Automation in Manufacturing
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Week – 12
CNC technology
Lecture - 02
CNC machines and interpolation

I welcome you to the lecture 2 of week 12. In this lecture, we will be studying various CNC machine configurations and the concept of interpolation.

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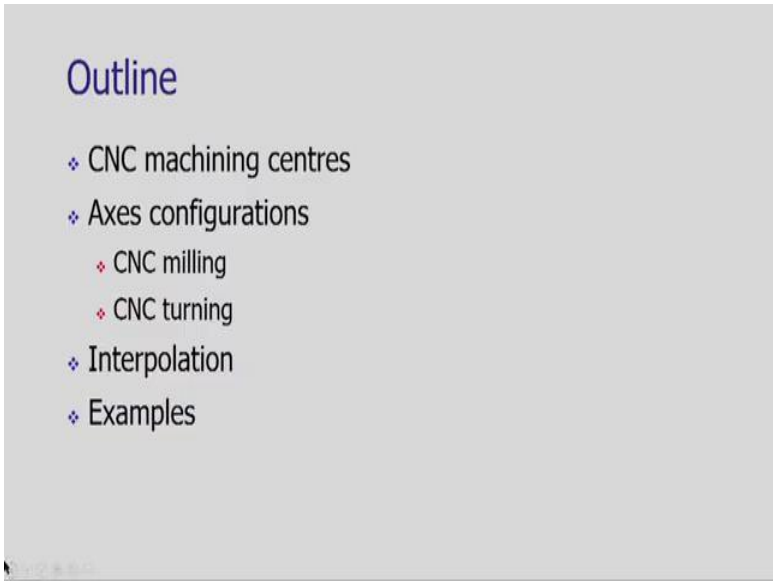

The outline of the lecture is in front of us. In this lecture, we will be studying various CNC machining centres and their configurations, what are the various elements of the CNC machining centres. For CNC milling and CNC turning operations, what are the various access configurations being utilised in the industry, we will have a discussion on that. After that we will see the important concept that is the interpolation.

Based on interpolation only, the machine control unit is controlling the axis movements of the machine tools. We will solve certain examples to understand the concept of interpolation.

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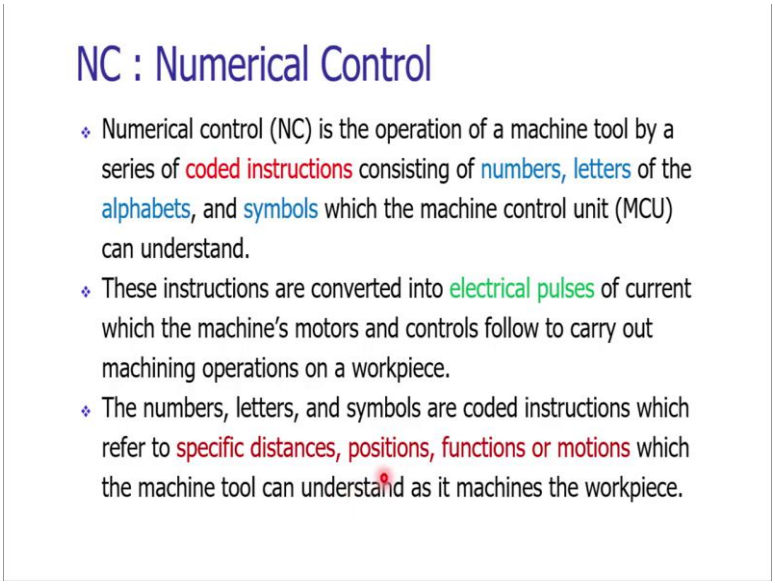

Let us begin the lecture 2. The numerical control technology popularly called the NC technology is widely used in the industry nowadays and now we call the NC technology with the addition of computers with integration of computers or we can call the assistance of computers, is a computerised numerical control technology.

The NC technology in which we are controlling the machine tools, we are controlling the operations of machine tools by using coded instructions. We have to send instructions to variety of elements of a typical equipment or a machine tool and that we need to code them.

What the instructions are having? The instructions are having the numbers, letters, various alphabets and symbols. These numbers, letters, alphabets and symbols are arranged in a typical format and that format is given to the control unit of that machine, control unit of that equipment and that is called as the machine control unit, the MCU.

These instructions will be converted into the electrical pulses by the machine control unit. And that electrical pulses of current are operating the motors, and they control the various machining operations or the processing operations.

These numbers, letters and symbols, which are there in the coded instruction format, they are referring to specific distances that to be followed by the axis, that to be followed by the drives, positions of many elements such as tool, work piece, inside the work volume, many functions

need to be carried out such as coolant off, coolant on, door closed, door open, changing the cutting tool.

These coded instructions are written in a format which can be easily understood by the machines machine tool, and which can be easily be developed or written by the programmer or the end user.

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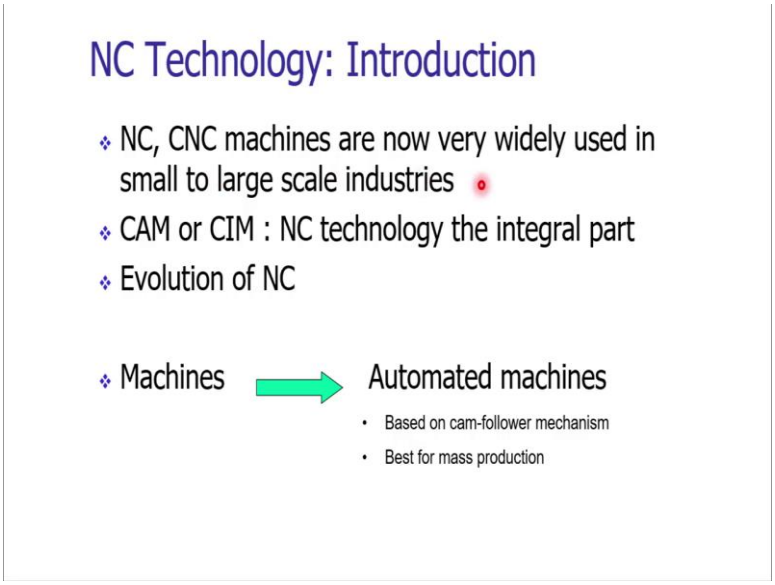

As mentioned, the NC or the CNC machines are now very widely used. They are very popular in the industry from the small scale industry to the large scale industry. In tool rooms as well these machines are widely being used. As far as the CAM philosophy is concerned or the CIM that is computer integrated philosophy is concerned, the NC machines or NC technology based equipment are now integral part of these systems.

Let us look at the evolution of NC. The NC was being developed in the mid-1950s. Earlier as we know that machines were developed in 16th century which are converting one type of motion to the other type of motion, and they are even transferring the forces as well.

With the advent of the cam follower mechanisms started developing in 18th century. And these automated machines were utilised for the power generation and the loom application that is the textile applications.

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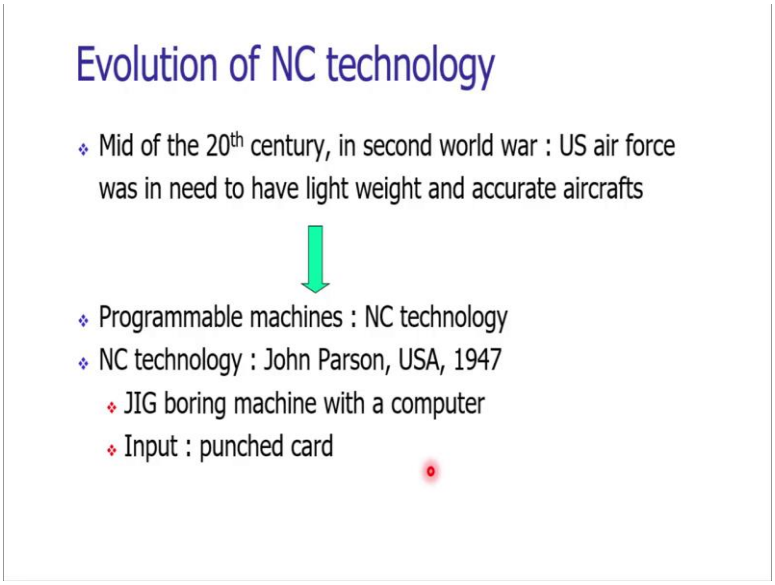

Well in the mid of the 20th century, around 1950s, during the Second World War, the US air force was in need to have a light weight and accurate aircrafts. For that purpose, they were trying to have a technology which will generate freeform surfaces. They want to develop a supersonic aeroplanes which will move in a very rapid way. For that purpose, the aerofoils need to be generated. To machine the aerofoils we need to have the freeform surface machining.

US air force approached MIT in USA, and they developed the NC technology in collaboration with MIT. John Parson has been considered as the pioneer engineer or scientist who developed the NC technology. Initially he used the NC technology for jig boring machine with computer, and the input was the punch card system.

But the problem with punch card is that to have very small program, even the punch card length used to be in metres and the storage would be very difficult. In case of editing of the program, we need to scrap, we need to discard the entire the punch card.

For that, we need to have a technology which can help us for the editing as well.

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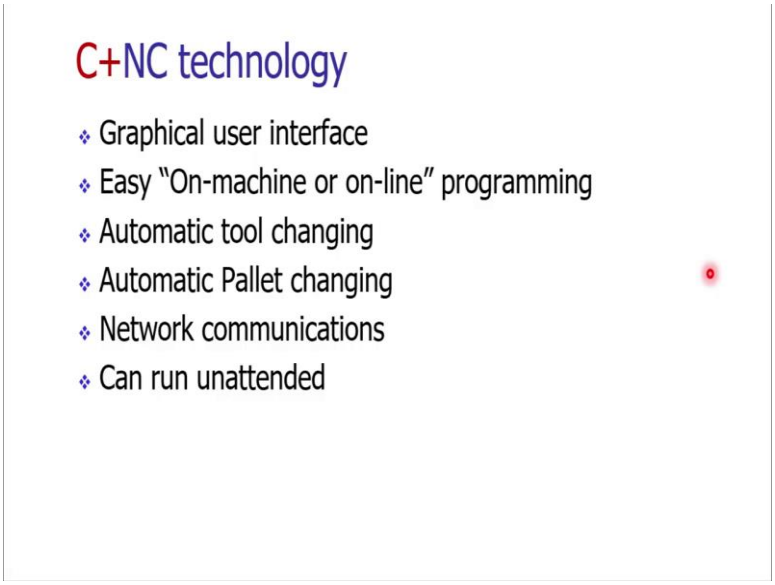

With the advent of computers in 1970s, the NC technology got tremendous popularity due to its powerful capability of editing the program online, and the memory storage capabilities. The computers are helping to have graphical user interface where you can check the NC program, you can edit the NC program, you can modify the NC program or you can even simulate the NC program. Graphical user interface made the NC technology very user friendly.

We can do the machine or online programming easily. With the use of the computers, we can automatically change the tools. We can have the facility of palette changing as well. With computers, it was very much possible to communicate with the variety of machine tools around and to have the control of variety of machine tools by using a single computer, so that we call the DNC – direct numerical control.

A single computer is controlling the operations of the variety of numerical control machine tools. With computers, now it is possible to have the machine tools run unattended. There is no need of any human intervention to operate the machine tools.

We can say that once you set the program, once you upload the program, and the program has started working and it is controlling the operations in the machine tool it can be run unattended.

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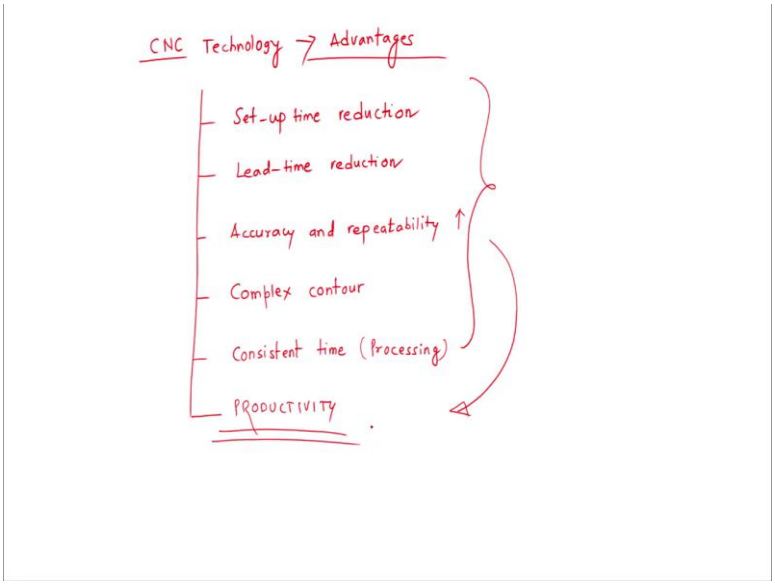

The CNC machine tools offers various advantages. We can list the advantages. The first advantage is that there is a reduction in setup time. In CNC machine operations, the tool is being set by the machine tool itself, so that is helping to reduce a lot of time.

That setup time reduction is leading to reduction in the lead time as well, the lead time reduction. The CNC machines are improving the accuracy and repeatability of the process, accuracy and repeatability is getting improved.

We can manufacture complex surfaces; we can have complex contours easily manufactured which otherwise is difficult by using conventional machine tools. We can have the consistent cutting time. As the entire process of manufacturing is automated the processing time is consistent processing or the cutting time is consistent.

It is easy for us to monitor, to have the record of the processing time. In general, all these factors are contributing to improve the productivity. The productivity will naturally will improve with the utilisation of the computer numerical control systems.

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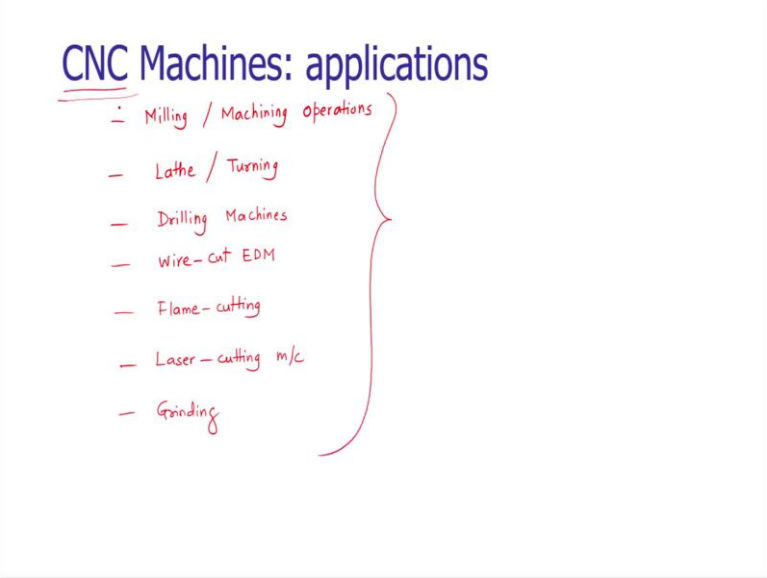

What are the various applications of CNC machine tools in the industry? We can use the CNC machines for milling operations and machining operations. We are also using it for lathe operation or turning operation; for drilling operations, drilling machines, for wire cut EDM, for flame cutting operations, for laser operations, laser cutting, laser based cutting, for grinding operations as well so on and so forth. There are enormous applications of the CNC technology in the manufacturing industry in the machine tool.

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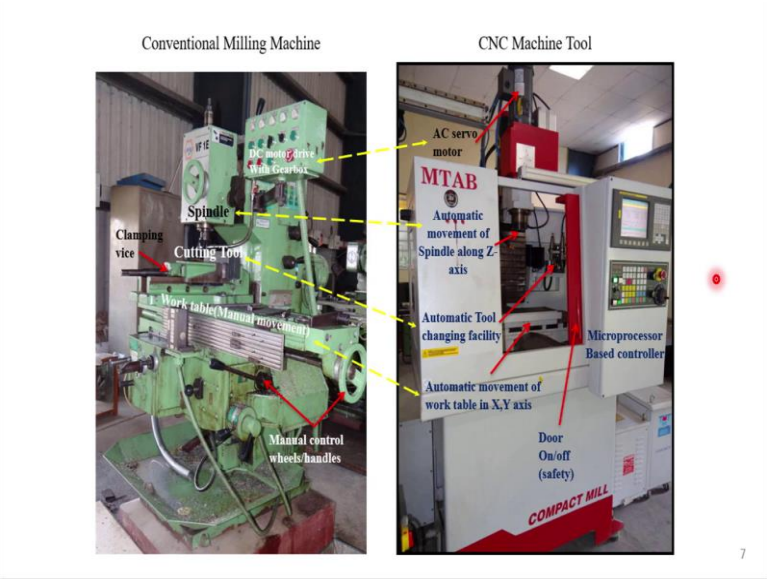

Now, let us take a simple example of the conventional milling machine and how the computers are helping to improve its performance. On our screen, we can see a conventional milling machine. It is having a spindle and there is a table. On the table, the clamping vice is there. And in the clamping vice, we are holding the work piece.

This is the spindle. This is vertical milling machine. And on the spindle, we are having the cutting tool. This is the DC motor drive with gearbox. By changing the gearbox settings, we can have a variety of the cutting speeds.

The work table is manually controlled; in the tool movement is also the manually controlled. The manual control wheels you can see on the screen. It is a complete manual control machine tool. Once the rpm has been set by the operator, the operator has to operate the wheels, and accordingly there would be relative motion between the cutting tool and the work piece.

The accuracy, the productivity is entirely dependent upon the human being that is the operator. As mentioned when we want to manufacture the complex surfaces, when we want to manufacture the complicated parts at mass scale at a higher scale, then we need to incorporate we need to take help of the mechatronic based system, and that is the purpose of this course, the automated system.

We can automate the process to provide the automatic movement of the z axis, automatic movement of the x and y-axis, and it is to be controlled by a microprocessor based controller. When we are carrying out the automatic movement, we need to monitor their performance, we need to monitor their movements. For that purpose, we need the mechatronics based the hardware which we have seen in our previous lectures.

We can automate or increase the productivity of conventional machine tool by providing the automatic tool changing facility. Auxiliary facilities such as coolant on and coolant off, all the things can be automated and these are automated by the CNC technology.

With the use of computers and mechatronics based systems, we can easily have a productive, accurate and reliable machine tool. The CNC machine tool is considered as the best and simple example of the mechatronics based system in the manufacturing industry.

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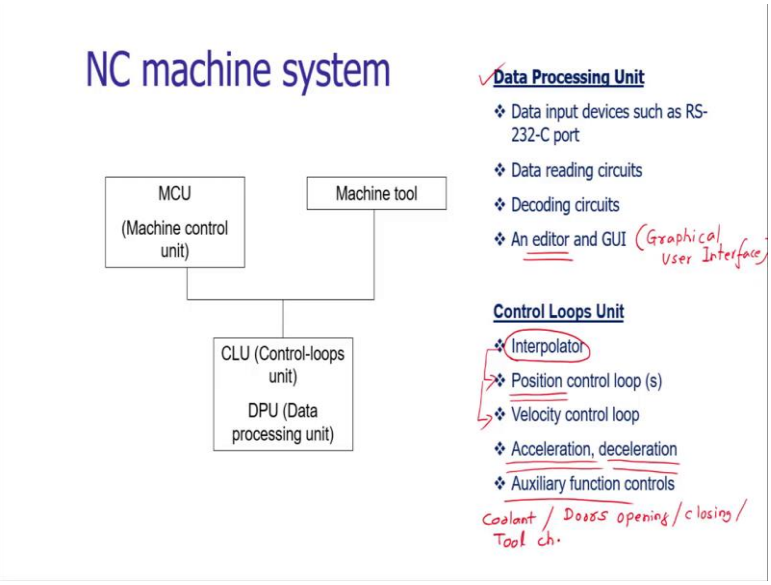

The NC machine system is having basically three parts. The first part is the machine tool, the hardware of the machine tool; the various elements such as the bed, table, cutting tools, spindle, various drives.

Then we need to have a machine control unit. This is an electronics hardware. It is controlling the various axis movements of the machine tool. It is giving signals to the machine tool elements and getting the work done.

There is a control loop unit as well. It is also called as the data processing unit. The data processing unit as the communication ports such as RS-232 C which was earlier nowadays with the USB as well we can have connection of the machine tools with the computers.

Nowadays, we also have the wireless connectivity with the machine control unit. The data processing unit has a data reading circuit, further there is a circuitry which is decoding the data given to it. It is decoding the instructions signals given by the microprocessor. It has an editor and graphic user interface.

Through data processing unit, we are entering the data, we are inputting the data to the CNC machine tool to the CNC equipment. We are editing that data, we are editing the instructions, and then that instructions will be given to the control loop unit.

The control loop unit is having an interpolator algorithm. And that interpolator algorithm is generating the signals that to be given to the position control loop. Based upon the distances

provided, based upon the locations provided in the CNC part program, the interpolator will generate the signals, and that signals are given to the position control loop and the velocity control loop.

Based upon the signals generated by the interpolator, the acceleration and deceleration of the drives will be decided. The control loop units are also carrying out the auxiliary function controls. For example, the control of the coolant or the doors, doors opening and closing, and the tool change operations.

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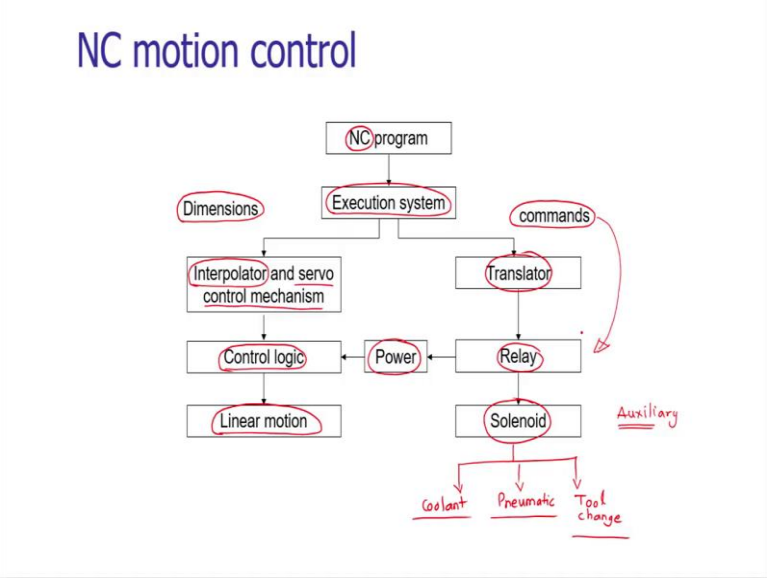

Now, let us see how the NC program is being executed inside a NC based machine tool, how exactly we are getting the motion control by using the numerical control. The NC program is given to the execution system. It is transferred to the execution system, which is basically taking out the two information's.

The first information is about the dimensions: what are the various dimensions, the distances or the position that to be achieved that to be controlled. And the second one is the commands or the auxiliary commands that to be carried out in the machine tool operations.

Based upon the detection of various dimensions, based upon the detection of various positions which are given inside the NC program, the interpolator will compute the distances, and that signals will be given to the servo control based mechanisms.

Servo control based mechanisms are basically used as the closed loop mechanisms, closed loop control systems. The servo control mechanism is utilising the control logic, and then they are generating the linear motions of the drive.

The control logic is also getting operated with the relay when the control logic is given to the variety of drive systems. Basically the CNC machine tools are using lot of servo motors, and these electrical motors are to be operated by using the relays. They also need the power that to be switched on and switch off during the operations.

Variety of commands which are related to the auxiliary operations as mentioned are coolant on-off, or change in the tool. These commands will be translated and that translated information will be given to the solenoids – these are the electromechanical the switches that solenoids are operating the auxiliary equipment.

It may be the pneumatic equipment, for example, opening of the collet during the tool holding operation or a tool clamping operation, it may be utilised for the door open and door close, it may be utilised to make the motor of the hydraulic pump on, coolant operations, the pneumatic operations, and the tool change operation.

Variety of auxiliary operations will be controlled by the solenoid, and that would be based upon the commands given by the execution system.

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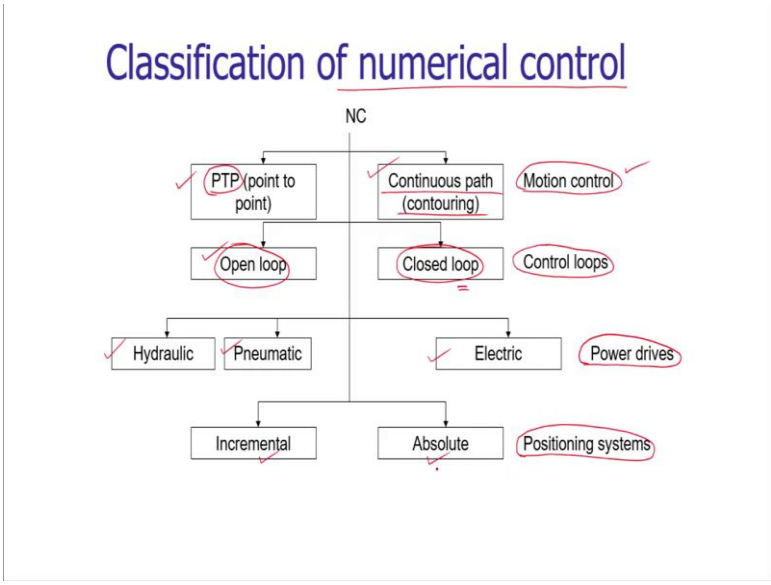

Now, let us see what are the various types of numerical control, what are various classes of numerical control, which are used in the industry, how can we classify the numerical control. To carry out the task, let us first take the motion control type.

The motion control, the motion control of the axis of the machine tool. When it is required to have the point to point control, so we are not bothering about the path that to be followed by the machine tool only we are interested to have the positions or the features that to be followed. That kind of numerical control it is called as the PTP numerical control.

When we are trying to have the contouring operations and when we are trying to manufacture the complex surfaces or contour contouring or the machining operations, in that case we need to bother about the continuous path that is being followed by the cutting tool.

Then we can have the classification based on the control loops whether the system is open loop, whether it is utilising the feedback from the drives, whether it is utilising the feedback from the various output devices.

The next is the control loops we can classify we can have two types – the open loop and the closed loop. In open loop, there is no feedback from the output devices. The motors are rotating and they are translating, they are converting the rotary motion into the translatory motion of the work table, but there is no feedback from the movement of the work table.

As far as the closed loops are concerned, there is feedback. There is monitoring of movement of the work tables or the output devices. And based on that, we are changing the process parameters. We are varying; we are editing the process parameters. In certain CNC based machine tools, we are having the adaptive control; the control unit itself is taking the decision to change the process parameters based upon the feedback given.

The next classification we can have based on the power drives when we are using electric motors, it is the electric drive based numerical control; certain CNC machine tools are utilising the hydraulic and pneumatic drives as well.

We can have a classification based upon the positioning system what kind of positioning system the machine tool is following whether it is incremental or the absolute one. We will be seeing what is the meaning of the absolute and the incremental positioning system in the next slides.

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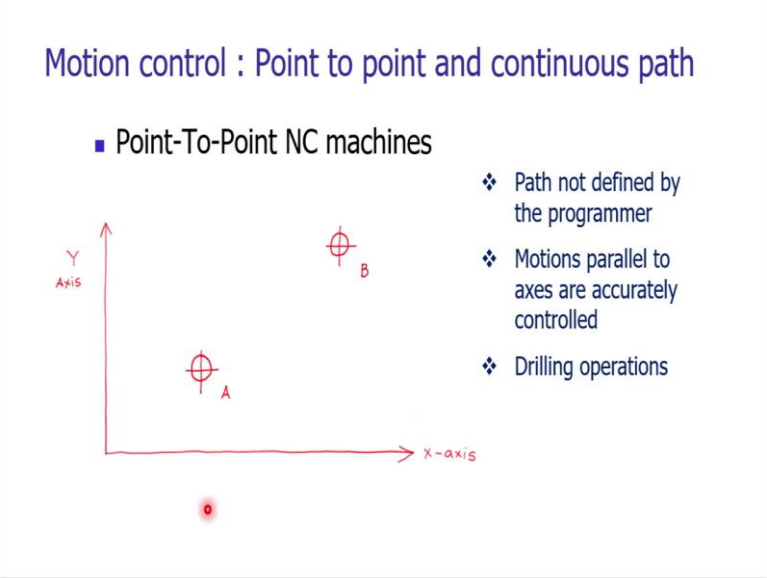

In point-to-point NC machines, it is interested to have the locations only. Consider in drilling operation. We need to carry out the drilling operation at A and a drilling operation at point B. The programmer is setting up these locations through the instructions in the program and that instructions will be converted into the required electrical signals by the MCU.

The programmer in this case is not defining the path. The machine itself is taking the decision it is generating the path from A to B. Either it may be from A to B in this way, or it may be from this way as well. In general, the point-to-point machine tools are very good when the motions are parallel to the axis and they are popularly used for the drilling operations.

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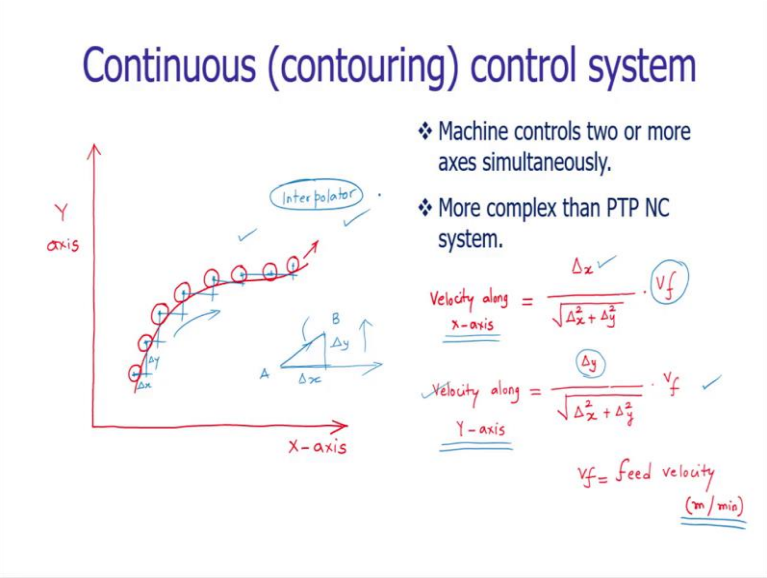

In continuous or contouring control system two or more axes are to be controlled simultaneously. On our screen, we can see there is a curve, and we need to manufacture these type of curve this type of contour on the CNC milling operation. To have such a curvilinear motion, we need to control two or more axes simultaneously. The control system which is providing the control of movement along x and y-axis simultaneously is called as the continuous control system, continuous contouring control system.

The controller is computing the velocity along the x-axis by using this correlation.

$$Velocity\ along\ x-axis = \frac{\Delta x}{\sqrt{\Delta x^2 + \Delta y^2}}.V_f$$

where V_f is the feed velocity that to be that is decided by the. Based on that, we can easily compute the velocity along the x-axis by using this correlation.

Consider we need to move along the inclined motion from point A to point B. To reach point B from point A, we need to move along the x-axis by distance Δx, and along y-axis we have to reach by Δy.

The velocity to reach point B is dependent on this correlation. The drive which is controlling the x-axis will have the velocity given by this formula. And the drive which is responsible to have the motion along the y-axis is generating the signals by using this correlation.

The velocity along the y-axis can be computed by using:

$$Velocity\ along\ y-axis = \frac{\Delta y}{\sqrt{\Delta x^2 + \Delta y^2}}.V_f$$

This control system will compute the delta x and delta y for all such points along the contour path based on this information, we can easily compute the velocity.

In this way, we can easily compute the next positions, and how to compute this position, so for that purpose the interpolation algorithms are using that is the task of the interpolator. We will be seeing the interpolator in the later slides of this lecture.

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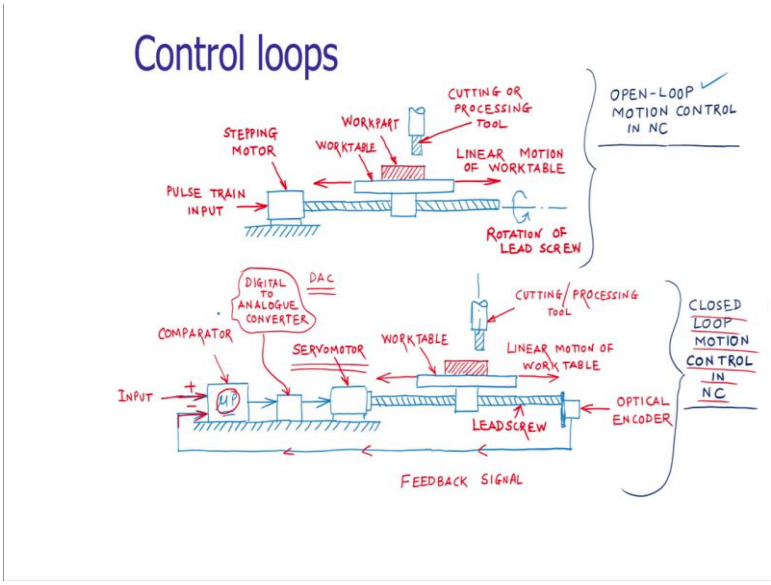

Basically two types of motion control NC configurations are used. The first one is the open loop NC configuration. On our screen, we can see there is a table. And that table is engaged to the lead screw, this is the lead screw, the ball screw which we have seen in our previous class in mechanisms.

The ball screw is driven by a stepping motor or a stepper motor. And that stepper motor has been given the inputs by the microprocessor pulse train input is provided to the stepping motor. The stepping motor is generating the pulses, and that pulses are given to the lead screw the ball screw, the ball screw is rotated.

As the ball screw is rotating, there is translation of the work table linearly. On the work table, we are having the work part, and that work part will move with respect to the cutting or the processing tool.

In this case, we are not taking the feedback from the rotation of the lead screw. There is no feedback, there is no information whether the work table has reached the destination or not. To get the information about the destination to get the information about the performance of the motion, performance of movement, we are using the optical encoders, and that optical encoders are monitoring the rotation of the lead screw and they are giving that information to the comparator.

Comparator is having the input from the microprocessor. It will compare the standard thing, it will compare the desired value, it is comparing the input given by the microprocessor, the true value and the value it is getting from the optical encoder.

The comparator is comparing the values, and it is sending that to the microprocessor and microprocessor accordingly changing the values that to be passed to the servo motor. To changing the control signals of the servo motor, but as we know that servo motors are the analogue devices, so we need to have the converter which is converting the digital signals into the analogue format.

We need a DSE device, which is converting the signals received from the comparator and it will generate the analogue signals to control the motion of the servo motor.

In this way the closed loop systems are also being utilised in the industry or we can have a simplified version we can have a very basic version that is the open loop of the NC control unit. Of course, the cost associated with the closed loop control system is quite high because of the utilization of the sensors and the devices such as comparator and the servo motor.

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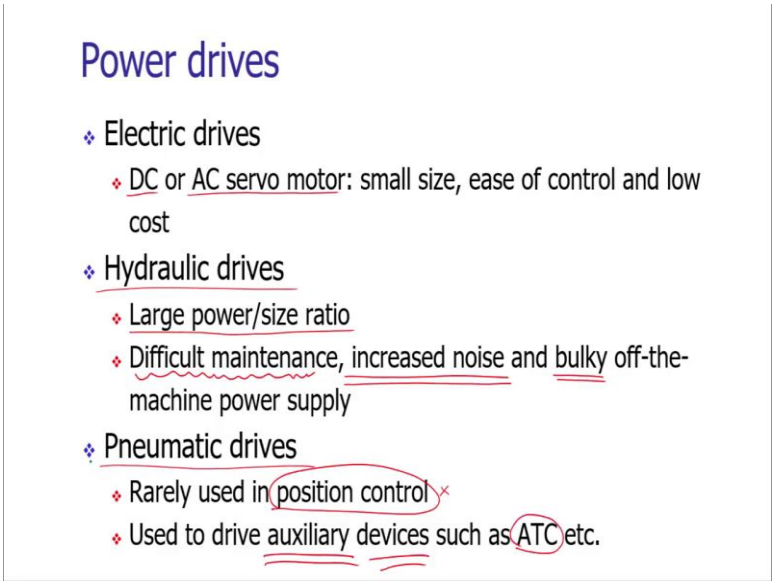

The NC machine tool configurations can also be classified based upon the drives. There we are using the DC or the AC servo motor drives, these are the electrical drives. Or we can have the hydraulic drives. For example, the CNC based shaping tools, shaping machines – they are using hydraulic drives. Hydraulic drives are providing very large power to size ratios.

However, it is difficult to maintain the hydraulic drives because of involvement of many devices. It requires its own motor; it requires the hydraulic power pack, the tank, filters, the coolers, various control valves. Many equipment is required in the maintenance of the hydraulic based drives, that is why quite tedious. Sometimes the hydraulic drives sometimes are increasing the noise. And of course, they are bulky – the weight of the machine tool would be very high.

Some machine tools are using the pneumatic drives as well. For position control, they are rarely being used. And they are using basically for the auxiliary devices. These drives are not very accurate that is why they are not used for the position control. For auxiliary devices such as automatic tool changing operations, the pneumatic drives are used.

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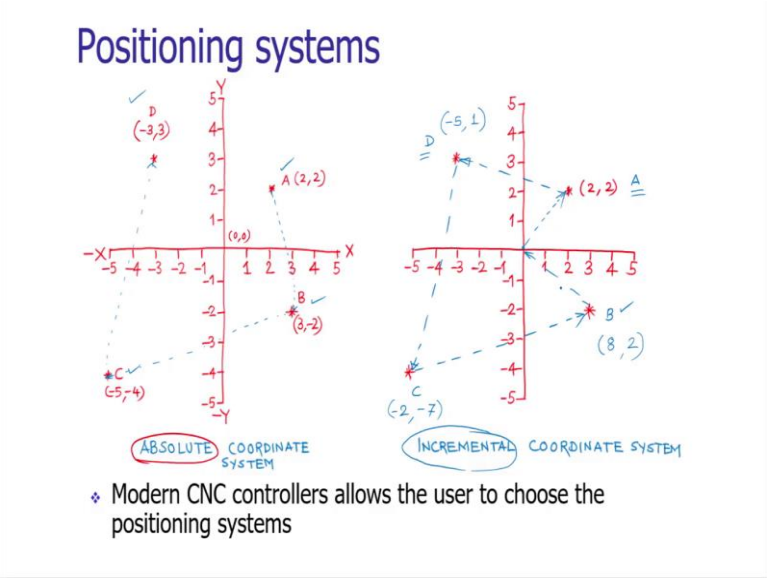

We can configure the CNC machine tools or the NC machine tools based upon the positioning system. In general, we are using two types of positioning system that is the absolute coordinate position system. An absolute coordinate position system the points in are instructed the points given in the CNC code are in terms of the absolute format.

They are with respect to the origin of the coordinate system itself. For example, there are various points can be seen on your screen. These are point A B, C and D. And they have been provided with respect to the origin; their positions are provided with respect to the origin.

Consider we need to manufacture a loop or we need to give a contour operation from point A to B to C and D, then we have to just specify its control units in this way. We have to specify the locations in absolute way and then the operation will be carried out. Now, let us consider if you want to give that into the incremental format, so to utilise the incremental coordinate system the path is very essential.

How it is very essential? For example, point A and we need to move from point A to point B, point C and point D. In incremental coordinate system, we are defining the location of a certain point with respect to its previous position, with respect to the coordinates of its previous location. It is not with respect to its origin. Consider a path is to be followed from point A to point D, from, from D to point C, and from point C it is to be B, and then back to the origin.

In this case from point A, the location of point D would be that we need to see in how many positions the point D is away from point A in x direction, and how many positions how many units it is away from point A along the y direction. Here we can see the absolute coordinates of point D are (-3, 3); here it is (2, 2). But now for how much distance we need to move from point A to point D that has to be mentioned.

How many units are there? 1, 2, 3, 4, 5 that is along the negative x direction. It can be written here, it is -5 along x direction. And how many units along the y direction? There is only one unit along the y direction. From 2 to 3, it is only one unit along y direction in a positive direction y that is (-5, 1). This is the incremental way of designating the location of point D with respect to point A. Point A has been designated with respect to the origin. Now, here if here starting from the origin.

Now, from point D how far the point C is, so that we need to find out. Point C is -5 in absolute, and point D is -3 in absolute. We need to move along x direction by two units.

We need to move along negative x direction from D to reach the point C. The C is on the left side. To reach C from point D along the negative x direction by - 2 units, and to reach point C along y direction we have to travel around 1, 2, 3, 4, 5, 6 and 7 units along negative y direction.

Similarly, if we want to go to point B from point C, how many units we need to travel along the x-axis 1, 2, 3, 4, 5, 6, 7, 8, around eight units along positive x direction. Along y direction how many units? 1 and 2, so the positive y is 2 units.

Here the path is very essential. Here the direction of motion is very essential. From zero – from origin to A, it is two units along x, two units along y; from A to D, it is - 5 units along x direction, and one unit along y direction. From D to C, it is - 2 units along x direction, and - 7 units along the y direction. From C to B, it is 8 units along x direction, and 2 units along the y direction.

In this way the incremental coordinate system is providing us the incremental way of movement in the NC operations.

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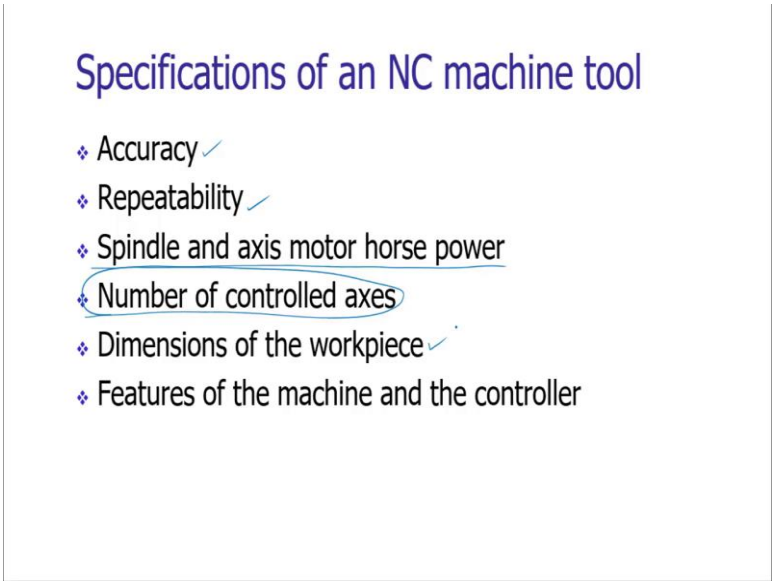

How do we specify a typical NC machine tool? We are defining the NC machine tool performance based upon its accuracy. Second point is the repeatability. The power that machine tool is providing us, spindle power as well as the axis motor power that is the horse power.

The number of controlled axes, whether it is a two axes control CNC machine tool, or it is the three axes CNC control machine tool, or it is or multiple axes are provided in the machine tool. The work volume that is being handled by the machine tool that is nothing but the dimensions, the features of the machine and controller what the advanced features the machine tool is having.

Nowadays, we are talking about the adaptive control. Nowadays, we are talking about the utilization of artificial intelligence. Whether the machine tool has the sensors embedded inside that what extra features the machine tool is carrying out whether it is able to communicate with other machine tools.

The control facility, the communication facility, the advanced sensing facility, all are adding up to the specifications of the machine tool in terms of the variety of features.

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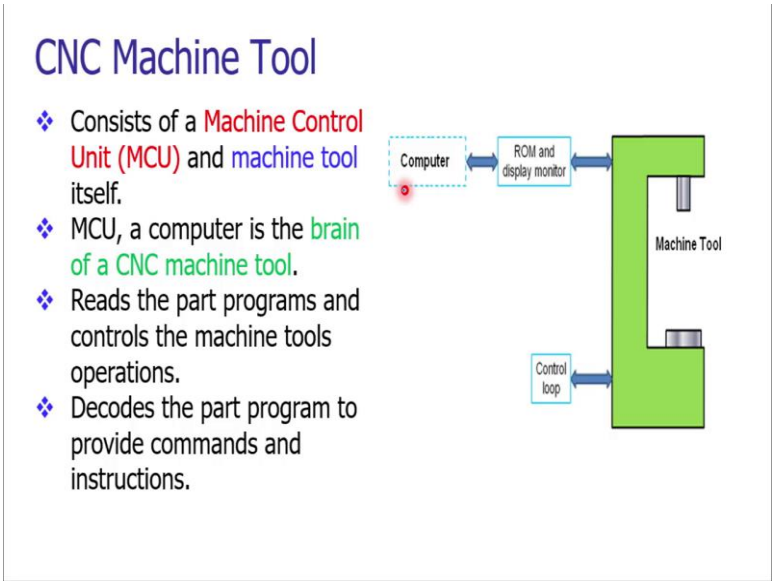

A typical CNC machine tool is having a MCU that is machine control unit. And the machine tool itself the control unit is controlling the operations of the machine tool. We can see, there is a computer which is controlling the machine tool operation. There is a display monitor and there is a there read only memory through which it is controlling the operations.

There is a control loop and that control loop is monitoring the performance of the machine tool and sending that to the computer.

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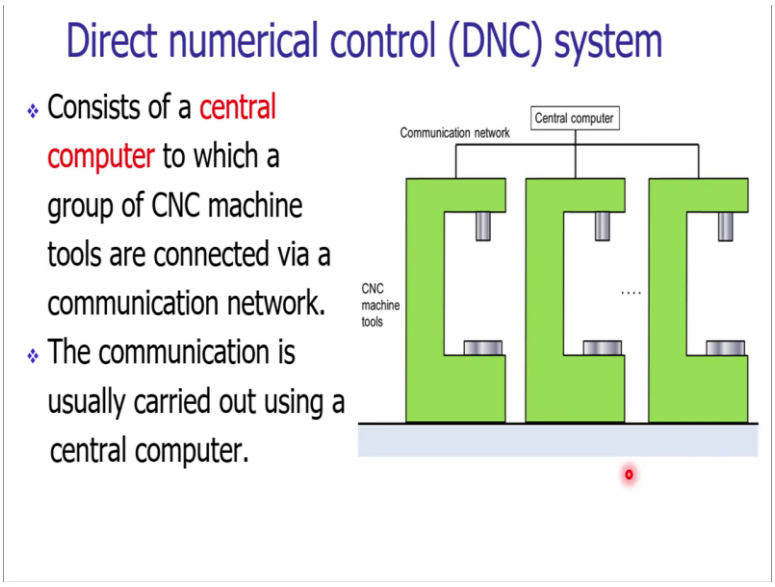

In direct numerical control type of system, there is a single computer that is called as the central computer, and that central computer is controlling the operations of a number of CNC machine tools. The communication of the central computer with the CNC machine tools will be carried out by communication network. We can have the communication through the local area network that is a LAN or we can utilise the Wi-Fi that is the wireless networks as well.

Here the advantage is that a single computer is controlling all the operation. It is easy for us to coordinate the variety of operations which are being carried out in a machine cell. As we have seen that the group technology is having a cells, physical cells are the virtual cells which are comprising of dissimilar machine tools.

At one location, all the data would be there in the central computer, and through which we can easily control the variety of machine tools, so that is called as the direct numerical control systems.

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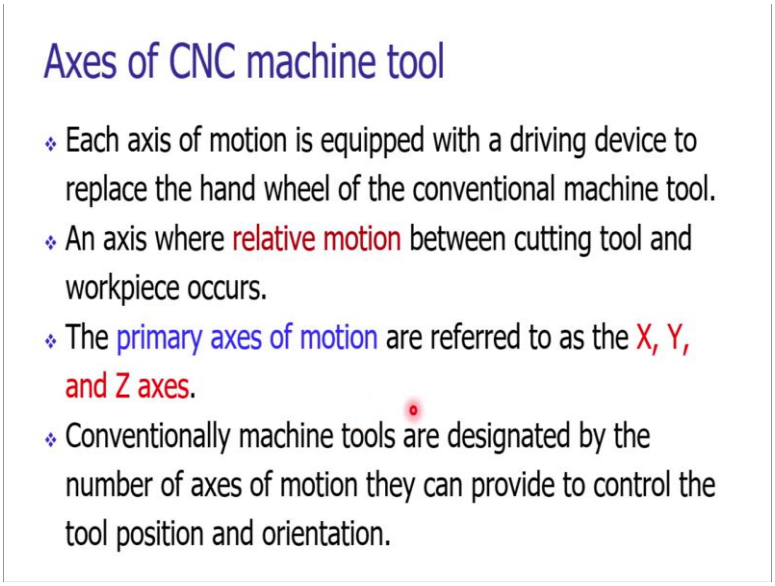

The CNC machine tools are designated based upon various access configurations. Each axis of motion is equipped with driving device that to replace with the hand wheel in conventional machine tool. Each axis is having its own driving device, which is the replacement to the conventional machine tool.

The axis also can be defined as along which we can have the relative motion between the cutting tool and the work piece. In general, the machine tools, in general the CNC machine tools they do have the primary axis of motions which are designated as X, Y and Z.

Conventionally we are designating the machine tools by the number of axes of motion which we can control during its operation. These motions can provide to control the tool position and the orientation.

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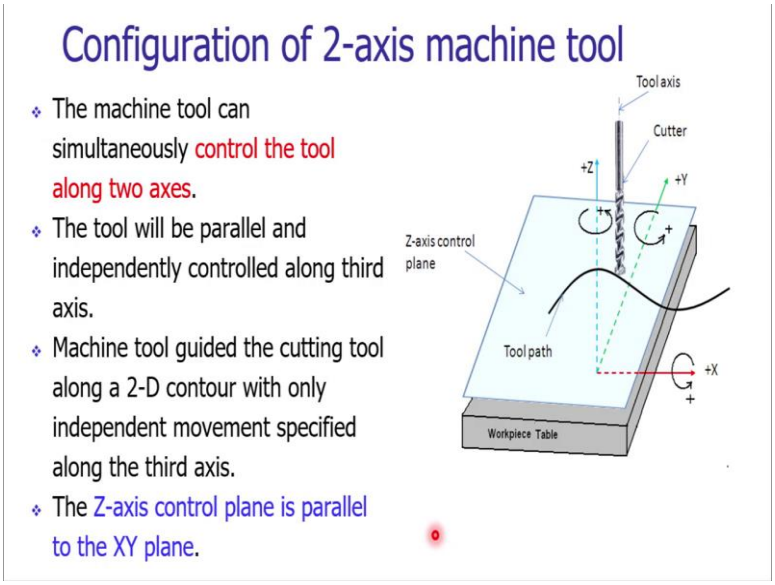

Let us look at the various configurations of the axes control movements. The first one is the configuration of 2-axis machine tool. On our screen, we can see a work table and there is a cutting tool or a cutter.

Along this direction, we are considering as the positive X, this is negative X. Perpendicular to the positive X in the same plane we are having positive Y, and towards us is negative Y. Along the cutter direction we are having the positive Z, and away from the cutter movement it is the negative Z.

This configuration suggests that the machine tool can simultaneously control the tool along two axes. We are having the cutting tool which is along the Z direction, and there is a work piece table over which the work piece would be held by having the relative motion of the work piece with respect to the cutting tool the machining operation would be carried out. This

configuration is suggesting that the tool movement with respect to the work piece would be in two directions simultaneously.

In this case, the cutter is rotating, and it is independently moving with respect to X and Y direction. In this case, we are moving the tool in a downward direction for whatever the length of the cutting depth that we want, and then it would be rotating at that location only.

The cutting tool will not move; now we are moving the work piece with respect to the X and Y direction simultaneously. As we move the table in X and Y direction simultaneously, there would be the relative motion of the cutting tool with respect to the work piece in XY plane only simultaneously.

Let us consider this. This is the curvilinear motion which is there in the XY plane. This curve tool path is in XY plane. The tool is rotating at its own position. It is not moving along the Z direction when the table is moving along X and Y direction. Only two axes are being handled or being controlled by the NC machine tool. Here it is to be noted that the axis of the cutter, tool axis is parallel to the Z axis.

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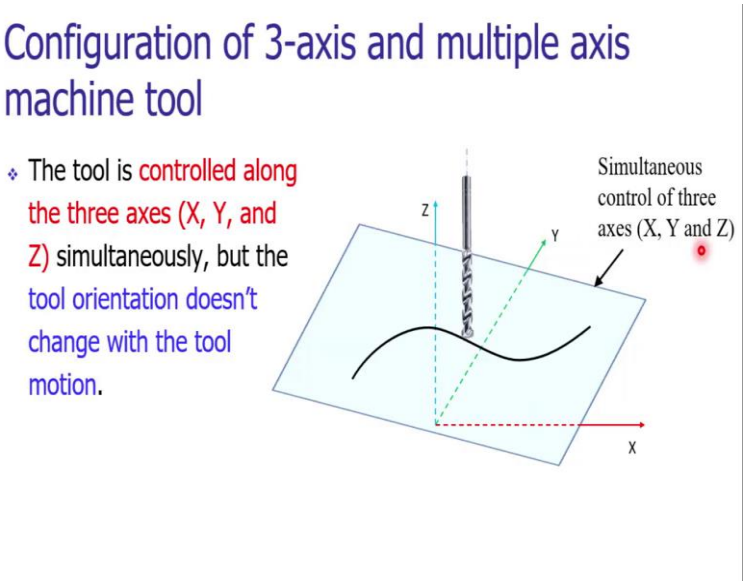

When we are saying that there is simultaneously control of three axes, in this case we are trying to control the Z-axis movement, we are trying to control the movement of the cutting tool along with the movement of X and Y direction. Table is also moving and the spindle which is carrying

out, the spindle which is carrying the cutting tool that is also moving along the Z direction simultaneously.

When the axis of the cutting tool is parallel to the Z-axis, and there is simultaneous motion of the Z along with X and Y-axis that is called as a three axis configuration. When we are having the inclination of the cutter axis with respect to the Z-axis, then we are adding the additional axes to the configuration.

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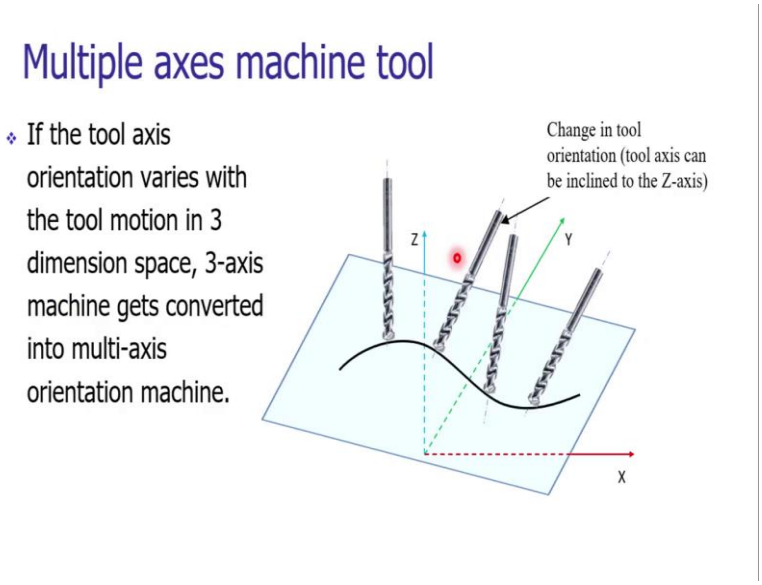

That can be seen on our screen. Here the tool orientation has been changed. The tool is not parallel to the Z-axis. By giving orientation, by giving inclination to the tool with respect to the Z-axis, we are adding more number of axes configuration. To have these kind of facility, either we can give another drive to the spindle head or we can give another drive another axis movement to the work piece table as well.

For example, in this case, the work piece table can be rotated about Z-axis; or in this case, we can have the rotation about the spindle head axes as well. In this way, by giving additional hardware, by giving advanced hardware, we can equip the CNC machine tools with multiple number of axes, and we can generate the complex surface machining components such as the turbine blades which we have seen in our the initial lectures.

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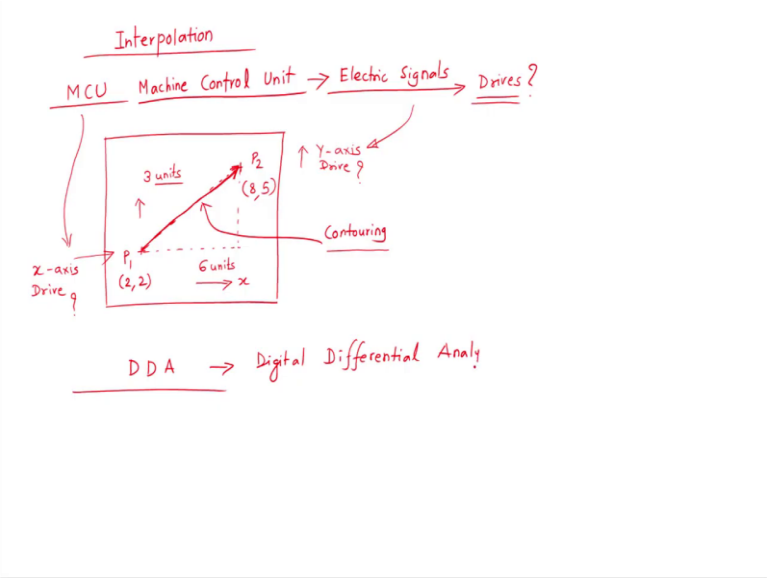

Now, let us study an important aspect in NC machine tools and that is interpolation. We have seen earlier that there is MCU that is machine control unit. And this machine control unit is generating the electrical signals which are controlling the drives. Now, how these electrical signals are controlled based upon the geometry which is given that that is the task and that we need to study. For that purpose, the interpolation algorithms are being utilized.

Let us consider one example. We are having a point P 1 the location of point P 1 is 2, 2. And we are having another point P 2 and it is location is 8 and 5. Now, we need to ask the controller to move from point P 1 to point P 2. Along X direction, there is movement of about 6 units; and along Y direction, there is movement about 3 units.

It may be mm if it is a micro machining centre, it is centimetre or metre if it is a macro or meso level machining centre. 6 units are to be moved along X direction, and 3 units are to be moved along Y direction. And the path is essential; the path is important. This is the task of the contour manufacturing contouring.

Now to move from P 1 to P 2 along this direction, along this path, we have to give signals to the motor which is controlling the x-axis, the x-axis drive, and there is a y-axis drive. MCU is giving signals to y-axis drive, and it is also giving signals to the x-axis drive, but what the signals are to be given.

For that purpose, the interpolation algorithms are helping. Very basic algorithm of interpolation is the digital differential analyser. There is an algorithm that is very popular, very basic algorithm and it is digital differential analyser, digital differential analyser algorithm.

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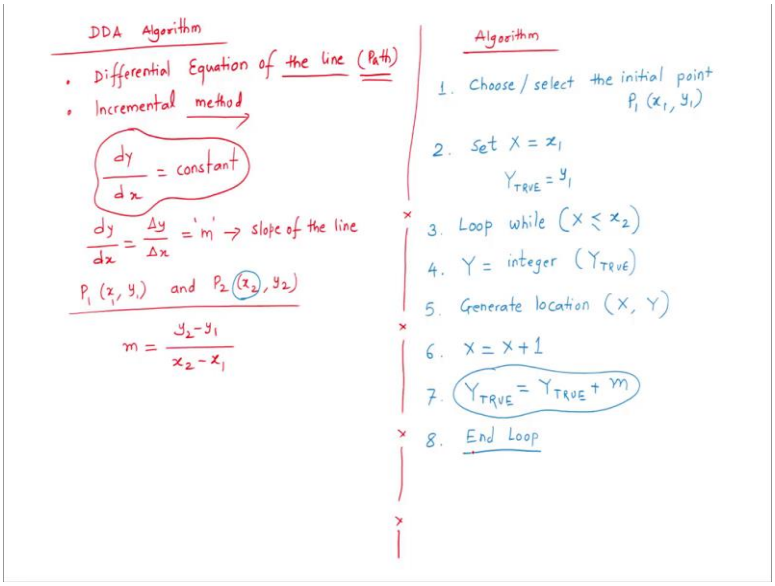

Now, let us see how this DDA algorithm works. It basically working on the principle of solving a differential equation of a line, we are solving a differential equation of the line, and that line is designating the path that to be programmed. And we are using the incremental method. This is the second characteristics that we are using incremental method to compute the locations of the points or the steps during following that particular path.

The differential equation of a straight line in generally is given by:

$$\frac{dy}{dx} = constant$$

We can write this equation in difference form as:

$$\frac{dy}{dx} = \frac{\Delta y}{\Delta x} = m$$

m is the slope of the line. If we consider there is a point P_1, which is having the location (x_1,y_1) and there is a another point P_2 that is (x_2,y_2).

And these two points are representing the endpoints of the , that to be followed during the machining operation. x_1, y_2, x_2, y_2 are the integers. And now we can find out the slope m as:

$$m = \frac{y_2 - y_1}{x_2 - x_1}$$

If we know this particular equation, then we can easily find out the successive points based upon the information of its the previous points. The DD algorithm is based on this philosophy only, this technique only. The DD algorithm follows this differential equation solution based upon the incremental method.

The algorithm has following steps. This is the algorithm.

1. The first step is that we have to choose the initial point. Choose or select the initial point that is P_1 (x_1.y_1).

2. In the second stage, we are using one variable that is capital X

$$X = x_1$$

We are using one more variable that is Y_{true}.

$$Y_{true} = y_1$$

3. Now, we are starting one while loop. There is a while loop. While ($X \leq x_2$) we need to carry out the following steps.

So, what are these following steps?

4. We have to assign Y = integer(Y_{true}). Y true maybe the real value. Why we are assigning there is another variable Y? We are assigning the integer of the Y true that is the step to be carried out when the value of X variable is less than the x 2.

5. The next step is generate the location X and Y. We are generating the location on the XY plane, as capital X we have to generate the location with the present value of capital X, and the present value of the capital Y. We got a location that we need to note down.

6. Next step is we have to increment the capital X with unit one.

$$X = X + 1.$$

We are incrementing the value of X by 1 that is the next step.

7. After that, we are modifying the Y true value as well.

$$Y_{true} = Y_{yrue} + m$$

8. And the last step is completion of the loop, the end of the loop.

What we are doing here? We are taking the initial point P_1 and end point P_2. We are setting the capital X variable with x_1 that is the initial position of the x-axis that is a point P_1. Y true is equal to y 1, we are writing or we are following a while loop. When the value of capital X is less than the x 2 value, the x location or the x-axis value of point 2, and Y would be equal to integer value of Y true. Y true maybe a real value because we are adding the slope inside the Y value, slope maybe in fractions that is why Y true maybe in real.

We have to consider only the integer value because we are having the limitations on the movement along the x and y direction. We cannot have the movement along the x and y direction as per the exact computation given by the controller unit. It is having the limitation the hardware is having the limitation.

The next step is we have to generate the location capital X and capital Y. We have to note it down. Then we have to increment x by one unit, Y_{true} would be changed by Y_{true} + m, then there is an end of the loop.

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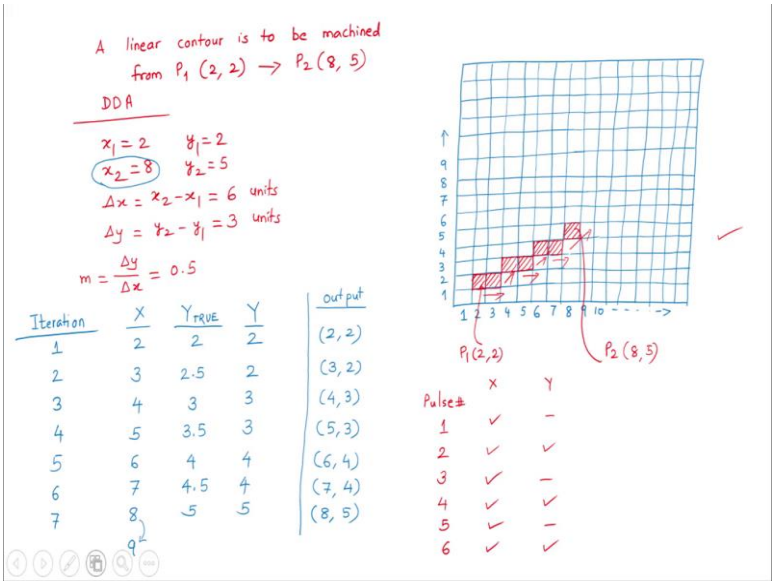

Now, let us understand how this DDA algorithm works. For that purpose, let us take one example. A line or a linear contour is to be machined. From P_1 (2, 2) to P_2 (8, 5).

Now, using the DDA algorithm, we will try to find out how the locations, how the signals will be generated. Now, the task is from P_1 to P_2, we have to move and we have to generate the signals for x drive and the y drive.

Here

$x_1 = 2$ $y_1 = 2$

$x_2 = 8$ $y_2 = 5$

$\Delta x = x_2 - x_1 = 6$

$\Delta y = y_2 - y_1 = 3$

$m = \Delta y / \Delta x = 0.5$

Let us prepare a table that will help us to move from point P_1 to point P_2 by following the DDA algorithm.

Iteration	X	Ytrue	Y	Output
1	2	2	2	(2,2)
2	3	2.5	2	(3,2)
3	4	3	3	(4,3)
4	5	3.5	3	(5,3)
5	6	4	4	(6,4)
6	7	4.5	4	(7,4)
7	8	5	5	(8,5)
	9			

As 9 is greater than x_2, the algorithm will allow us to move out of the loop, and the algorithm will stop computing its properties. Now, based upon the output, we have to generate the scene has that to be given to the x drive and the y drive. We got the initial point that is the (2, 2).

Let us plot this on a graph. A grid or a graph can be seen on our screen. Now, let us plot the output here. The first point is (2, 2). Then we are having the (3, 2). Then we are having 4, 3; so this is (4,3). Then we are having (5,3), (6,4). Then we are having (7,4) and (8,5).

Now, to reach the final destination that is P_2 (8, 5). How many number of pulses are to be given to x drive, and how many number of pulses are given to y drive and in which sequence that is the task of the interpolator and this will give that particular information. Now, P 1 is (2, 2). The next position which is generating that is a (3, 2). There is increment along the x direction, but there is no increment along the y direction. Next step is that the Y motor, Y drive has to be given the pulse.

For this, we can draw another table.

Pulse	X	Y
1	✓	-
2	✓	✓
3	✓	-
4	✓	✓
5	✓	-
6	✓	✓

In this way this algorithm is suggesting then when to give the pulses and to which axis the pulses are to be provided. In this case, only x-axis is required to have the pulse, here both the axis, then again x-axis, both the axis, only x-axis, and at last both the axis. In this way, we are getting the movement along the defined or the desired contour path by using the DDA that is a interpolation algorithm.

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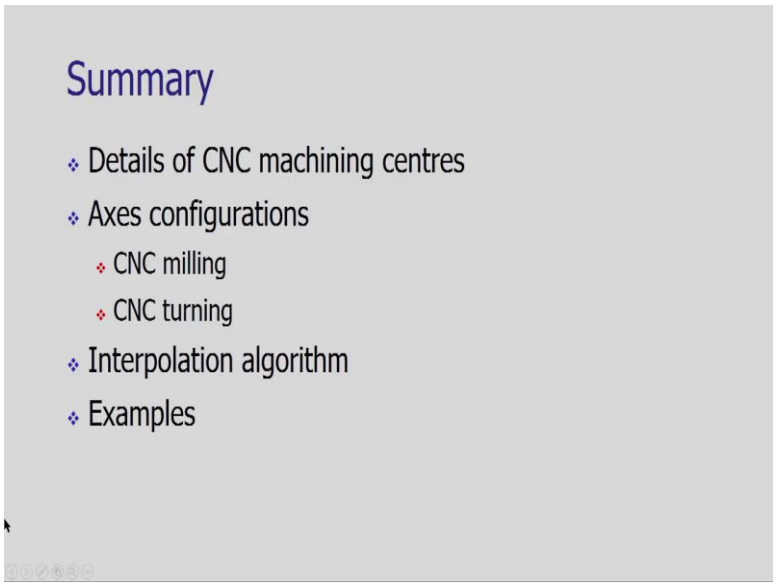

So, let me summarize the lecture 2. In lecture 2, we have seen the details of CNC machining centres and their configurations. We have seen the axes configurations pertaining to CNC milling operations and CNC turning centre. We have seen the interpolation algorithm which is useful to control the axis movements of the CNC machine tools. We solved certain examples and we understood the concept of interpolation in a better way.

Let us see what is there in the next lecture that is the lecture 3.

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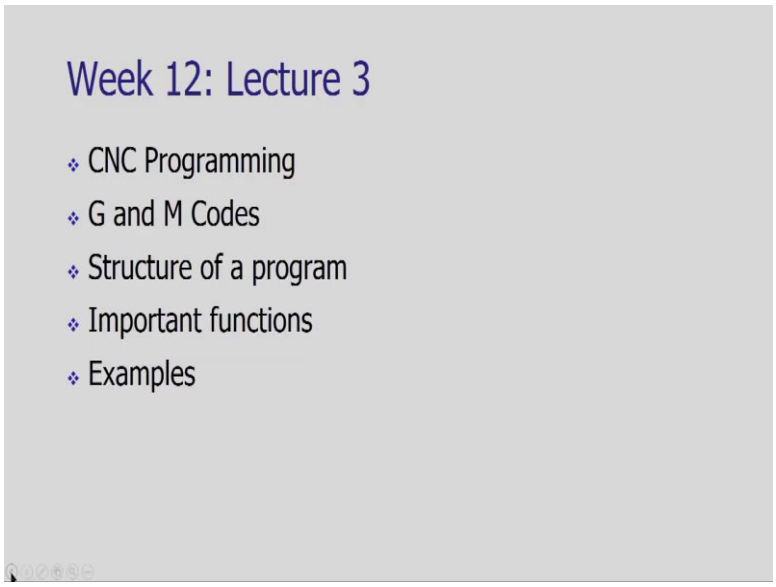

In the last lecture of this course, we will be studying the CNC programming, variety of preparatory and miscellaneous codes being utilised in CNC programming. We will study the structure of a program, what are the various building blocks of a typical CNC program.

There are various important functions such as CAM cycles, tool length compensation, tool radius compensations, so these various important functions will be studied in the lecture 3. At the end of the lecture, we will solve certain problems, we will write the programmes for typical examples. Till then goodbye.