Production Technology: Theory and Practice
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Lecture - 21
NC/CNC Machines: Program Input Device

Hello and welcome to the discussion sessions of the production technology theory and practice series of lectures. Let me remind you that we have started discussing in our last session the NC and the CNC machines, computer numerically controlled machines. Now there what we said is that because of the greater flexibility basically the numerically controlled machines came into picture. And the greatest advantage of the NC, CNC machines is that it can have more flexibility in comparison to the conventional machining.

Because we have the prime mover individually in different axes, all the axes can be moved as per our choice and various relative movements between the tool and the workpiece can be given.

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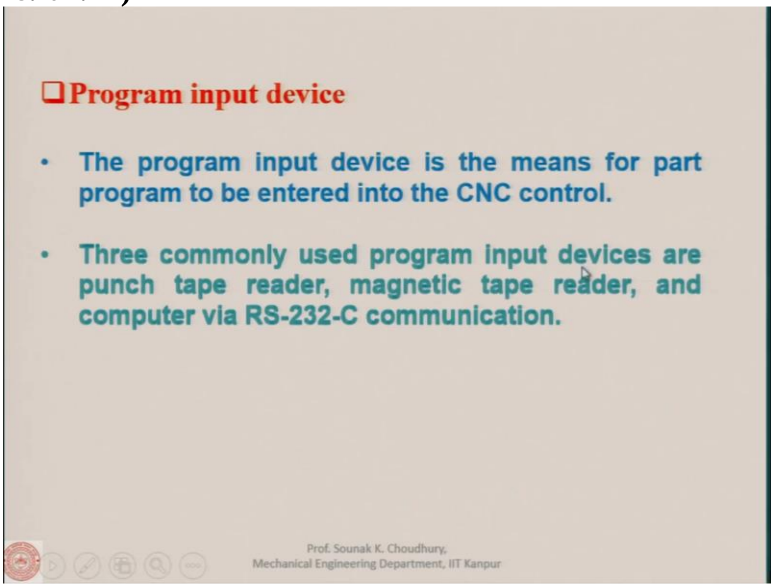

Now what we discussed last time is the program input device and we said that it is meant for part program to be entered into the CNC control.

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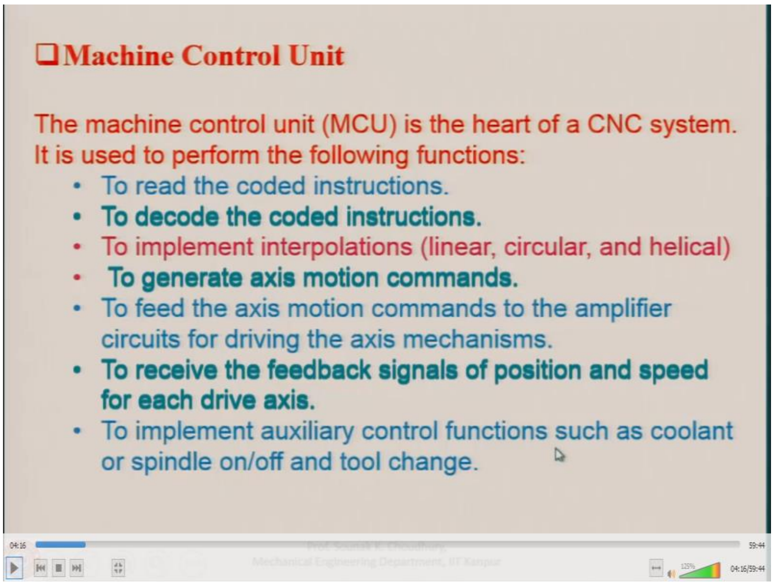

Machine control unit is another unit which we said as the brain of the machine, this is also the heart of the CNC system. This is used to perform the following functions. To read the coded instructions, to decode the coded instructions, to implement interpolations, implement interpolation means whether the tool has to move linearly or the tool has to make a circular movement, this decision has to be made according to the program

It can also have a helical movement to generate axis motion commands to feed the axis motion commands to the amplifier circuits for driving the access mechanisms, to receive the feedback signals of position and speed for each drive axis. Here it is not only that simply program is given that the signal is given, but there is a feedback that is taken, we will discuss that what are these kinds of feedbacks, what kind of feedbacks are used here.

The feedback means that once the signal is given, the signal has gone that the tool has to move linearly by 5 millimetre let us say. Whether the tool has really moved 5 millimetres or it has moved only by 4.98 millimetres or 5.01 millimetre that has to be monitored and this feedback will be sent to the machine control unit so that it can have proper tracking of the movement.

And if the tool has not moved according to the desired program, then the machine control unit will make the correction it will give some additional signal to the prime mover so that the tool movement can be corrected. This is the receiving of the feedback signals of positioning and speed. Next is to implement auxiliary control functions such as coolant or spindle on off and the tool change. All these functions are coded in the program and the machine control unit has to understand what is the code by the program given and accordingly execute the program.

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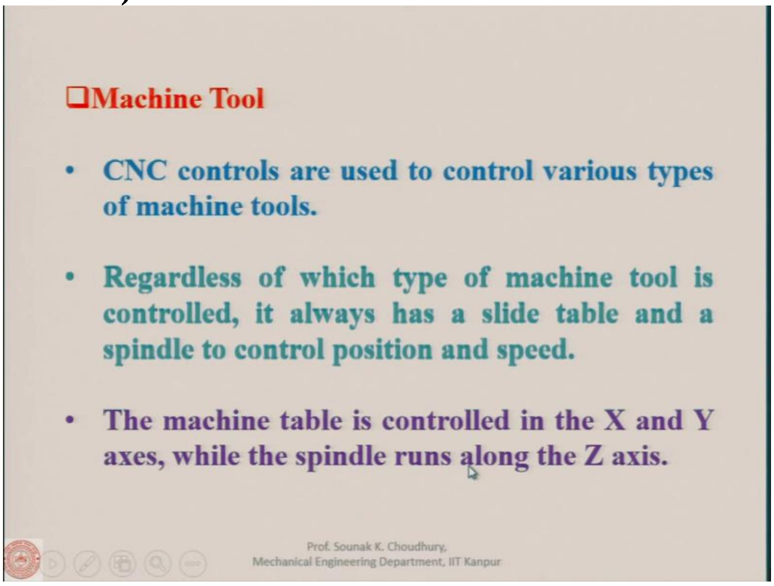

Another one is the hardware that is the machine tool. CNC controls are used to control various types of machine tools. Regardless of which type of machine tool. It always has a slide table and a spindle to control the position and speed. The machine table is controlled in the X and Y axis while the spindle runs along the Z axis. This is the normal standard procedure.

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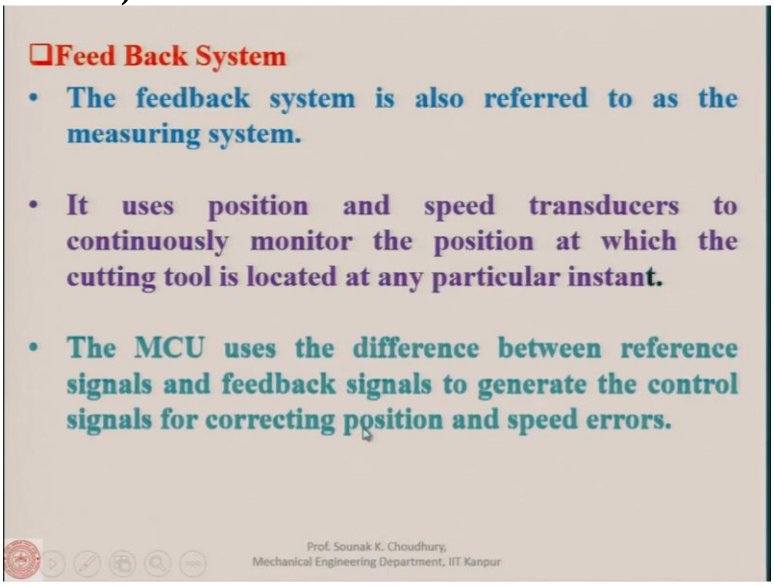

Feedback system: the feedback system is also referred to as the measuring system; sometimes the feedback system is called a measuring system, it uses position and speed transducers to continuously monitor the position at which the cutting tool is located at any particular instant.

This is the feedback system that we have to make sure that the tool has been positioned according to the program which is given.

And the tool had to be positioned according to our requirement, if it is not then the correction has to be made. For that we need to have different kinds of transducers position. One transducer could be that it will sense the signal of the tool movement occuring as per length. And it will calculate how much the tool has moved then that signal will be given to the machine control unit and the machine control unit will take the decision subsequently.

The MCU which is the machine control unit uses the difference between the reference signals. And feedback signals to generate the control signals for correcting position and the speed errors. I will show you later in a block diagram how this function is carried out.

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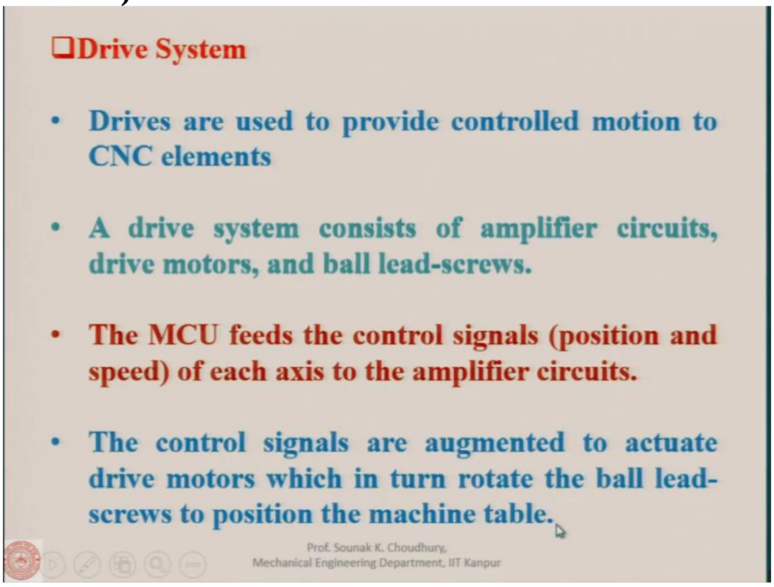

Drive system, drives are used to provide the controlled motion to the CNC elements, this is to move the tool. So, this is moving the spindle or moving the lead screw for the feed movement. A drive system consists of amplifier circuits, drive motors and ball lead screws, as I said, the machine control unit feeds the control signals that are positioning control and the speed control of each access to the amplifier circuit separately.

It will be along the X axis or along the Z axis; in case of turning these movements will be recorded and this movement will be sensed by the transducer and it will be sent to the machine control unit. The control signals are augmented to actuate drive motors which in turn rotate the ball lead screws to position the machine table. This is how it is executed .

Machine control unit will compare it with the reference signal and it will generate the error signal which is nothing but the signal that is required to correct the position if it is not proper or correct the speed if it is not proper and so on.

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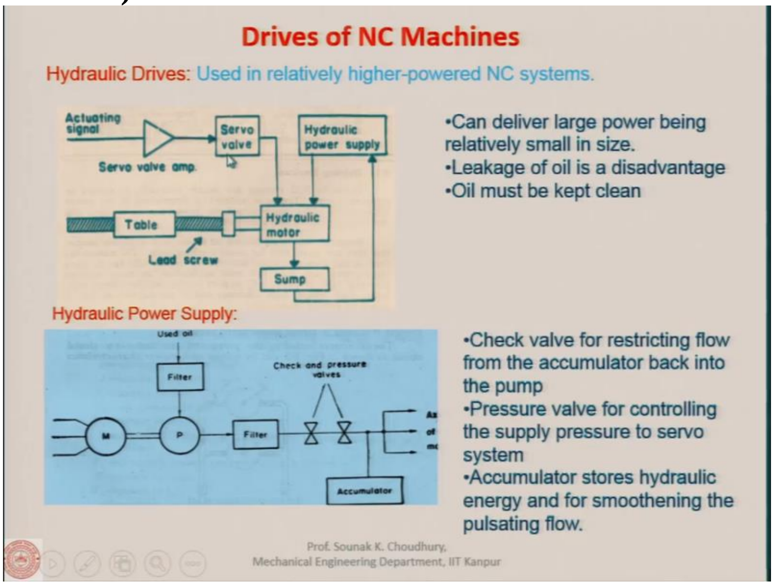

These are the drives of the NC machines; they could be either hydraulic drives or DC motors or stepper motors. Now hydraulic drives are used in relatively high-power NC systems where the higher power is required. The hydraulic system as you understand that they have the higher torque carrying capacity. And very big advantage of the hydraulic drives is that the hydraulic drives are compact.

Small with that compactness in comparison to an electric motor, their power is much more. For smaller size valves, for example, hydraulic valves, they have a lot of power or the hydraulic drives the actuators, their sizes are not very big, not as much as the electrical motors but they are more powerful. Overall, that torque carrying capacity is higher.

Here are the hydraulic drives shown. These are the details of the hydraulic drive, that it is the actuating signal is given to the servo valve amplifier. Here through the servo valve amplifier the actuating signal is amplified and it is given to the servo valve, servo valve is nothing but opening or closing a port through which the signal goes and that is sent to the hydraulic motor.

To the hydraulic motor, the hydraulic power supply is connected and it gets the hydraulic fluid from the sump from here. The hydraulic motor in its turn depending on the signal it is coming from the actuating signal it gets the required amount of fluid to the hydraulic motor and therefore, the pressure. So, it will create the torque and it will rotate the lead screw on which we will have the table with the tool post or whatever is required there depending on the machine.

That table with the tool will be moving along the lead screw to the left or to the right depending on the signal that has been given through the hydraulic motor. And in it's turn the hydraulic motor will get the signal from the actuating signal and the servo valve. After hydraulic motor completes the operation at the exit, the used oil is filtered.

This used oil is cleaned and comes to the sump from where with the help of the pump it is pumped to the hydraulic power supply once again and the whole cycle is repeated. Complete diagram of the hydraulic power supply is shown here. Hydraulic power supply has a 3-phase electric motor and the pump. The used oil comes through the filter to the pump.

Used oil comes from the sump. Here we have the filter and through the filter it goes to the pump from the pump it goes to the motor. This fluid or oil will be going through the check and the pressure valves and then it will go to different axis of the motor X, Y or Z.

In between the valves and the outlet, we have the accumulator. Check valve is for restricting the flow from accumulator back into the pump. It may so happen that the accumulator has its pressure high and the fluid can go back to the pump and the motor because of this. This check valve will stop that movement, stop that flow and it restricts the flow from the accumulator back to the pump.

Pressure valve is for controlling the supply pressure to the servo system. This will control whatever the supply pressure is required, this much will be provided; if it is less, in that case the accumulator will be activated, it stores hydraulic energy and for smoothening the pulsating flow.

If the pressure becomes low then it will activate the accumulator and from the accumulator, it will go to the axis and so on. This in fact, checks or controls the supply pressure to the servo system. And from here it goes to the, as shown by the arrows, axes of the motor. This is the hydraulic motor. In this mode, there could be three motors on three axes or it could be a 5 axis machine . Here, one axis is shown which goes to the hydraulic motor.

And the hydraulic motor rotates the lead screw along with the table. This is the system of the hydraulic motor. In the case of hydraulic motor, as I said that the greatest advantage that it has a very high torque carrying capacity and their sizes are very small, they are very compact. Hydraulic drives have the disadvantages also. One very big disadvantage is that the oil has to be absolutely cleaned.

If any dirt comes, see what happens is this servo valve is very complicated and their ports are very small. In case a dirt comes in and accumulates in the port, the servo valve will not work and that movement may be in micron, the movement of the valve can be in micron to open or close the port, so if a dirt comes in and that gets accumulated in those ports, the entire valve can get clogged. That is one factor.

Second factor is that when the whole system works, the temperature evolves, temperature rises and at that temperature the viscosity of the fluid that is oil can be changed that is another disadvantage. Therefore, viscosity may not be constant depending on the temperature, if the temperature varies. And next disadvantage is that the hydraulic system will always have some leakage.

When it goes through the servo valve or it goes through the actuator, hydraulic cylinders there always will have some leakage. It may be small leakage but that has to be taken into consideration. In many designs the design has to take care so that the leakage is eliminated or the leakage is minimum and there are various designs of the hydraulic cylinders to make the leakage minimum.

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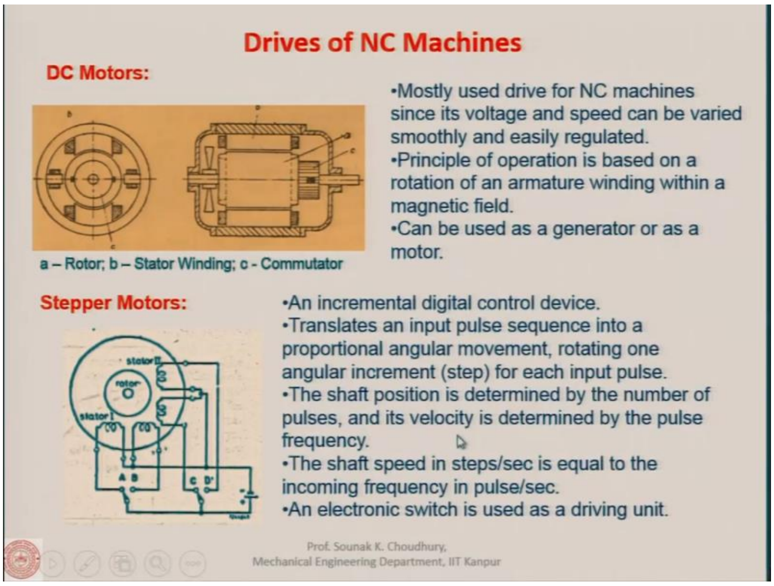

These are the DC drives. Direct current mostly used for the NC machines drives. DC motors are very popular since its voltage and speed can be varied smoothly and easily regulated. For control it is very convenient because it's voltage and speed that can be smoothly varied can be regulated very easily. Principle of operation is based on the rotation of an armature winding and this is the armature wire winding here.

Here it is shown and this one is within a magnetic field. So, this armature will be rotated depending on the winding and depending on the magnetic field that we have, so this is the armature and here also we have the winding. This is the armature and the armature winding which rotates within the magnetic field.

This can be used as a generator or as a motor. The shaft can be rotated and it will produce electricity or if you pass the electricity the shaft will be rotated; when the shaft is rotated this works as a motor or if the shaft is rotated by an external source of energy and then the power can be created. This then works as a generator. Here you can see, that 'a' is given as the rotor, 'b' is the stator winding.

This one and the 'c' is the commutator, commutator is to take the current because shaft is rotating. The third type of motors that are prime movers are the stepper motors. The stepper motors are not of very high torque carrying capacity like DC motors or hydraulic drives. Therefore, the stepper motors are used when the machines are of smaller size.

Basically, they are not of very high torque carrying capacity. Schematic diagram of the stepper motors is shown here. This is an incremental digital control device and the stepper motors translate an input pulse sequence into a proportional angular movement. So, input is given to the coil, to the drive from the outer external source which is some kind of pulse.

And that pulse will be given in a sequence and then as a result the output will be the rotation of the rotor angular increment. One angular increment step for each input pulse that is the kind of the rotation it may have or it may have other scale for example, for each input it may also have the half rotating or in each input pulse there can be two rotating so that depends on what kind of stepper motor it is and what kind of winding we have in the rotor, in the stator and so on.

The shaft position is determined by the number of pulses, the number of pulses given here at the input. So, the shaft position is determined by the number of pulses and its velocity that is what is the speed of this shaft that depends on the pulse frequency, at which frequency the pulses are given.

Number determines the position that how much it will be moving and then it will take a position and then how fast it will be moving, i.e. the velocity, that is determined by the pulse frequency. The shaft speed in steps per second is equal to the incoming frequency in the pulse per second this is what it is said here that the velocity is determined by the pulse frequency this is a pulse frequency and the velocity is the shaft speed.

An electronic switch is used as a driving unit. This electronic switch can be automated to make the changeover from one coil to another coil, so that the rotor can be rotated either clockwise or anti clockwise direction. This is the switch that switching system will determine the rotation of the rotor.

Here is the stator; there is a winding and the rotor will rotate depending on the input pulses which are given and this is explained here that this rotor is the shaft; this is the shaft which you are rotating or positioning. So, positioning will depend by the number of pulses you are providing to the input system, to the input circuit. And what is the frequency of the pulse that is provided that determines the speed of the shaft or speed of the rotor.

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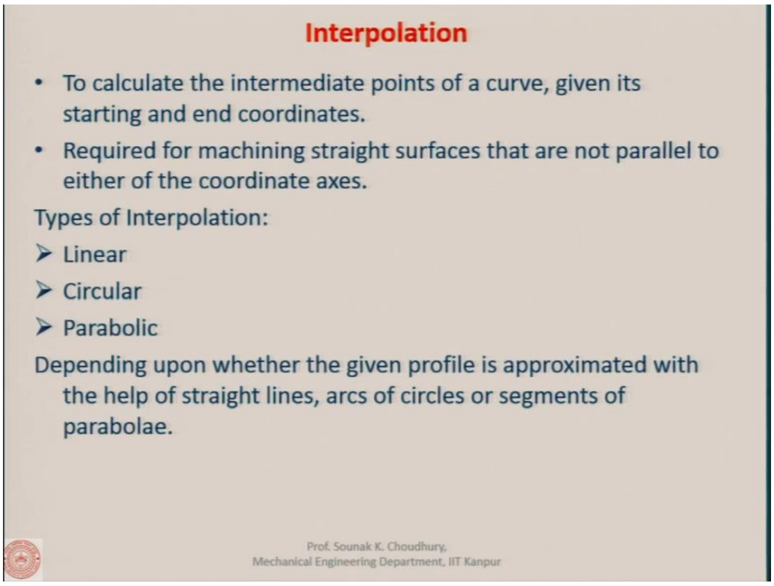

Now let us talk about the interpolation, let us see what is that interpolation? Interpolation is to calculate the intermediate points of a curve given its starting and the end coordinates. I told you earlier also that when the tool has to move from one point to another point in a linear movement, there we have to calculate the coordinates from which point to which point it is moving.

And then accordingly we give the movement or the program or the signal to the tool that is called the interpolation or the tool can go from one point to another point in a circular way. Depending on the radius or the diameter of the curve, the coordinates will accordingly give the signal to the tool and the tool will be moving exactly according to that path that will be the circular interpolation.

Calculate the intermediate points of a curve given its starting and the end coordinates. Depending on the intermediate coordinates, you understand that the tool can move linearly or in a circular way required for machining. It can be straight surfaces that are not parallel to either of the coordinate axis.

If it is parallel to the X axis, X axis here in the turning or Y axis here in the turning. In that case there is no problem because you are 'asking' the tool to move according to the program, that X and Y it will move, but if we want to move it not parallel to any of these axes, in that case, we have to say what should be the interpolation either it will be then linear interpolation or it will be the circular interpolation.

The types of interpolation, as I was telling, can be linear, it can be circular, it can be parabolic. Linear, circular and parabolic - these are the 3 types of interpolation which are popularly used in the programming or in the CNC machines depending upon whether the given profile is approximated with the help of straight lines, arcs of circle or segments of a parabola. Segment of a parabola is the parabolic interpolation segment of arcs of circles. This is this circular interpolation.

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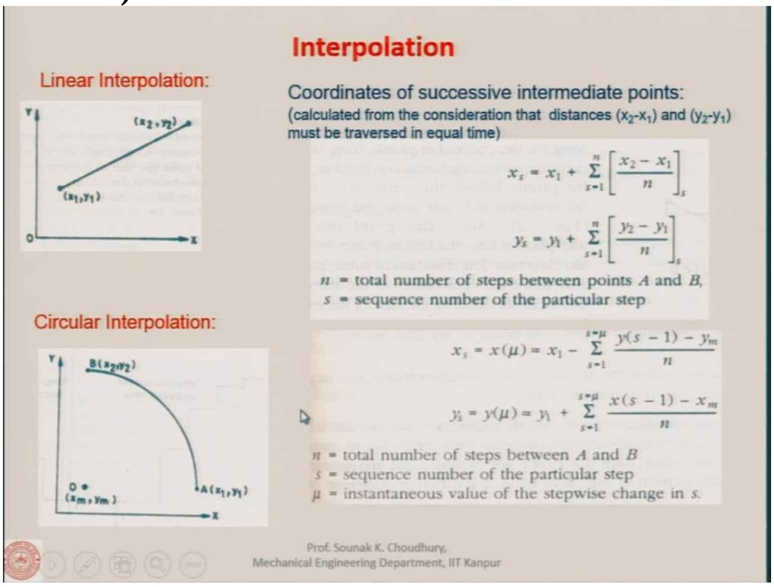

Let us see how the linear interpolation can be done. We have the x and y coordinates. Coordinates of successive intermediate points that are if (x_1, y_1) is the starting point and (x_2, y_2) is the end point. In that case, these successive intermediate points can be calculated from the consideration that distances $(x_2 - x_1)$ and $(y_2 - y_1)$ must be travelled in equal time because it is a straight line.

Therefore, the successive intermediate points will be x_s ,this is $x_s = x_1 + \sum_{s=1}^{n} \left[\frac{x_2 - x_1}{n} \right]_s$ and the y_s is similarly $y_s = y_1 + \sum_{s=1}^{n} \left[\frac{y_2 - y_1}{n} \right]_s$ is the total number of steps between the A to B. Depending on the steps that you are taking 1 here suppose 2 here and so on, n value will be accordingly varied.

And you can find out what is the coordinate for next to next to next and so on. And then these coordinates are joined. This joining will be done by the machine. The intermediate coordinate will be calculated, by the machine control unit MCU that we said is the brain or heart of the machine.

That we need the linear interpolation and we are giving the coordinates of (x_1, y_1) and the coordinate of (x_2, y_2), these are the coordinates which are the 2 points in beginning and the ending and the tool will decide how to go. Why to calculate the intermediate points? Because it will be the shortest path that the interpolation will calculate according to our drawing.

And the *s* is the sequence number of the particular step that is *s = 1, 2, 3* and so on. x_s here in this case if it is given as the A (x_1, y_1) and x_2, y_2 coordinate is given as B (x_2, y_2). And this is the centre of this circle; this is the path or the sector of a circle. In that case the x_s is $x(\mu)$ let us say some point and this will be $x_s = x(\mu) = x_i - \sum_{s=1}^{s=\mu} \frac{y(s-1) - y_m}{n}$

Here the *n* is also that total number of steps between A and B like in here, *s* is the sequence number, μ is the instantaneous value of the stepwise change in the s. In that case with the O as centre the tool will be moving from A to B with this interpolation.

There is a code for circular interpolation or there is a code for the linear interpolation where it is used. Let me also tell you that like circular the linear interpolation for example, this is the turning length turning NC CNC turning machine, in that case the tool point has to move from one point to another point or the drill has to move from one point to another point. If it is not parallel to x or y axes then it is a linear interpolation.

Because we are linearly moving the tool in this case. If we have to make a contour, then we have to tell that there is a movement that is required in the semi circular movement and for example, in case of case of milling cutter. In case of milling cutter, we need to give a profile we need to cut a profile and for that profile, we need to have the movement of the milling cutter in circular interpolation.

So, we have to give the coordinates. This is the formula that will be used by the machine control unit to calculate the coordinates of the intermediate points. This is the theory behind this. And it will finally move the tool from one point to the other another point which we have designated, which we have set there.

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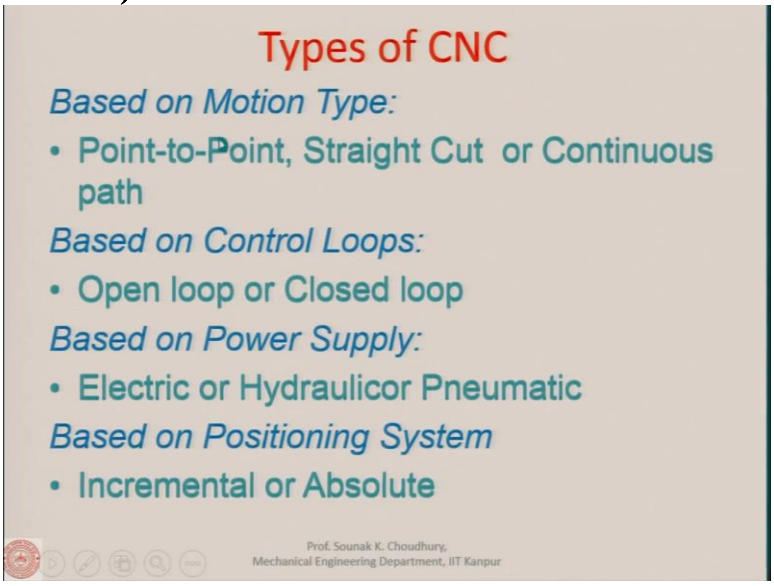

Now, if we see the types of the computer numerically controlled, that means what types of numerical controls exist, there are different types based on the motion type we have. The point-to-point control, straight cut control or the continuous path control, based on the control loops, we have the open loop or the closed loop systems, I will explain each of them in details.

Based on the power supply we have either electric or the hydraulic or the pneumatic-based on the positioning system. We have the incremental or the absolute these things we will discuss one by one. Based on the motion type we said that there is point-to-point, straight cut and the continuous path; these are the examples.

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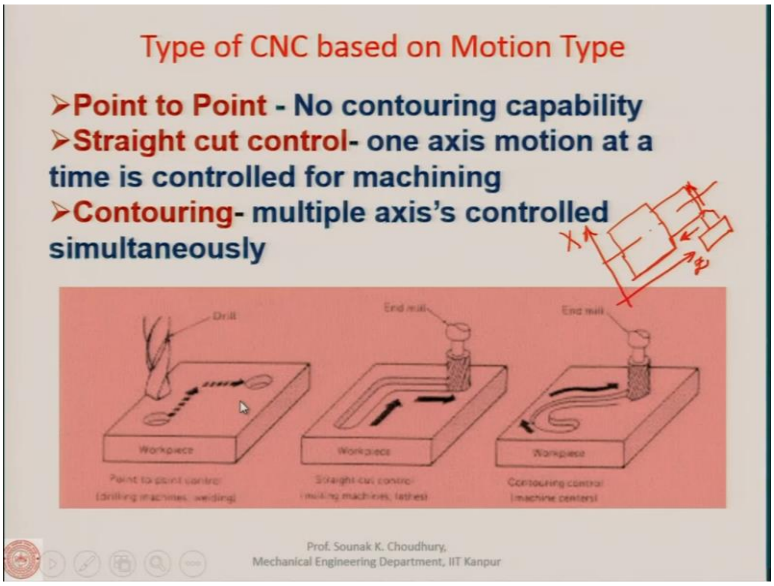

Now point-to-point that has no contouring capability; here is the example that means, suppose we have a drill or we have a spot welding machine or the spot welding head. The spot welding has to be moved from one place to another place. Let us say the manipulator, the robot hand is holding that and it is moving from one place to another place or the drilling machine is moving the drill spindle with the drill after it drilled a hole it has to come up, come out and then it will move to another position.

This is point-to-point and here how the tool will be moving that is not important, but only the coordinates will be given from one point to another point. Here in the point-to-point there is no contouring capability in the sense that it can move only in the linear way. The straight cut control, one axis motion at a time is controlled for machining.

The straight cut control is shown here that means, in this example, what is said is that the end milling cutter is moving along parallel to one of the axes either parallel to this axis or parallel to this axis, it also can be saidin the case of the turning, let us say we have to turn this workpiece. And another tool, tool is here and this tool can move in this direction.

When the facing is required or when the turning process is required, it will move like this, then it can move from here to here. That means it is moving either parallel to this axis or parallel to this axis. In this turning case, we said that this is x and this is the z. Either it is along the z or along the y axis.

So, this is shown here that the tool either it is a turning tool or it is a milling cutter, the tool can move at a time parallel to one of the axes either x axis or z axis in the case of turning, but in case of milling it is x and y. The third one is the contouring, contouring is the multiple access controlled simultaneously that means, in that case, let us say we have an end milling cutter and the end milling cutter is required to make a contour groove here.

This control rule is to make sure that the tool moved in a very complicated path like this. That means we have to then control both axes together. This is contouring which is not possible with the help of the straight cut control or with the help of the point-to-point control, but if you see the capability of the contouring control, then you will realise that the contouring control can be used for the other two as well.

This can be used for straight cut control or the point-to-point control. The other two cannot be used for contouring control, but the straight cut control can be used for point-to-point control. Point-to-point control is the easiest and the simplest. This is also the cheapest that can be used only for the point-to-point and cannot be used for a straight cut control or the contouring control. But greater version like contouring can be used for both of them this can be used for the point-to-point and so on.

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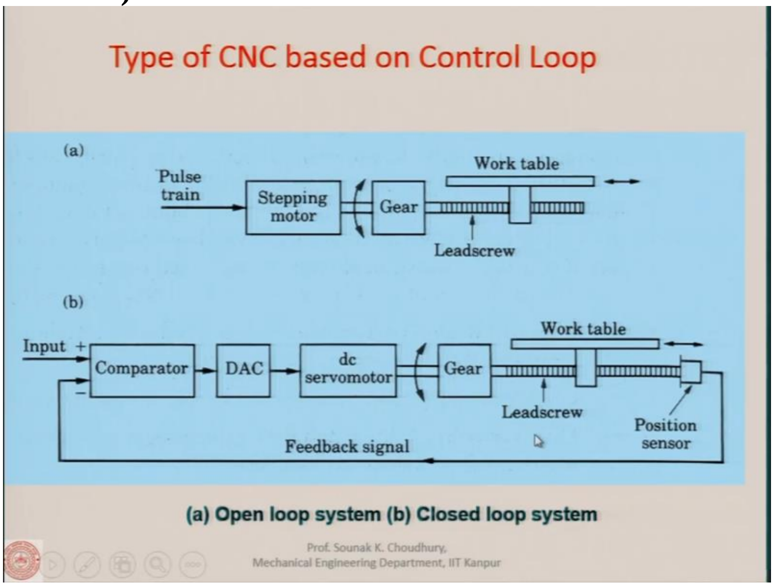

Types of CNC: based on the control loop there could be the closed-loop feedback control systems or it can be an open loop control system. In case of open loop feedback control system, the input signal is given to the stepping motor and the stepping motor which we already discussed that for each pulse, the motor can be rotated at a certain angular angle.

Let us say that this is the movement of the stepper motor output shaft depending on the input pulses given and with the gear train this will be then moving the lead screw and on the lead screw we have the work table along with the work piece. So, the work piece will be moving either to the right side or to the left side on the lead screw. Now the pulse train let us say we are giving the signal here in the input for stepping motor to move to a certain degree of rotation.

But whether that has been accomplished or not that we are not measuring at the output; so output is open. That is why it is called the open loop control system, those open loop control systems are cheaper and simpler and we can use them when we are absolutely sure that whatever the input signal is given to the to the mover, the output signal will be accordingly.

So, it will be precise movement or it will be precise motor so then we do not need to check the output, do not need to control the output but when we have to control very precisely that whether the input signal is being followed at the output, then we need to have the feedback control and the feedback control is like that - here is the input signal this is a comparator, this is the DAC that is the converter.

This is the DC servo motor, this is for the converting digital to analogue because this is the servo motor and the servo motor will rotate the gear train and in its turn it will rotate the lead screw, lead screw with the worktable. After that how much it is moving that is being sensed by a position sensor which is absent here as you can see this.

The lead screw will be moving along with the worktable; this will be sensed and this sync sensor, signal will be sent to the input, the input and this signal will be compared in this comparator and the error signal is produced. Error signal is something which is the discrepancy between the input and the output signal if any. Suppose according to the input signal the worktable has to move let us say 20 millimetre.

And it has moved to 19.5 millimetre, so, there is a discrepancy of 0.5 millimetre. This discrepancy signal that is in terms of the error signal, that is in control technology it is called the error signal, this error signal is the discrepancy between the input and output signal; it is generated so that the performance of the device is improved, that it can be corrected. The error signal is again converted from digital to analogue.

And this is given along with the input to the DC servo motor to tell that at the output the signal is not as per the desired level and it has to be improved, it has to be corrected. So, the DC motor accordingly gives the correction, moves more or less so the positioning can be done accordingly, according to the input signal. So, you can see that this is a closed loop control system, that means the feedback is continuously monitored and accordingly the compensation is given to the input.

So that the output signal can be corrected if it is not according to the input signal. Both these systems can be utilised. We will discuss a little more about the feedback system in terms of the adaptive feedback system adaptive feedback control how they work because most of the modern machines, particularly the CN and the CNC machines, they are fitted with the adaptive control systems and they are very useful because they improve the performance of the machine.

Once more, these are more complicated because they have to have a position sensor and it cannot be given directly to the input but it has to go through the pre amplifier and the amplifier to amplify the signal because this signal from the sensor can be very weak. So, it has to be amplified. There has to be a pre amplifier to pre amplify that and then amplify the signal coming from the pre amplifier.

Then this signal can be given to the input. Sometimes the phase also has to be changed. If the phase has to be changed then there has to be a phase changer and then the output from the phase changer has to be supplied to the input. Then the input and this signal will be compared. Therefore, these systems are more expensive and complicated. But they are more accurate because the output signal is always measured, monitored and corrected. The output signals you can say that it is always as per the input signal, as per the desired level that is why these are more accurate and more reliable.

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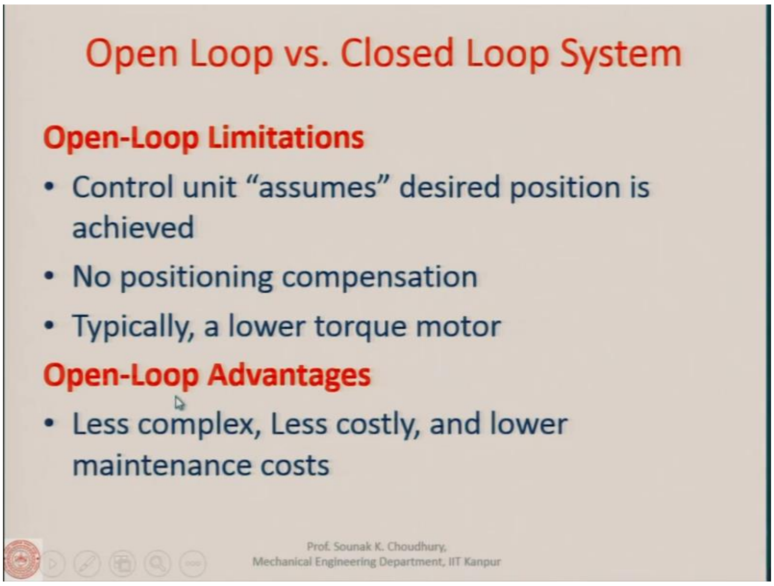

Open loop: I have already told that open loop limitations are that control unit assumes that the desired position is the achieved. There is no compensation and typically a lower torque motor like stepping motor is used. Whereas in case of open loop, the advantages are the less complex, less costly and lower maintenance costs. These are the open loop advantages.

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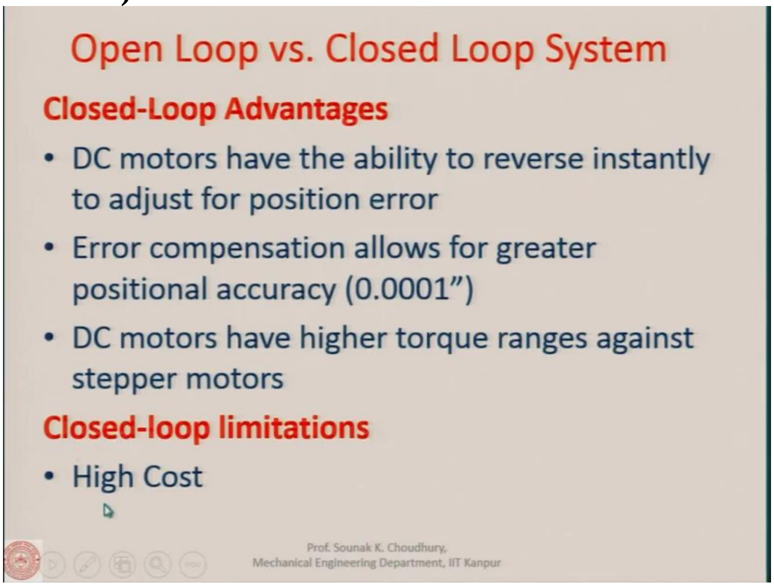

Whereas, the closed loop advantages are that the DC motors have the ability to reverse instantly to add just for positioning errors. Whether it will be plus or minus this can be instantaneously done by the DC motors. The error compensation allows for greater positional accuracy and positional accuracy can be of 0.0001 inch. Now the DC motors have higher torque ranges against the stepper motors.

And the only limitation is that it is complicated. Therefore, it is more expensive, because we have to have a transducer and we have to have a loop, this is the feedback signal with an amplifier, pre amplifier and so on.

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Now let us discuss a little bit about the adaptive control system, what are the adaptive control systems? Adaptive control systems they are the closed loop feedback control systems which are fitted in the many of the NC and the CNC machines particularly the modern NC and the CNC machines. The output can be always monitored and output can be always compensated for.

Let me give you an example that why these adaptive control systems are required, let us say we have the turning process, this is a simple process. And we have calculated the force required for the turning depending on the parameters, depending on the tool and the work piece material combination and we have selected a tool for a certain hardness of the work piece material. We assume that the hardness is homogeneous.

But while machining that cylindrical piece in the turning lathe at certain depth, we have encountered carbide particles, which is very hard particle. The tool when it is encountering the carbide particle which is embedded there, the force goes very high because they are very hard particles, for that high force the process was not calculated and the tool can break.

Whereas, if the feedback control or the adaptive control is used, in that case that inclusion will be automatically sensed and immediately the tool will be retracted back so that the breakage of the tool can be avoided or in some cases there are some adaptive control systems where if the force exceeds in that case the entire process will be stopped.

So, you will be knowing that something happened that the force has exceeded and it can be eliminated and so on. In some adaptive control systems, it adapts itself that the process continues and this system does not break down. Let us discuss this. Although NC has a significant effect on downtime it can do relatively little to reduce the in process time. Let me give you a little more detail because we have not talked about the downtime or the process time.

NC system can reduce the downtime it can reduce the downtime means when the machine is not working machine, it has failed and stopped but it cannot do much about the in-process time. The machining time is something which we have said that we have the L that is the length and that divided by N into f feed that is the time taken for machining a particular length. The NC machine cannot change that feed.

That is why L is constant that is this the length of the work piece divided by N is constant this is the RPM but if it can be varied, but *f* it is not varied in the conventional system where there is no NC system *f* is constant and therefore, the time taken is constant in the NC machine as well. Therefore, the NC system using these constant parameters, has no leverage no possibilities to change the machining time.

And changing the machining time means that it will accelerate the production rate. But in case of adaptive control system these systems can have the effect on the in-process time that means these control systemscalculate the parameters, at each point, the cutting parameters are calculated by the adaptive control system and the actual machining parameters.

The optimum machining parameters are calculated for each of the points and since the machining happens at the actual, at the optimum cutting parameters therefore, the time taken is optimum and it is not like in case of the NC machines, whereas NC guides the sequence of tool positions or the path of the tool during the machining as I said just now, adaptive control determines the proper speed and or feed during the machining as a function of variations in such factors as work material hardness, width or depth of cut.

Thus, in adaptive control systems we determines what should be the optimum speed or what should be the optimum feed during the machining and that will be by varying such factors as work piece material hardness, width, depth of cut, etcetera, how it is done, we will see now.

Adaptive control has the capability to respond to and compensate for these variations, in these factors. Now adaptive control system can be used under the following conditions, where the in process time consumes a significant portion because normally the adaptive control we said that these have the effect on the in process time.

So, when the in process time consumes a lot of time,then it makes sense to have some control over that so that it can be reduced, then it will be feasible because otherwise the process is expensive. Using the adaptive control system will always be more expensive than not using it. Now there are significant sources of variability in the job for which adaptive control can compensate. That means the adaptive control adapts speed and or feed both to those variable conditions. And one of the variable conditions I said is the work material hardness

This is an example of the variation in the work material hardness that the inclusion of the hard particles. The work piece material hardness is varying or width or depth of cut because these are the errors in the process.

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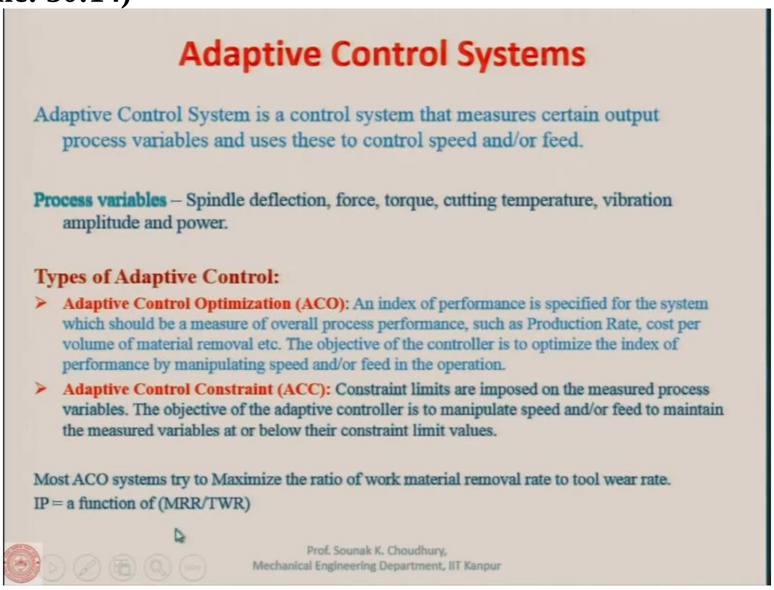

Adaptive control system is a control system that measures certain output process variables and uses these to control speed and or feed that means, it will constantly measure the output,

output maybe the cutting force or it may be the relative movement between the tool length the workpiece, it may be the vibration, it may be many other parameters, it may be temperature.

What is the temperature which is occurring? If the temperature is higher you may activate the process to do something, let us say coolant starting otherwise you are not putting the coolant on. As soon as the temperature goes beyond certain values, which will be measured by the temperature sensor, then your feedback control will be working, So, that is also an adaptive control system.

What I overall mean is that at the output there can be different kinds of sensors to measure different outputs, either it is a movement of the carriage or movement of the tool post vibration of the tool with respect to the work piece and so on. Once again, adaptive control system is a control system that measures certain output process variables and uses these to control the speed and the feed.

As I said the speed is varying so you are measuring the forces at the output and stabilise it. So that can be stabilised by varying the feed or the speed these are the two parameters that the adaptive control takes as the controlling parameters. By controlling these parameters, variables can be stabilised now the process variables can be therefore different so spindle deflection, force, torque, cutting temperature as I was telling vibration and vibration amplitude and power.

Any of these and many others maybe the examples you can come up with. These can be the process variable. One of them or all of them are important for us to stabilise then we will be using a suitable sensor which will sense one of them or all of them separately so all these are separate sensors and then take those signals to the input, create the error signal and correct the system. That is the adaptive control system.

There are 2 types of adaptive control systems. One is the adaptive control optimization and another is the adaptive control constraint. Adaptive control optimization as you can see in the slide, there is an index of performance specified for the system which should be a measure of overall process performance such as production rate, cost per volume of material removal etcetera.

Here the overall index of performance is the production rate. So, through the production rate we can evaluate that particular production like that. You select or you as the decision maker you select the performance index of a particular process or a system and then that particular performance index has to be optimised by manipulating speed and or feed in the operation.

So, once again, that is the index of performance it is the index of performance that has to be selected it can be many, it can be different, that is production rate, cost per volume of material removal etcetera and that has to be optimised by manipulating the speed and or feed in the operation. This is the adaptive control optimization. Second type of adaptive control is the adaptive control constraint.

Now adaptive control constraint has a constraint limit and constraint limits are imposed on the measured process variables. The objective of the adaptive controller is to manipulate the speed and feed to maintain the measured variable set at a lower or below the limit. This is different than the optimization in the sense that in case of adaptive control optimization, we have the index of performance and that we are minimising or we are optimising.

In case of constraint we say that example that I have given that we have a certain value of the force which cannot be exceeded. If the tool meets with a portion of the material which is of higher hardness, the force will exceed and if the force exceeds that value, which is the adaptive control constraint, in this case it will be changing or the process itself will manipulate the speed and or feed to maintain the measured variable at or below that constraint limit values.

Meaning that whenever that signal will go to the input and it will be compared with the input signal, there will be an error signal produced and the error signal will automatically change the speed or the feed so that the force is decreased to that value which is required. How it is done that is the tool we simply retracted, a feed is given less, the speed can be decreased.

So that the force comes down below or to that limit which is given as a constraint. Once again, these are the two different types of the feedback control systems one where we have the adaptive control optimization where we have certain index which has to be optimised. In case it is the index is the production rate for example, then the production rate has to be maximised.

Take the first derivative of that equation and take it equal to 0 it will be the maximum you can get. But in case of adaptive control constraint, you set the value of certain parameters that you are interested in, it can be force or it can be temperature or amplitude of vibration, it can be deflection of the spindle and so on. And then whenever this change happens, then the feed and the speed can be changed by the adaptive control system itself.

So that the parameter which he wanted to stabilise will be activated. Most ACO is the adaptive control optimization they try to maximise the ratio of work material removal rate to tool wear rate. We said that in ACO we have to have an index of performance which is very popularly used as the ratio of the material removal rate and the Tool Wear Rate (TWR).

A tool wear rate has to be maximised so that tool wear rate can be less and material removal rate can be more. These are the 2 types of the adaptive control systems. And I will give you in my next discussion session some examples that will describe how effectively we can use the adaptive control systems and how we can use them in practice. Thank you very much for your attention.