity with consistent quality that means, if I keep changing the tool in appropriate time, assume that tool here is not there, and nowadays many CNC machines are coming, which have provident to automatically detect, whether the tool life is over or not. Then in those type of circumstances, you can produce many components in a day. And they will all will have consistent quality that means, quality of each

component will be almost same, because you are doing it by machine, you are not doing by hand.

Then reduced scrap and rework because, quality is very good therefore, part will be past in the inspection, and there will be less number of a scrap, in these CNC machines often online inspection system is also integrated, so that is also advantage. And need for rework is not there, in sometimes operator has made some component, and then the supervisor says no, there is some problem here, these dimension is more, then he goes and he modifies that those type of things are eliminated. So, lot of productive time is saved.

Then reduced inspection time; inspection time is saved that means, you do not have to spend much time on the inspection, you can be rest assured that the machine is making properly. And if it has online inspection system, then even that leading also comes. So, there is a inspection has reduced, it is not that you will do 0 inspection, maybe still you see the component, and but you know there will not be much time wasted on that.

Then reduced non-productive time that means, lot of non-productive time. Suppose, the part gets scrap, and then you run here and there, those type of things will go, and it produce a reduce a non-productive time or suppose you are changing the tool by hand, even the tool changing is taking time, those type of things go.

Then reduced manpower; of course, the manpower gets reduced, people will not get fatigued, they can do lot of work. And I can even control 4-5 machines at a time. So, manpower requirement here has reduced that manpower which has been reduced from here can be utilized do for doing some other fruit full job. So, naturally that we will utilize the manpower in a proper way, not that they will become jobless, they will do some other type of things. And this way, there will be growth of the any nation and overall humanity.

Then shorter cycle time that means, for making any product and doing the whole operation from starting from putting the work piece to this one, cycle time will be reduced. In fact, now the machines are coming like that that machine is doing the machining operation inside the work area enclosure.

Here and here, I have a pallet changer. In this pallet changer, there is a provision supposed to mount to work piece. So, one has gone here to do this one, and when that component is getting machined, simultaneously I am fixing my job here. So, once that job will be done, then the pallet changer will go inside, take the that particular job, then turned - 180 degrees, so that the new job comes into the position. And the old job comes out that type of automatic pallet changer are shutter table, those type of things done.

So, when I am doing the machining of one component, simultaneously I am putting that another component on a pallet changer. So, overall cycle time will be reduced. And then naturally we will get higher accuracy, because everything is being done by the machine, so we will have higher accuracy, you see that we will have very high accuracy.

Then reduced lead time that means, suppose you order some component, and then by the time it is ready that may that time got will be very less, so lead time is very much reduced. And increased operational safety; I have already told that in most of the places everything is enclosed in the workshop work area enclosure, so operator is quiet safe. And there are safety interlock, safety feature, and since you will there is lot of electronics and computer. So, naturally these sensors can be fitted. Even if accidentally operator puts his hand at some place, sensor will guess it, and then immediately stop the machine.

Then machining operates advanced materials. I can machine very advanced materials due to various type of these type of advantages. And then complicated shapes and contours are manufactured with relative edge; the things which require artistic skill. Suppose, I want to make this type of say free form surface or something, here operator has to move tool in his way, but now I can program this surface point by point that how the tool has to go, and then I can may make those contours very easily by the machines. So, these are the advantages of CNC machine.

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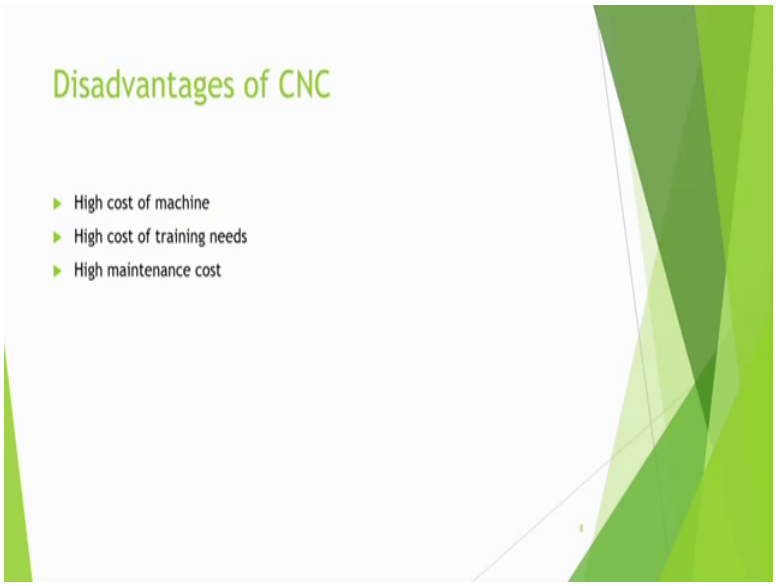

But, with this there are some problems it is not that everything nothing comes for fee. So, there may be some problems like that like that I am talking about disadvantages. First is the high cost of machine. Machines are usually costly than normal machines, which you can purchase, but these machines will be having high cost, because for cost is also right now high. Because, such type of machines we do not purchasing that much bulk quantity, so benefits of mass production are gone.

If I take a sophisticated machine that company which produces that machine may get about a say may be 10 machines order in a year, and in that they have to recover overhead cost and so many other things. So, naturally there will be high cost of machine. So, you have to decide that whether purchasing such type of machine will be profitable.

Usually they will be one break even quantity that means, break even quantity means if I produce a product of this much quantity, then I will get profit. If I produce the less, I may not get profit. If I produce more naturally, I will get profit. So, break even is exactly that quantity which I produce and in which I should not have any profit or loss at the breakeven point. After that quantity, I may get profit.

So, high cost of training needs naturally if I take any person, it will very difficult to train in only 5-10 days, we have to teach him programming. And we have to then he will understand, and he will have to even if he has basic skills of operating the machine, but I have to train it for operating CNC machine, so that training cost is there.

And then high maintenance cost; these components are also very costly. So, if the component gets damaged, then we have to procure. So, naturally high maintenance cost is also associated with those components. These are the some disadvantages of CNC machines, otherwise this is CNC machine is exigent.

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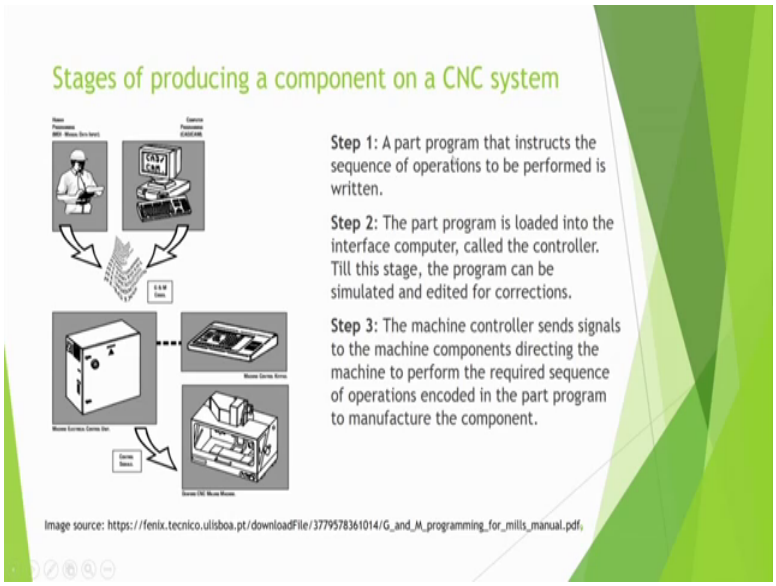

Now, let me discus about what are the various a stages of producing a component on a CNC machine. So, a step 1 I am showing this one. So, one is a step 1 a part program that instructs the sequence of operations to be performed is written. So, he is a part programmer. He is writing that type of program. Now, he has he may give that type of data by means of the this one some tape or somewhat even some device that by which data can be transfer to computer or by some data disk or whatever, simple pen drive or anything, but he is writing the program he is making that.

One thing is that he is doing that, but it can be nowadays can be done automatically that means I just make a component in the correct can software here. And the correct software in correct software I designed the component. Then the correct software automatically has may that program. I do not have to program it, and this computer has automatically done it. And then hole data can come, so this type of this one.

So, a step 2 is that the part program is loaded into the interface computer. So, the program which makes that which that the machining of the part that is called part program is loaded into the interface computer. This is the interface computer in which I

am loading machine. This is a computer in which I am loading. And it is also called the controller till this is stage the program can be simulated and edited for corrections.

Here I can simulate it, I can I have loaded I can see this on the screen. And I can see whether the operations are going or not. Going these type of things we can do that. In a step 3, the machine controller sends signals to the machine components directing the machine to perform the required sequence of operations encoded in the part program to manufacture the component.

In the third a step there that machine controller it sends the signal to the machine components, and accordingly the operations have done. So, usually there are these types of a step are there. And then we do this type of information we can get on various companies websites. They have put their manuals, they are in the open domain actually.

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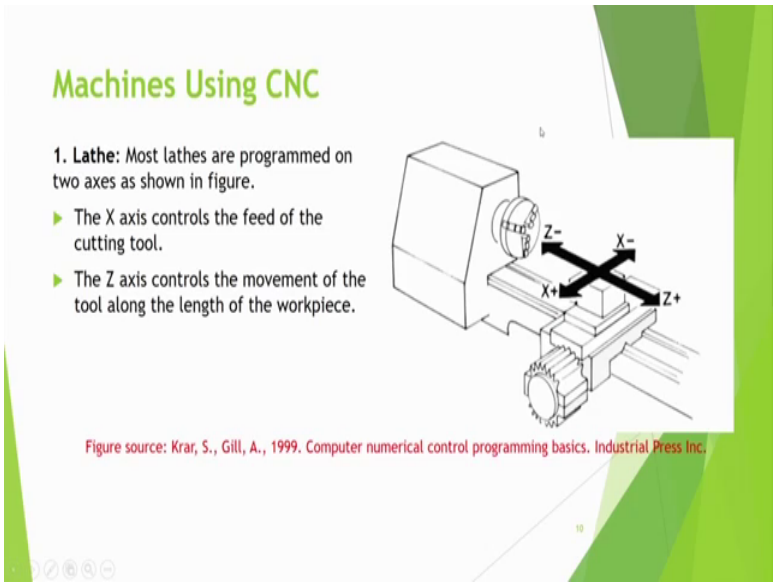

Now, let us see that machines using CNC which type of machines can be there is lathe. And in this one lathe is most lathes are programmed on two axes as shown; that means, they move a say suppose here X axis movement can be decided. And this is a this is X, this is Z, Z axis is only towards be spindle convention is that a spindle direction will be Z axis. And then Z axis controls the X axis controls the feed of the cutting tool. And the Z axis controls the movement of the tool along the length of the work piece.

Usually there is no need of the Y axis that means tool is not moving up and down. We have to move in the lathe machine is spindle is automatically rotating. So, I have to give two motions to my tool that my tool has to move like this and like this. Usually these two motions they can be controlled. So, I can do the programming.

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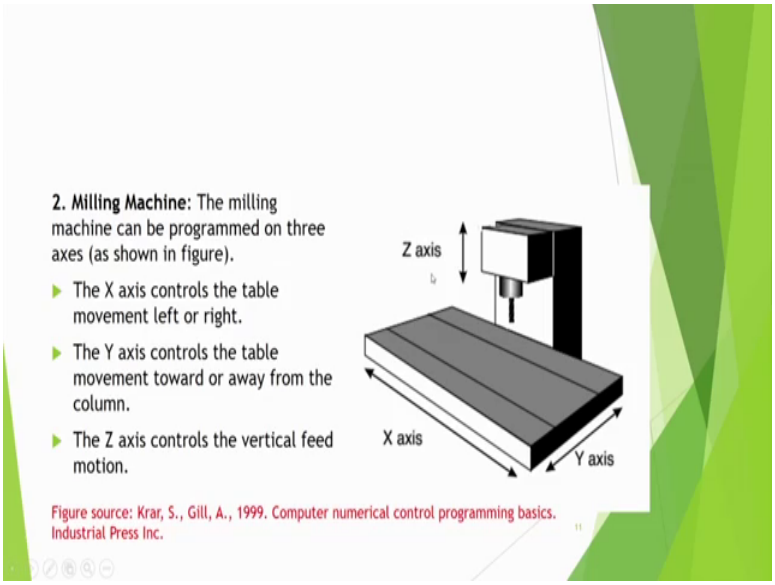

Now, in the second figure that you see milling machine, it is a typically schematic diagram of milling machine. You observe it here that even Z axis I have made along the direction of a spindle in the milling machine also. And here I have taken this X axis and Y axis. Now, I make the three dimensional shape by controlling the three axis XYZ.

And machine can be programmed on three axis X axis controls the table movement left or right, Y axis controls the table movement towards are away from the column, and the Z axis controls the vertical feed motion, so that type of thing is usually done. So, Z axis controls the vertical feed motion. And this also I have taken it from a open source book this material.

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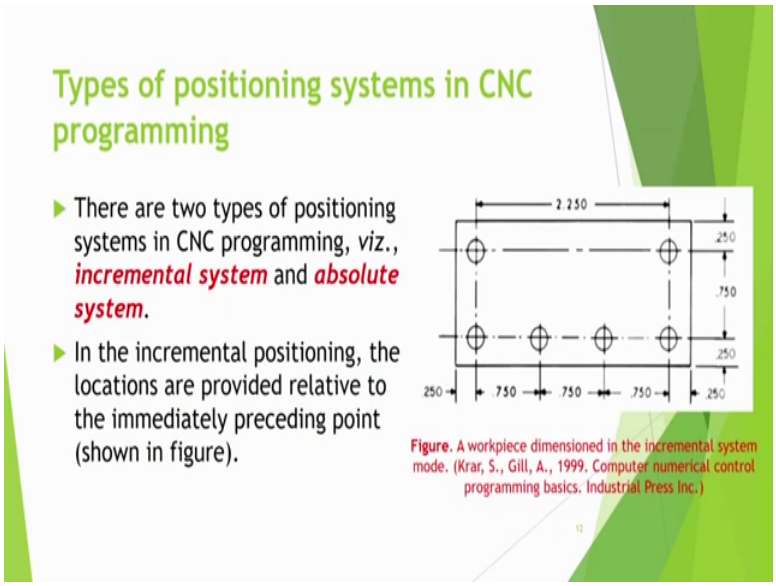

Then let us discuss something in detail about the types of positioning systems in CNC programming. Now, there are two types of positioning systems in CNC programming two types of positioning, positioning means at how you position the tool or in a simple way how you change the position of the tool. So, there are two systems incremental system and absolute system.

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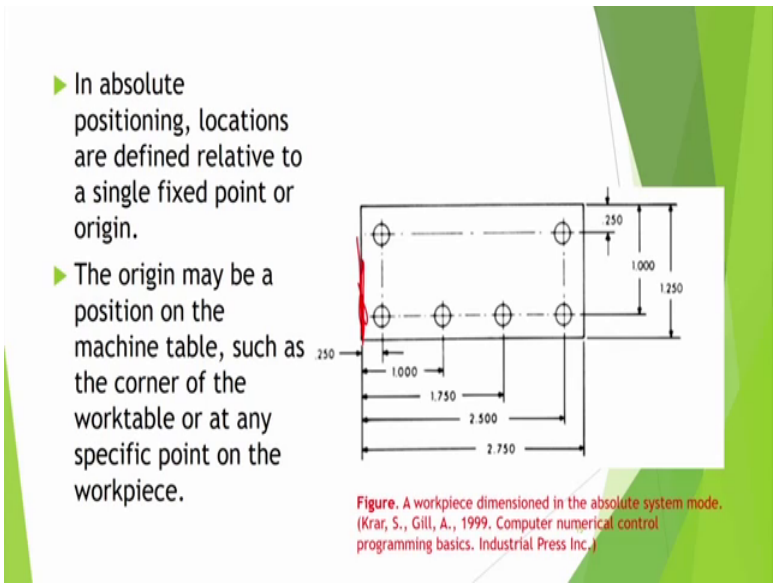

In the incremental positioning system, the locations are provided relative to the immediately preceding points. Suppose between this hole to this hole there is 2.250

distance is there. I can give the absolute position or I suppose I am making one hole already suppose I have made this hole. Now, this hole is I had position 0.25. This is actually 0.75 from the previous one.

So, increment why this position is 0.750, but absolute one will be from the beginning if I take this has a beginning position, then it is 0.25 plus 0.75 means 1. So, incremental wise I am giving the difference of what is my current position of the tool, and how much increment I have to give. So, this is 0.75, so sometimes this type of system is easy that is why incremental positioning system.

In absolute positioning system locations are defined relative to single fixed points or origin or some datum. Supposed we have taken this surface has datum, this surface has 20 taken as a datum. So, we define the position of each hole like this not like that this hole is 0.75 distance from this. We say this is 0.25 this is 1.

Then this is 1.750 or the time I am measuring from fix datum so that is called absolute dimensioning system or absolute positioning systems that locations are defined relative to a single fixed point or origin. The origin may be a position on the machine table such as the corner of the work table or at any a specific point on the workpiece. These type of things can be there.

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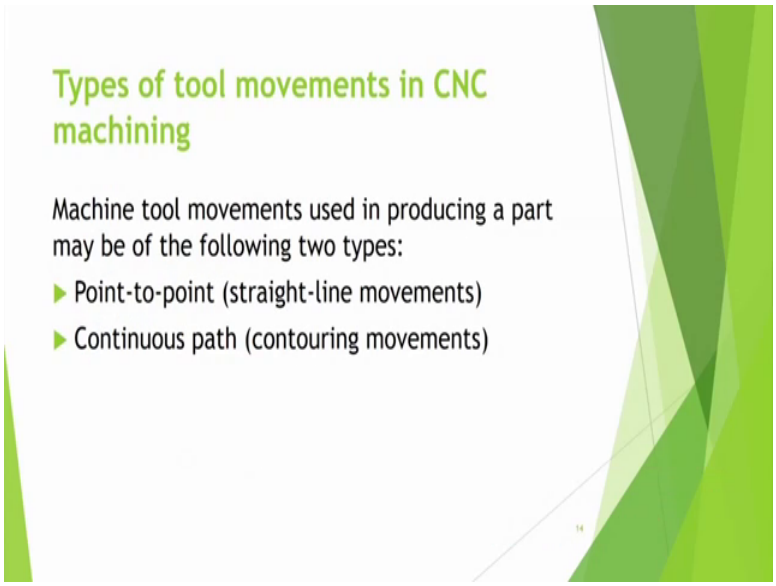

Now, types of tool movements in CNC machining. Now, machine tool movements used in producing a part may be of the following two types. One is point to point that means, only we have to go a straight line movement. I can go from this point to another point, and it can be continuous point. Usually point to point machining system is usually imploding drilling machine CNC drilling machine. I have one position then I can go to other position. And in continuous path I can move continuously, and can do the cutting.

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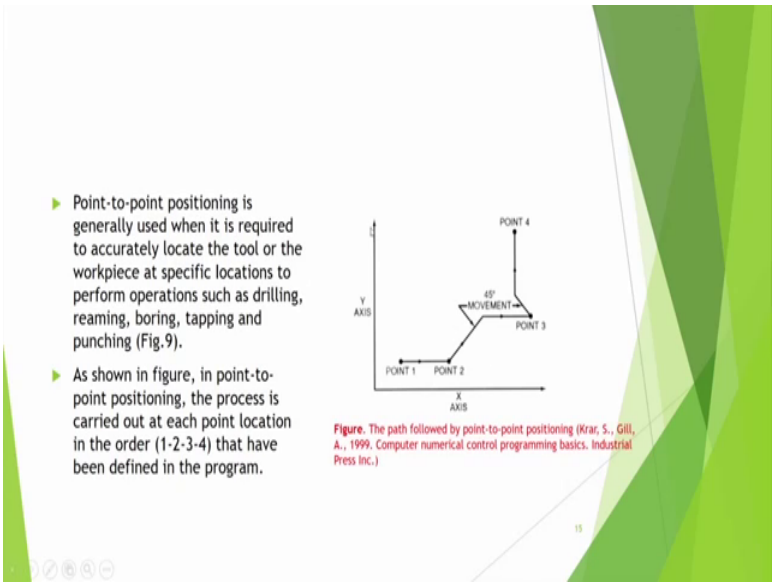

So, point- to- point position is generally used where it is required to accurately locate the tool or the workpiece at a specific location to perform operations such as drilling, reaming, boring, tapping and punching. I will have first my tool is at point 1. Then I will go at point 2 a straight, and then I will go here, I have show a point-to-point positioning system may follow this type of path.

And I shown in this figure in point-to-point positioning the process is carried out. At each point location in the order of this one. I first a drill a hole at point 1, then I drill a hole at point 2, then I drill a hole at here at point 3, then at point 4 like that. So, it these things have been already defined by the program.

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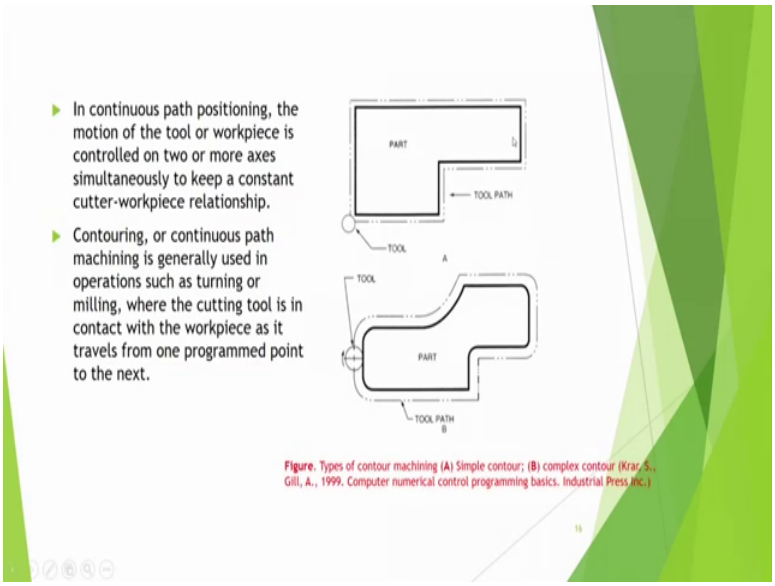

And this is the in continuous path positioning the motion of the tool or workpiece is controlled on two or more axis simultaneously. To keep a constant cutter workpiece relation that means, it is moving like that that tool is there. And this tool is going from here to here. Then it is following that tool path is shown. And then it is going like this, it is going like this; it is going like this, and entire path it is making. It can move in this type of controlled location also the tool is moving suppose like this is the path of the tool which follows.

So, in continuous path positioning the motion of the tool or workpiece is controlled on two or more axes. Simultaneously to keep a constant cutter workpiece relationship contouring or continuous path machining it generally used in operations such as turning or milling. In turning tool is continuously moving and cutting it is not like drilling that where the tool goes from one location to other location and at that particular location it makes a hole. In the lathe machine it is continuously moving. In the milling machine also usually it is continuously moving. So, cutting tool is in contact with the workpiece as it travels from one program point to the next point.

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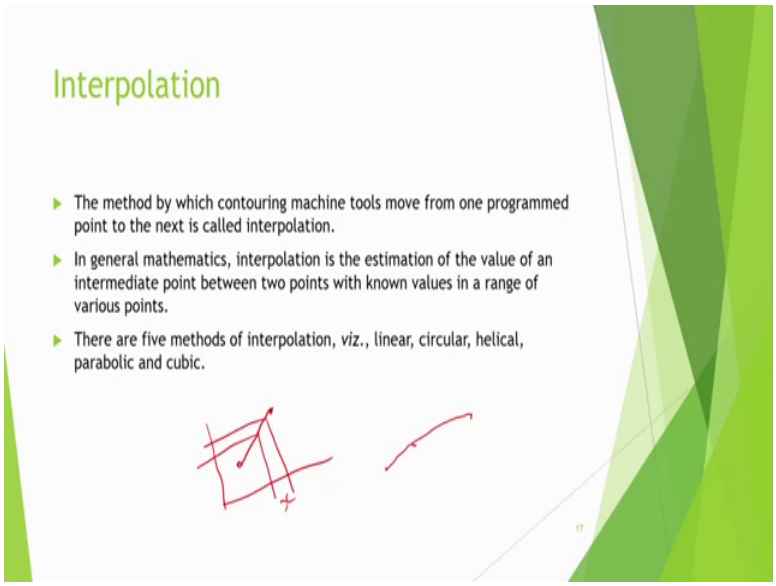

Then interpolation, what is interpolation, suppose I have got several points 1, 2, 3. And I just a draw a curve passing through these points and something this is called interpolation ok. We can interpolate we can is interpolate by a straight line that means, if we joint these points by a straight line or we can do the quadratic interpolation or cubic interpolation, so these types of things are usually thought in the course, and numerical methods in general.

But in machine CNC machining what is it is a significance the method by which contouring machines contouring machine tools move from one program point to the next is called interpolation. It is interpolating in general mathematics interpolation is the estimation of the value of an intermediate point between two points with known values in a range of points.

So, in general mathematics we say interpolation means as I have already told suppose you have one point and another point. I interpolating by straight line, so I joined it by a straight line. Now, if I want the value at this point suppose X is this, then I know that it is a straight line I go and say this is Y. If I need this point, I know this is this one. So, they are all I can have some data you know a suppose in a steam table also. You are doing such types of things that is you are interpolating and doing this one.

So, there are five methods of interpolation. Namely, linear circular, helical, parabolic and cubic that means, you can two these operations by various points by linear circular

helical parabolic and cubic methods. You have various points you can already fit a cube are these things nowadays can be done very nicely in the computer. And it can be done.

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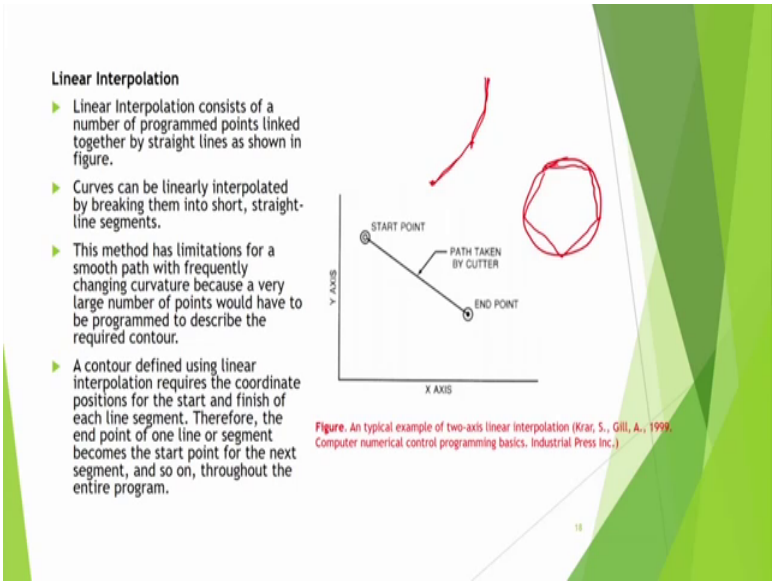

So, let us discuss little bit in more detail about the interpolation. Suppose linear interpolation, linear interpolation consist of a number of programmed points linked together by a straight lines as shown in figure. Suppose you have got a start point and then you have got a end point in between it interpolates in a linear fashion. So, all the points are lying in this particular a straight line. If you want to know that you can that this is the X value, then this will be Y value.

So, curves can be linearly interpolated by breaking them into short a straight line segment. I have to make this type of curves suppose, but what I can do that I can do the linear interpolation from here to here. And then from here to here or I can break into five components in that case there will be less error. So, any curve can be broken into straight lines. This method has limitations for a smooth path with frequently changing curvature but, suppose your curvature is very frequently changing. Then you require to break it into many a small a small straight lines. So, this creates some problem, because a very large number of point should have to be programmed to describe the required contour.

If I want describe a circle by means of a by means of, so many straight lines, you can is imagine that how many a straight lines I need. I have to move my tool in the circular path, but you want to do only by linear interpolation. So, may be that suppose I am

making this type of say I am showing include interpolation like this I have done. So, this is 1, 2, 3, 4, 5 so, by pentagon I have done. Then I can moderate by hexagon are these types of things I can do.

So, this method has this limitation that linear interpolation or though easy to program, and for contour from control point of view may be is here, but it has difficulty of accuracy. So, a contour define using a linear interpolation requires the coordinate positions for the start and finish of each line segment. Therefore, the end point of one line or segment becomes the start point for the next segment and so on throughout the entire program. So, this particular thing goes on and then you can do like that.

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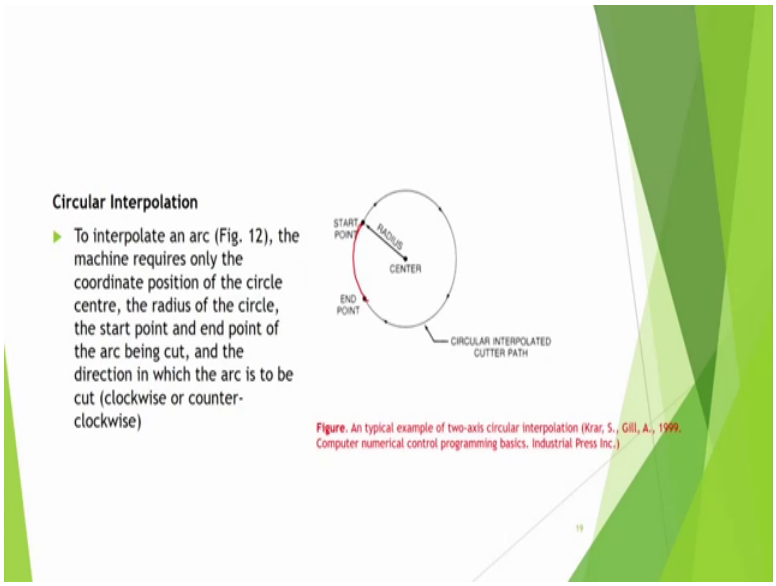

So, now coming to the circular interpolation; circular interpolation is often implied. To interpolate an arc like in this figure it is shown. The figure shows a typical example of two axis circular interpolation. In this it is interpolated from a start point to end point. This is the radius; this is the center machine requires only the coordinate position of the circle center. And then the radius of the circle you have to tell. Then a start point and end point of the arc being cut, and the direction in which the arc is to be cut.

So, suppose I have told my center point. I have told my radius. This is my center point. So, they program software knows that this is the center point. Then it knows that this is the radius, it knows that this is the circular a start point, and it knows that this is the end point. And then it also knows that I have to move in this particular cohesion that means I

have to move in a clock wise manner. Otherwise suppose you just use start point and end point then it name of in this direction also which you do not desire so that is why you have to also tell that whether it has to move clockwise or inter or anticlockwise.

Now, so these type of, so now machines have these facilities for circular interpolation. It becomes very easy. And you can you can easily program you can make arc or you can make full circle.

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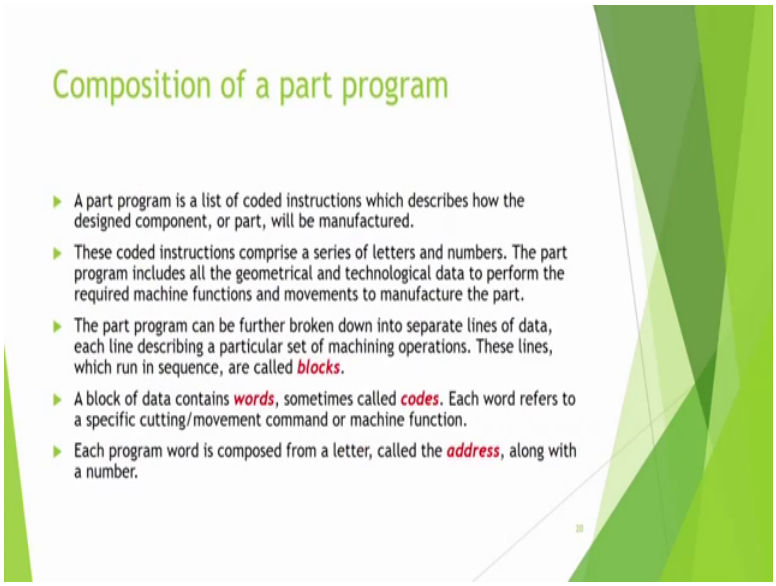

Now, machining you can do. Now, I am going to tell that what are the typically composition of a part program. Now, a part program is a list of coded instructions, which describes how the designed component or part will be manufactured. So, this is a coded instruction. Now, these coded instructions comprise a series of letters and numbers.

The part program includes all the geometrical and technological data to perform the required machine functions and movements to manufacture the part. So, part program can be further broken down into down into separate lines of data there is a big program, but in that there all for each data there are separate lines. This line describes a particular set of machining operations these lines which run in sequence are called blocks. So, we say those are blocks.

So, a part program is comprised of comprised of number of blocks. A block of data contains many words. They are sometimes called codes. Each word refers to a specific

cutting movement command or machine function. Like I can give one command for tool change so this is one word. And each program word is composed from a letter called the address along with a number. So, each program word each composed from a letter some may be some M or something and then along with some number will be there.

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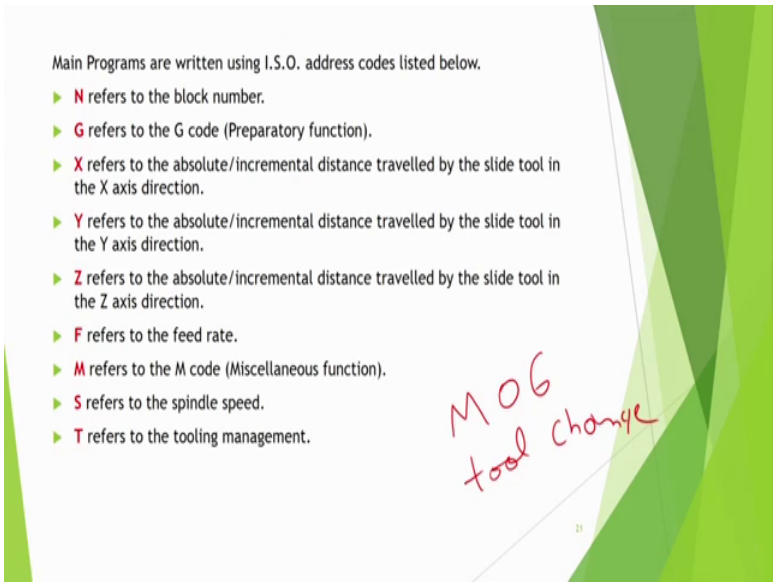

So, in according to ISO system, these are the things in part programming. N refers to the block number. Like in a program I can have 50 type of blocks 50 type of different distinguish think operations. Like blocks mean these are basically particular set of machining operations. So, I can hope 50 operations. So, maybe I can have 50 type of N may be N may starts from N 1 N 2 up to N 50 N 0010002 like that.

G refers to the G code. It is a preparatory function that commands usually that how the tools should be moving. And X refers to the absolute or incremental distance travelled by this travelled by this slide tool in the X axis direction. So, I if I give X 50 that means, you have to move 50 mm depending on what thing you have a instructed either in absolute coordinate system or in the incremental coordinate system. Y refers to the absolute incremental distance traveled by the slide tool in the Y axis direction. Z refers to the absolute incremental distance travelled by the slide tool in the Z axis direction. F refers to the feed rate.

So, what is the feed rate that means, millimeter per minute of the tool. And M refers to the M code that means, miscellaneous function like M 06 is per tool change so that

means M 06 means tool changing. So, if I give the M 06 command, it will change the tool like that we have different type of M type of things no need to memorize, it much, it will automatically come, when you practice, it many times. S refers to the spindle a speed I can give S 100 that means, may be 100 Rpm. T refers to the tooling management that means, I can have designation of the tools T 1 T 2.

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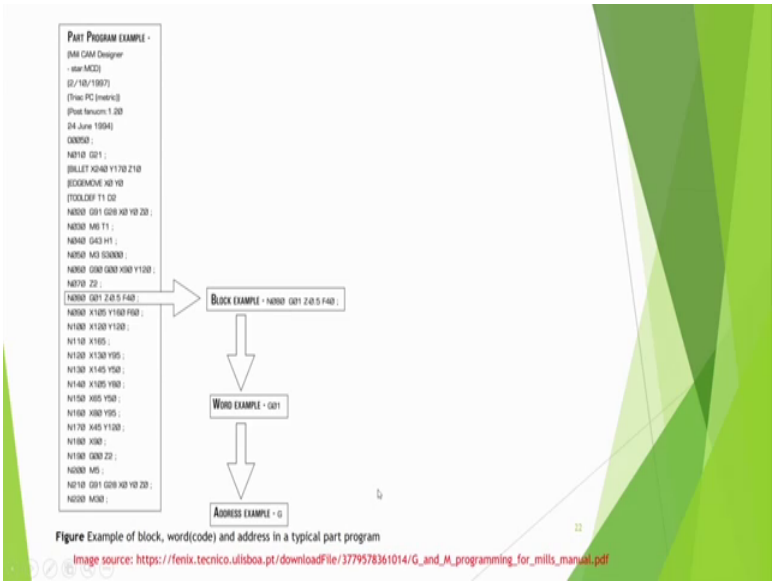

Figure Example of block, word(code) and address in a typical part program
Image source: https://fenix.tecnico.ulisboa.pt/downloadFile/377957836101 4/G_and_M_programming_for_mills_manual.pdf

So, this is a typical part program we will look. I think you are able proceed this is part program example. It was made in mil CAM designer that means automatic software might have some drawing, and by that it extracted, and it made, but one can right it manually. And it was made in 97 and this is ah. So, these are the commands suppose we have N 010 so that means, program number a block number is 10.

Then it is degrade that they have given the position. And then this is 20, N 20 this command is there G 91 N 30, N 40, N 50 like that they are going numbering. Why they are doing N 50, N 60 why not 50, 51. Suppose in between I want you in sort some line or block I can put it here N 55 like that.

So, typically suppose this is NAT. So, block example is NAT G 0 1 Z Z minus 0.5 and F 40. So, feed is 40 Z means coordinate in the Z direction G 0 is propriety function about this one. So, this is the complete thing is called block. And a typical word may be G 01 We can say G 0 is 1 1 which that some operation. And its address is basically G that

means it is propriety code. So, example of over a block word and address I have shown here.

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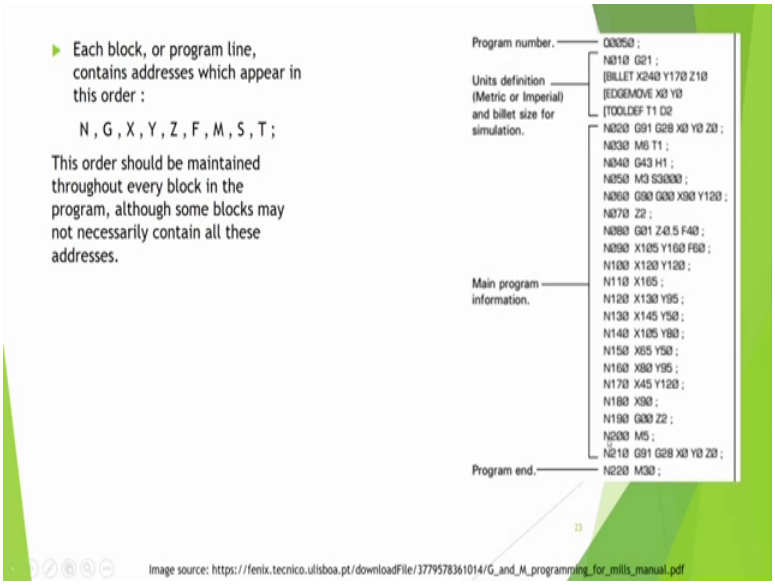

Now, each block or program line contains addresses, which appear in this order N will come first that means, block number. Then G means what type of functions X means I am talking about X axis movement, Y Y axis movement, Z means Z axis movement. And F means feed rate. M is miscellaneous function like tool changing M 0 6. Then S is a spindle a speed, tool is some tool management.

This order should be maintained throughout every block in the program, although some blocks may not necessarily contain all these addresses may be they may stop at N, G, X, Y, Z that is all. So, example is that suppose program number may be 0050 I have written. Then I am giving N 010 that means, N 10 G 21.

So, units definition I have in this particular thing. I am only doing the definition of the units that means, metric I can define whether it is metric I think 21may be metric. And then billet size for simulation etcetera that I hope added it here. Then main program information is from here is start from G 91 that means, positioning system. Then G 28 X 0, Y 0 to the Z 0 initially it is here. Then after that these operations are going on. And then here program is ending.

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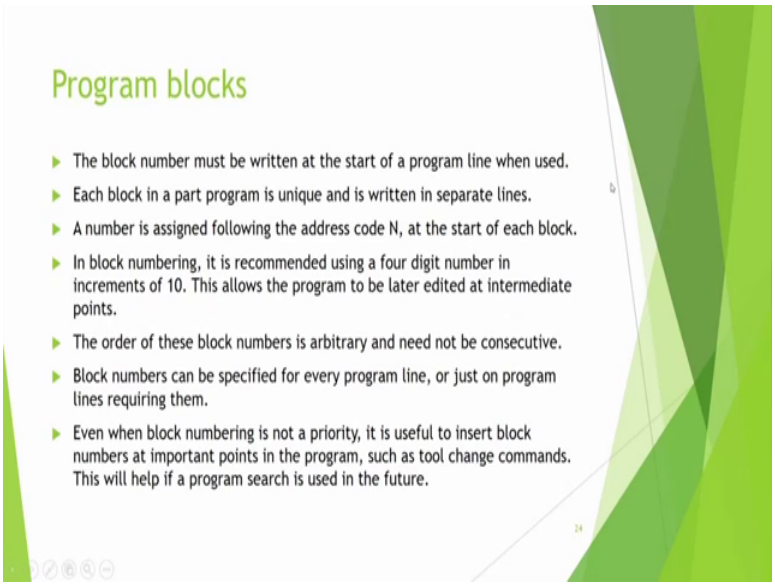

So, program blocks. The block number must be written at the start of a program line when you used. So, block number must be written at the start of a program line here. We have written always block number N 30. Each block in a part program is unique and is written in separate lines. So, do not mix up that means N 30 is here N 40 is in the next line. A number is assigned following the address code N at the start of each block that we have seen N 40.

Then what happens in block numbering it is recommended using a 4-digit number in increments of 10. So, we use 4-digit number in increments of 10 that means. So, up to 1000 suppose we can write. So, had 100 lines can be written. This allows the program to be later edited at intermediate points I can it is not that I am doing 30, 40 I cannot write 35, but I deliberately you have you have those numbers. So, that if I want to write 35 I can write here. I can even write 34.

The order of these block numbers is arbitrary and need not be consecutive. So, ordering can be this one, but we can usually we write in a systematic way. And block numbers can be specified for every program line or just on program lines requiring them. So, this is an even when block numbering is not a priority. It is useful to insert block numbers at important points in the program such as tool change commands. This will help if a program search is used in the future. So, always it is better to give block numbers always here.

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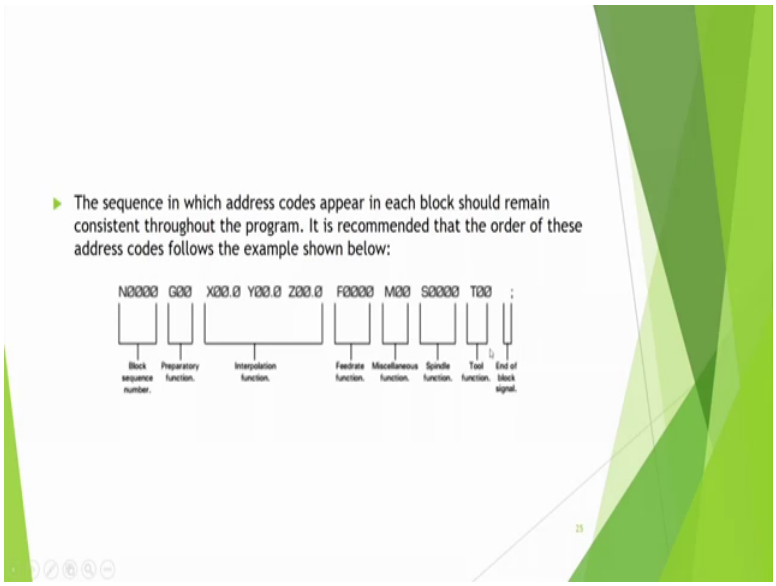

And sequence in which address codes appear in each block should remain consistent throughout the program. It is recommended that the order of these address codes follow the examples this. First we have block sequence number, so we give N. And this we give four numbers, then we give propriety function, then we give interpolation function X 0, Y 0, Z 0. Then we use federate function and then we are giving miscellaneous function then we are giving a spindle function; that means, a spindle is a speed will be decided here then we are giving tool function and then we are giving end of block signal. So, these things I have done.

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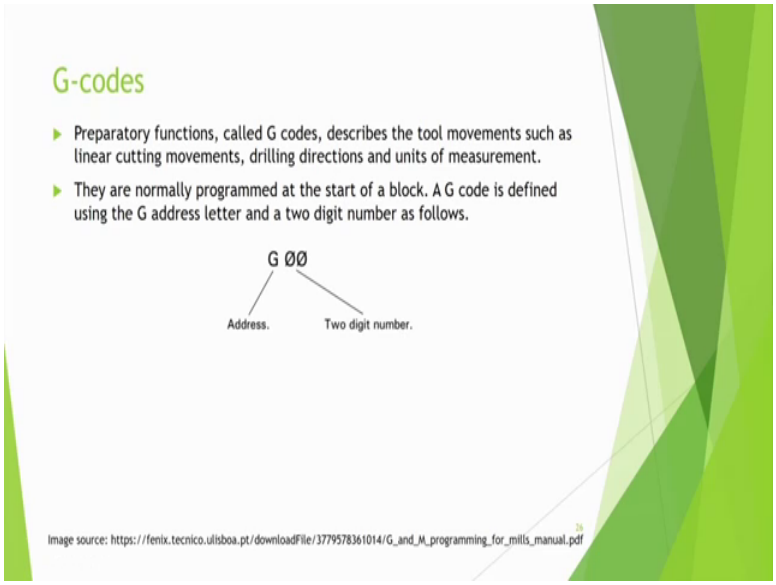

Then coming to the G-codes; now, coming to the preparatory functions, called G-codes. Now, G-codes describes the tools movements such as linear cutting movements, drilling corrections and units of measurement etcetera, means related tool how tool should move. So, they prepare the tool. So, they are preparatory functions.

They are normally programmed at the start of the block that means; first thing we prepare the tool. A G code is defined using the G address letter that means, we once we give G it understands that you are talking about the tool control. And then we give two digit number, these are only two digit number 0, 0. This type of thing we do.

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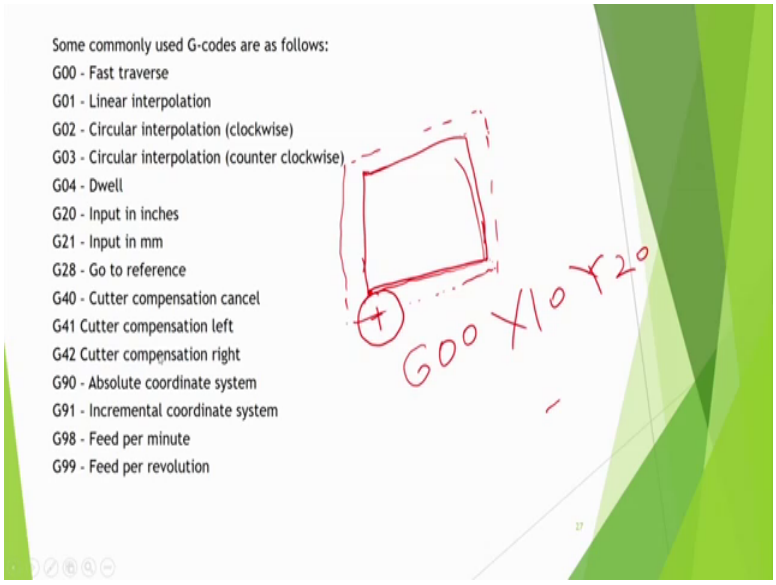

So, what are commonly used G-codes are there well there are 100 and this one commands, but I am only telling you something. If I write G00 that means, go to that position at a very fast traverse. I can write say G00 X 10, Y 20 so that means, go to that position, but very fast a speed. Because, may be you are not doing any cutting at that time you are just want to locate the tool at that position.

G01 is for linear interpolation, G02 means circular interpolation, but the tool will move clockwise. G03 means circular interpolation, but the tool will move counter clockwise. And G04 is dwell that means, tool may be a spending some time there itself that is called dwelling. It will a stop at that some particular location are just a spindle will keep rotating, like in drilling I want to remove the burses etcetera. So, I am not moving the tool, but I will be held (Refer Time: 52:38) at that is part, so that is dwell.

Then G20 is input in inches. So, if I want do input in inches, I would G20. Otherwise G21 is input in mm, G20 means 28 means go to reference point, and G40 is cutter compensation cancel, use give some cutter compensation right. G41 is cutter compensation left cutter compensation right, what are the cutter compensations. Suppose, I want to make this type of component; so, I want to machine these surfaces, I want a I may I program, but I will only take the coordinate of this line, this line, but my cutter is of a big diameter.

So, cutter center points has to move here, so that path is quite different, this path is quite different, this path is quite different this is this one. So, actually I my center has to move this way. And if I change the cutter diameter, naturally my center path will become different. I want to machine this portion means I want cutter is to touch these surfaces, but the cutter diameter is a big. So, depending of than center movement will be different.

Now, in the machine the movement of the center is important. So, each time I need not do the programming again or I do not have to understand that how the center will move. I just give the diameter of the cutter, and I say that a start cutter compensation. So, cutter compensation automatically will take care about that. So, a tool cutter may be towards the right hand side are it may be towards the left hand side of the job, so that is why you have cutter compensation left and cutter compensation right. And then you can kind see it by G40.

G90 means you follow the absolute coordinate system. Like here, you have seen that somewhere they have written G91 that means not the absolute, but follow the incremental coordinate system. And G98 means feed per minute has to be it given. And if I give G99 that means, feed per revolution like in the turning machine that it is in millimeter per revolution and or that type.

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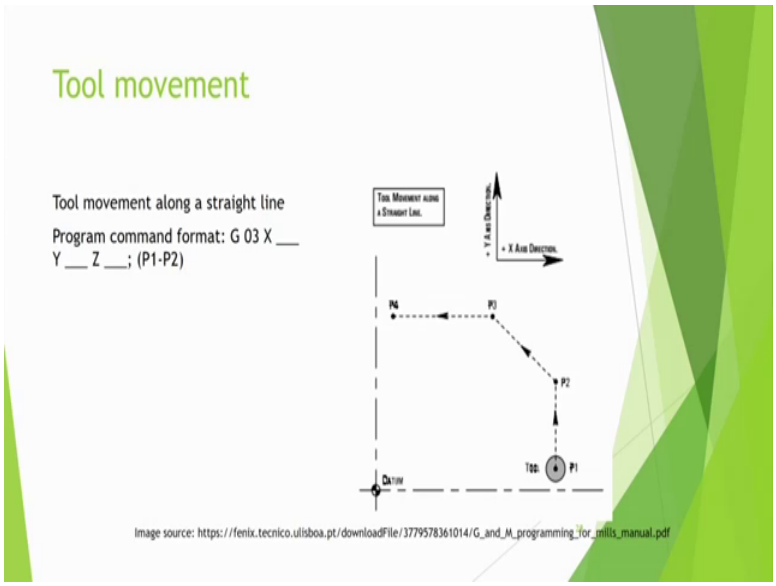

So, let us talk about the tool movement. Suppose, we have to do tool movement along a straight line; so, I said that G03 is the circular interpolation. So, in this case program command format, suppose circular should G if you linear interpolation, it should be G01, and I can give X, Y, Z. But, in the circular interpolation, I can right G03 X, Y, Z, and maybe I can go from P 1 to say P 2 ok.

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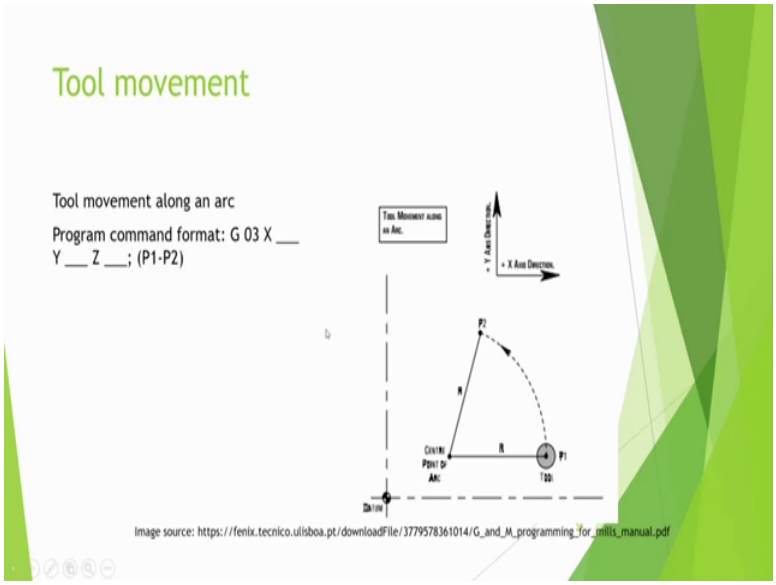

Then tool movement along actually this should be G01. This I think from open source, but even there was some may be some mistake in that manual. So, I should G01, because

I am moving in a straight line. This is a X axis, this is Y axis, so P 1 to P 2 I am moving. And now I am moving from along and arc. So, it is like that along and arc program command format is this.

So, G03 X, Y, Z and I am moving like this, so tools is moving from this to this. Center point of arc is given here, and this is P 1 to P 2. So, it is that (Refer Time: 56:15) have I have to do this type of motion, so G0 3 command is there.

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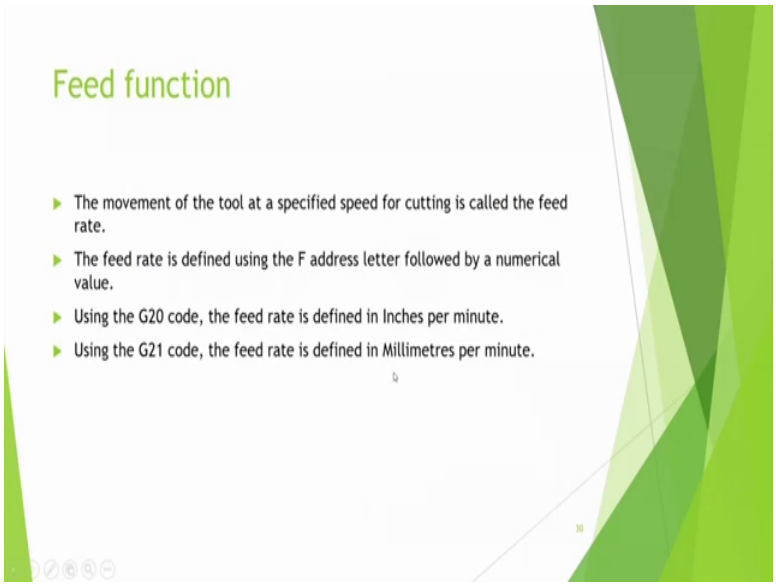

And then feed function. The movement of the tool that is specified a speed for cutting is called feed rate. And the feed rate is defined using the F address letter followed by a numerical value. Now, using the G20 code, the feed rate is defined in inches per minute. And if I would G21, then the feed rate is defined in millimeter per minute.

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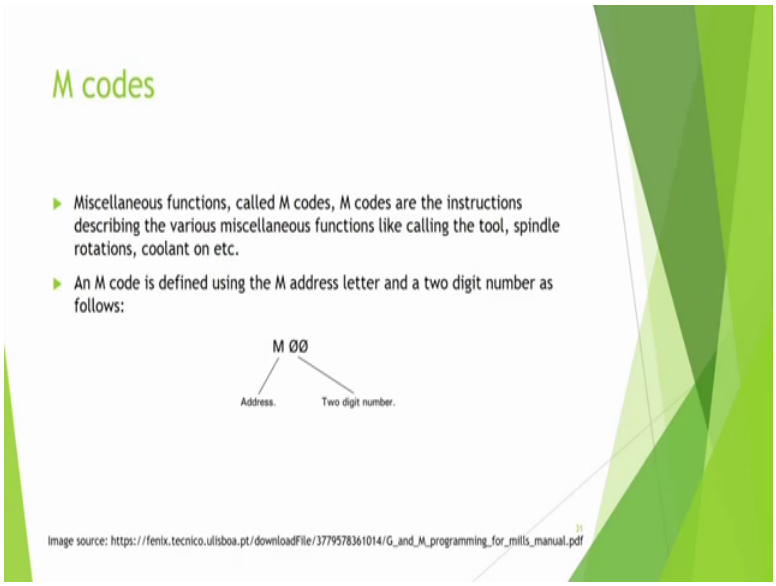

Now, miscellaneous function; so, before that see feed per minute also is a specified G91 8 and here feed. So, using M codes miscellaneous functions called M codes. M codes are the instructions describing the various miscellaneous functions like calling the tool, spindle rotation, coolant on.

These are things can be controlled by M codes. I can do by coolant on, so coolant on by M. M code is defined using the M address. If I write M that means, it is miscellaneous function. And a two digit number is as follows if I say that M, and then I say 0, 0 that means, this is the address is M and two digit number is 0, 0.

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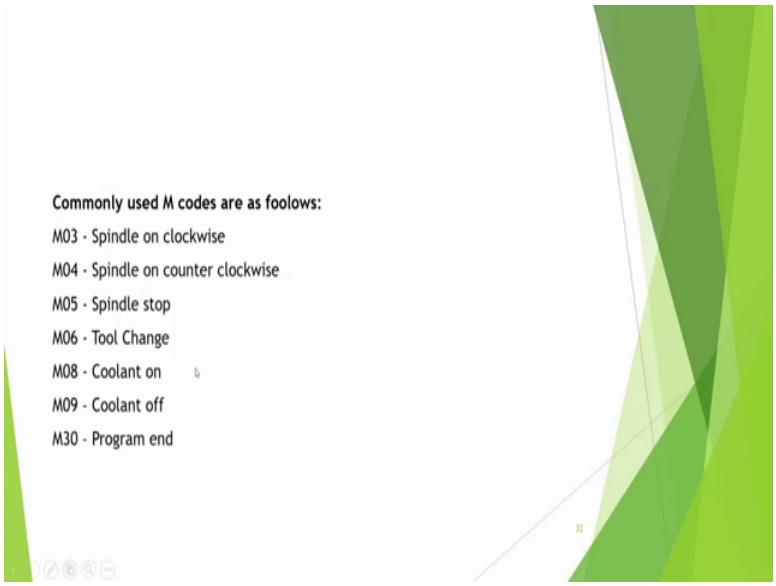

So, commonly used M codes are as follows, I say M03 that means, I want a spindle on clockwise. So, movement the computer gets that command M03, it on the spindle in the clockwise fashion. And M04 is a spindle on counter clockwise, and M05 is a spindle a stop, I stop this spindle. M06 is means tool change ok. And M08 means coolant on if I give M08, my coolant will be on. M09 means coolant will be off. And M0 M30 means program end.

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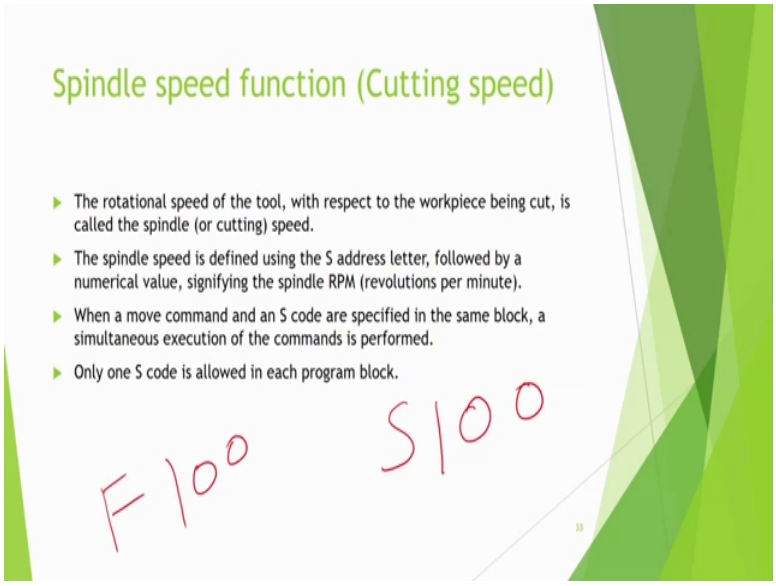

Then is spindle is speed function that means, cutting a speed. The rotational a speed of the tool, with respect to the workpiece being cut is called the a spindle are cutting a speed that means is spindle a speed may be in RPM. The spindle is speed is defined using the S address letter. If I give S that means, computer understands that you are talking about this one S100. He will understand that you are talking about this speed to be kept at 100. If I give F100, he will understand I am talking about the feed.

So, this spindle a speed is defined using S address letter, followed by a numerical value, signifying the spindle RPM that means, revolution per minute. When a move command and an S code are is specified in the same block, a simultaneously execution of the command is performed.

If I give a move command and in that I can put S code also, then simultaneously it will go only one S code is allowed in each program block that means, you cannot write in the same line that you write S100 and S200. If you want 200, then you write a separate line in that separate line are block, you can write about that S200 this one is there.

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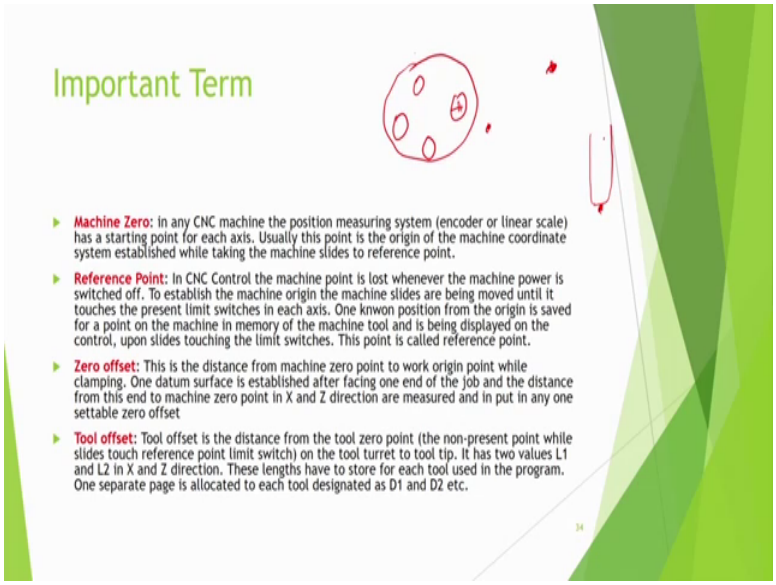

So, now I am going to tell you some important terms related to CNC machine. One is the machine zero, in any CNC machine the position measuring system e it may be encoder or linear scale that you know how to you understand the position that where it is this one. So, encoder is a rotary device. It generally that majors that how much rotation of the ball

screw has taken place and we know the pitch of the ball screw. So, I can know that how much slide has moved.

So, encoder is typically a sensor type of thing that you can understand. Suppose, this is a this can in which I have got this wholes to be in very crude way that. Suppose, I just have four this one type of force and through which the light can pass and other side is a detector. And now you it a (Refer Time: 60:36) at this position it gets one light and it knows gets one pulse. And the next you move at other position, then it knows that I got the second signal that means, 90 degree movement has record.

So, I am just giving the example of that in which there are four holes usually in the encoder, you will have many holes and through which the light is passing, and sensor is detecting. So, it knows the position or it can have linear scale which may work in the principle of interference. And there also there may be a big a scale in which there may be gratings that means, a dark and open binds through which the lights are passing. And he sensor is understanding that how many pulse is I got.

So, how much is the linear movement that type of thing it has understood. So, usually this point is the origin, so we can use the in coder or linear scale to get the feedback. In any CNC machine the position measuring system, which may be in coder or linear scale has a starting point for each axis. So, usually this point is the origin of the machine coordinate system. Establish while taking the machine writes two different point, so that is called machine zero that means, it is in built in the machine company decides that ok, this will be machine zero.

Then reference point is in CNC control the machine point is lost whenever the machine power is switched off. To establish the machine origin the machines slides are being moved until it touches the present limit switch in each axis. One known position form the origin saved for a point on the machine in memory of the machine tool and is being displayed on the control, upon slides touching the limit switch. So, this point is called reference point. So, one reference point is also taken.

Then what is zero offset, this is the distance from machine zero point to work origin point machine zero point work origin may be different machine zero may be different, so that is called zero offset. I can give the zero off set from the program, I know that my machine zero is here, but my work zero is here. So, I can I have written the program

according to my work zero. And I can till the offset, so it will understand. So, one datum surface is establish after facing one end of the job and the distance from the this end to the machine zero point in x and z direction are measured and in and are in putted in any one settable zero offset.

Tool offset is the distance from the tool zero point, non-present point while slide touches reference point limit switch on the tool turret to tool tip. It has two values L1 and L2 in X and Z direction. These lengths have to store for each tool used in the program. One separate page is allocated to each tool designated as D1 and D2.

So, we can have tool upset also, because tools are also of different size. So, we can know that this is the upset ok, so that we can touch it by first by flow by it can know that this is the offset of the tool. And this is the coordinate, and depending on these operations are there.

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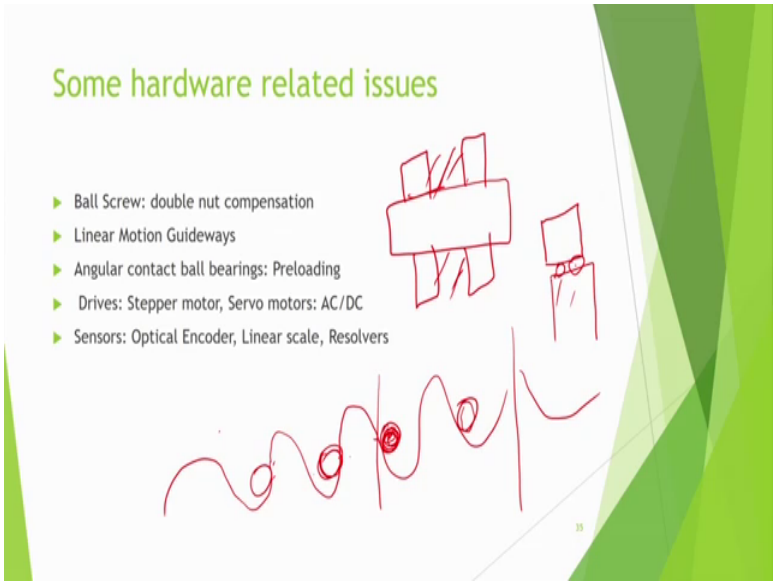

Then there all some other things, I want to tell about that there are lot of hardware related issues. Like we have say ball a screw instead of normal lead a screw in which there are helical have, suppose it is a helical path. I am showing the screw in a crude way and on that top of this there is a nut, nut threads are also helical. So, when this screw rotates, the nut moved.

But, in the ball screw in between there are balls and there are nuts, so that is what that it is moving, and it is a doing. So, it is basically just like a instead of general bearing use ball bearing. So, instead of that nut a screw both are same way. But, now what happens that here in between there are balls and when it is rotating, then the balls are re-circulating. They are moving on the helical path, then they will come back again through the helical path in the nut, and it will go on.

So, naturally these they do not have much friction, because rolling friction is very less. Efficiency may be about 99 percent, but you have to provide some double nut compensation, what is that see use see that here if I have shown the ball in a exaggerated way, so much gap is there. So, suppose I am doing the movement in one direction, then these balls I with I should have shown ok; suppose, I have shown this way and this way.

So, suppose I put two nuts on. In one nut if these two balls are pressings against this surface, in another nut these balls are pressings against these surfaces, then these two nuts are compensating each other that means, when I reverse the direction are though this balls can move freely in here to here, but these balls cannot moved. So, those balls are compensating for other balls.

So, these type of things are there and this is the thing and so that is called double nut compensation. So, usually two nuts are put. So, suppose I am showing from outside, this is screw. So, one nut is there. And in between I put is pressure, this is a pressure and so they pressurize the keep pressings the balls on the opposite sides of the surfaces. So, this is called doubled nut compensation with this the bio polarize is eliminated, and that can be this one.

Since, this ball efficiency is very high. These are reversible type of thing that means, if there is a weight, then the nut will start coming down and a screw will start rotating that means, if I rotate the screw, nut will move. If I move the nut, a screw will start the rotating. So, you have on the z axis when there where there is a heavy load, you have to put a permanent in a break that means, when the power is not there, then through a spring force that break is activated.

And when machine is a start, then only that brick is realized, so that type of provision has to be made. Otherwise, you cannot use ball screw, see you cannot use the ball screw in your bench wise because, otherwise you claim the peace and after that due to elastic

forces. The force will be applied, and it will bench wise will open on its own. So, it cannot be done like that, because there is no self rocking behavior.

Then what are the linear motion guide ways, again the same type of thing suppose I am moving on the guide ways, then I have to put some linear motion. Suppose, in a very crude way this is a slide and on that. There is another slide, which is moving and this guide way, but in between there all balls.

So, precisely it is of that type of thing there may be very different type of design, but they help in the linear motion, so that is these are linear motion guide ways. Then what happens that there is like this one, yes let me let me erase this. And I should explain you angular contact ball bearing ok, it is erasing it here erasing yes, erased yes, let me make it here.

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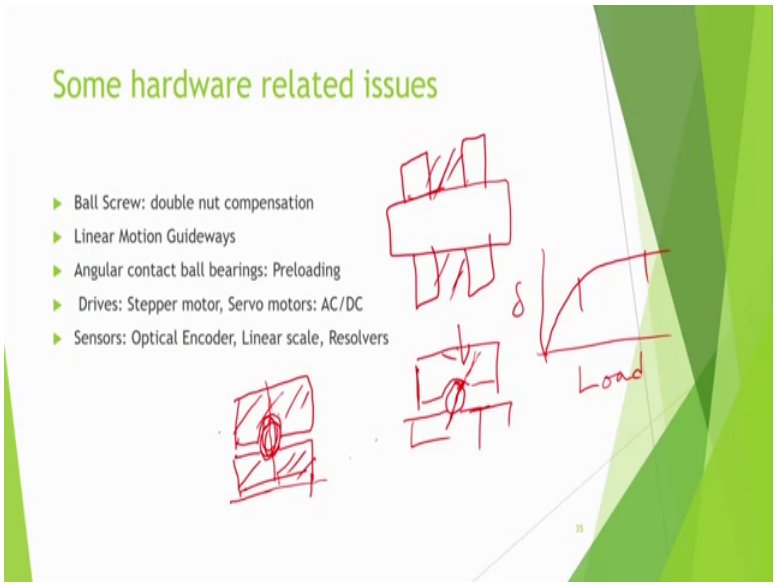

See normally in the radial ball bearing, you may have this type of situation. I have some say outer ways, then ball and inner ways, this type of thing is there I am showing the half view of that. And their some thing your mounting here. Now, you see there are outer race inner race and the it is balls are there. And there is a radial contact, but the force is getting transmitted like this. So, there it cannot support axial component.

In the angular contact ball bearing, it will be little bit displayed and the contact will be angular that means, it will be like this; may be that it is like this, may be another race is

in this position, so that these contact points are making angle. So, depend it may be high angle, high angular contact and are it may be low, so that means if I put a load, that load is getting transmitted here, so that means, it can support the axial component also. Not only the radial component.

So, these angular contact ball bearings are there, but they need to be pre loaded also that means, we have to already apply some compressive load on that. Why? Because, otherwise behavior of these balls is like that load versus deflection if you plot if you have this is load, and this is deflection delta, it is something like that. Initially, if you keep on increasing the load, then the deflection keeps it is not a very this one deflection is very high, but that slope goes on reduce.

After some time more or less, if you increase the load, and deflection will increase only slightly, initially there is only point contact. If you put on that this one point contact will become to some surface contact, and then there will be different type of stiffness. So, lot of change is there in the stiffness.

So, initially itself, you load it like that. If you initially itself, you load, so you will be operating in this region, so that means, further if there is a change in the load. Then that much change in the deflection will not be there that means, already you keep it loaded, so that is called preloading. You know that in this your cycle is spokes also, you already provide them some tension to this one is spokes that is called pre loading.

So, drives can be stepper motors that which take the command, and they move a step by step, one step, two step like that they have got some magnets or it can be servo motors, which takes the feedback about the motors, and they can be AC or it can be DC. Then we can may have to use sensors in which there can be optical encoder as I have told.

Linearly scale or resolver, which basically works on the magnetic principle, it is something that it will sense the position of the rotor. There may be two windings like a transformer and depending on at which particular orientation the rotor is there. Those windings will get different voltages. And that can be compared, so that type of thing resolver. So, either you can use encoder or you can take use resolver, these are this one.

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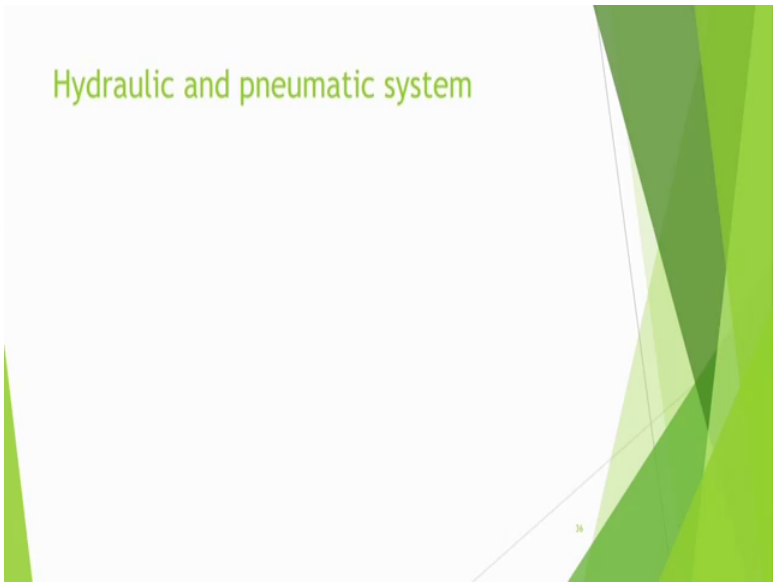

Apart from that in these CNC machines, you have to use lot of hydraulic and numeric systems for movement. But, this will be like this one that my, this means course does not have that a scope, to talk much about hydraulic and pneumatic systems. So, I am leaving at this stage only. And, we will continue to the last lecture.

Thank you very much.