Computer Numerical Control of Machine Tools and Processes
Professor A Roy Choudhury
Department of Mechanical Engineering
Indian Institute of Technology Kharagpur
Lecture 03
Classification of CNC Machine Tools

Welcome viewers to the 3rd lecture of the course Computer numerical control of machine tools and processes. So today we are going to discuss about the classification of CNC machine tools, how are they classified okay. To start with, let see in what is the spread of CNC technology in a manufacturing scenario.

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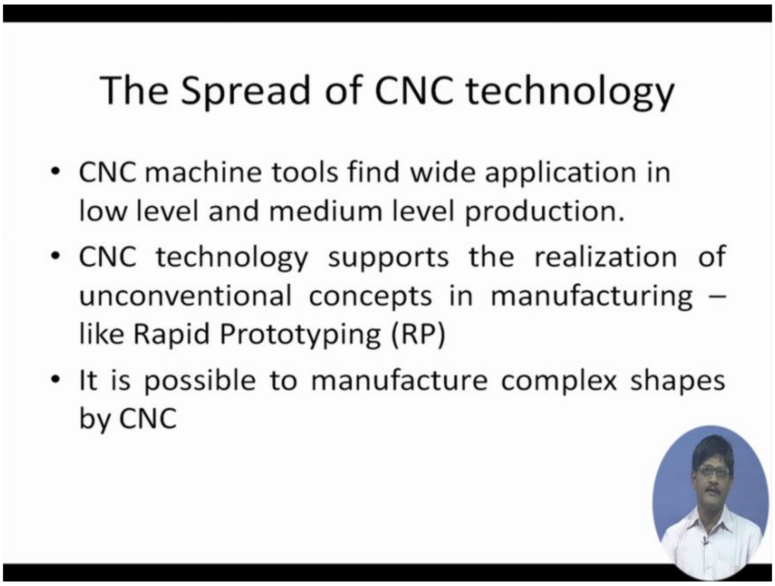

CNC machine tools find wide application in low-level and medium level production. CNC technology supports realization of unconventional concepts in manufacturing like Rapid prototyping. Had CNC not been there, Rapid prototyping would not have been realized. And also the manufacturing of complex shapes is possible by CNC; it is in these fields that CNC has found wide applications and others as well.

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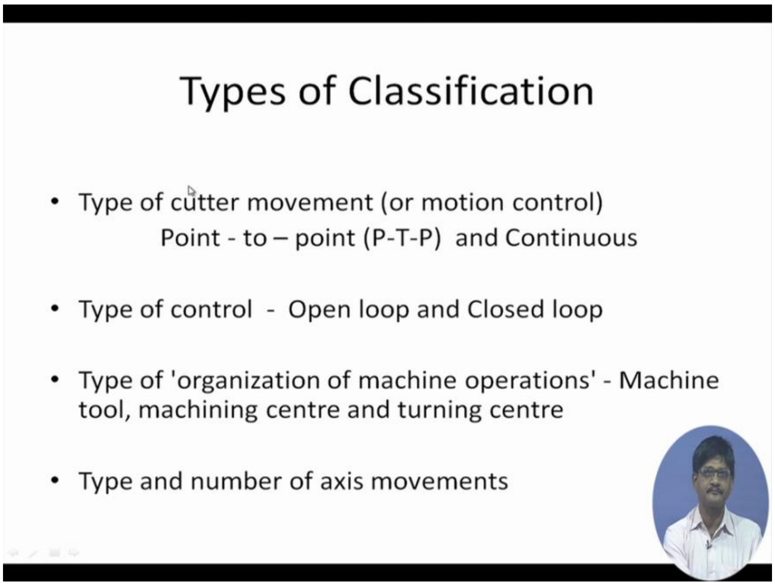

The types of classification for example, CNC might be classified as per cutter movement or cutter motion control, we can have point to point control as well as continuous control. There can be classification as regards to open loop and closed loop control, then type of organisation of machine operations like machine tools, machining centre, turning centre, et cetera. And by the type and number of axis movements. So 1st of all let us take up the discussion of point-to-point control.

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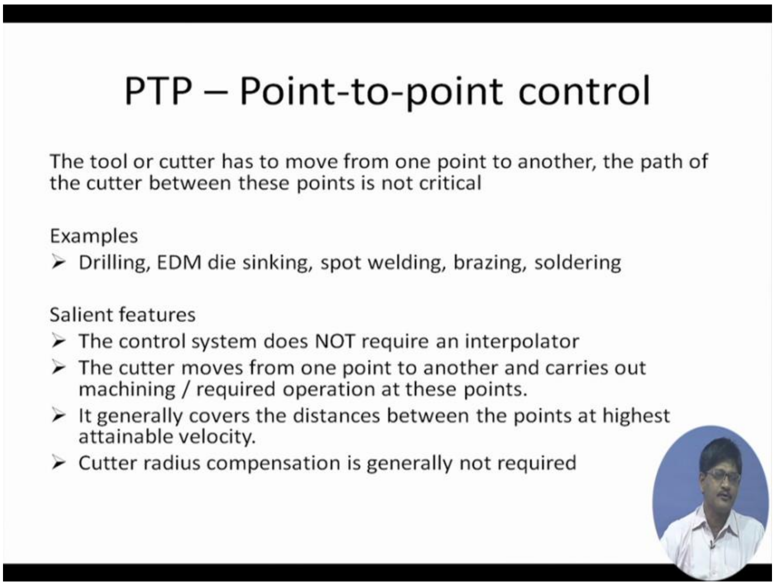

What is point-to-point control, we find that whenever we are talking of machine tools, there are some machine tools in which the the required operation is only at some definite points and the cutter simply has to reach those points and carry out the operation.

The path taken by the cutter between these points is not critical that means it is not very important; it needs not be along any definite particular contour. What are the examples? We might be having this sort of control in drilling, where holes have to be drilled at specific locations, we might be having EDM die sinking operation to be done at definite position, then spot welding, brazing, soldering, et cetera.

In all these cases the particular operation is to be carried out at definite locations, so there are some salient features associated with this type of control. The control system 1st of all does not require an interpolator, the interpolator calculates and implements the definite velocity relations between axes at the definite velocity value along the particular path, this is not required here, and we are not controlling the velocity in between definite locations. Next, the cutter moves from point-to-point one point to another and carries out machining or the required operation at these very points. Between the points, there is no cutting action and at these points there is no motion of the table, only cutter motion is there for cutting.

And the distance between these points is generally covered at the maximum possible velocity why, to save time. We are not cutting, so there are no forces involved in cutting during the movement from one point to another so why not employ the highest possible speed. And things like cutter radius compensation is generally not required in these operations. So how do point-to-point machines operate?

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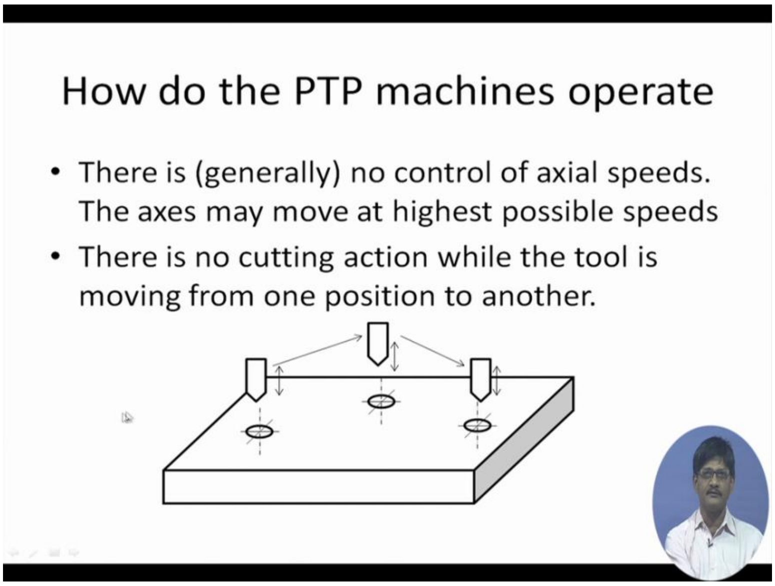

So this is a typical picture giving at definite locations some operations are being done. So this is a drill like cutting tool, it is supposed to move down, carry out drilling operation, come up, then go to the next point, it is moving straight, essentially it has to employ the highest possible velocity and then after reaching this point it goes down, carries out the machining operation, comes out and then reaches the 3rd point so on and so forth, this is the general scheme of work in point-to-point machines. No control over axial speeds, axis generally moving at highest possible speed and as we discussed no cutting action while tool is moving from one position to another.

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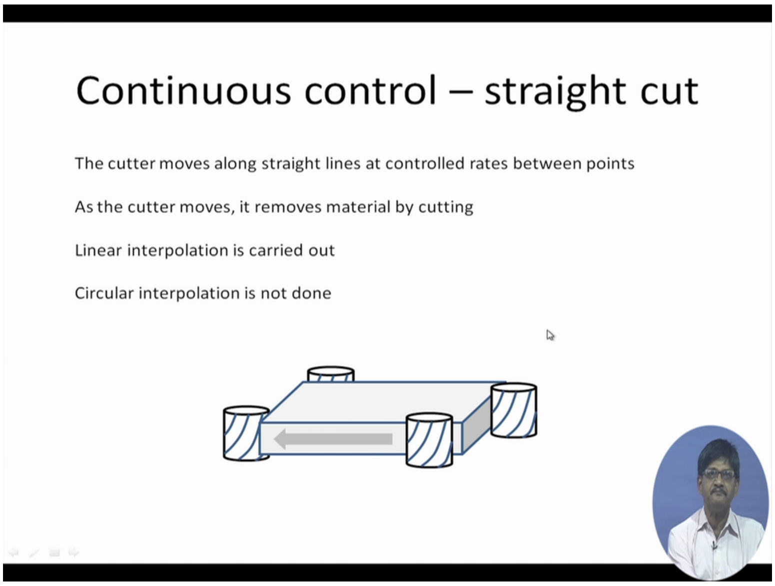

Compared to this, when we are talking of different types of machines, there is continuous control machine as well, which are continuously controlled. If it is moving from one point to another, it might be moving always along straight lines parallel to the axis of the machine. So here we are dealing with movements and during movements, cutting operation is being carried out and these movements are essentially parallel to the axis X, Y and Z axis or simply X and Y of the machine. So if I am moving and if I am cutting while moving, we essentially need to control this particular velocity and linear interpolation is carried out between these points.

Linear interpolation means moving in a straight line at a controlled rate, an interpolator finding out intermediate positions and of course velocity which is remaining constant, so this is continuous control with straight cut. On the other hand, we can have another type of continuous control in which both linear and circular cuts are going to be taken.

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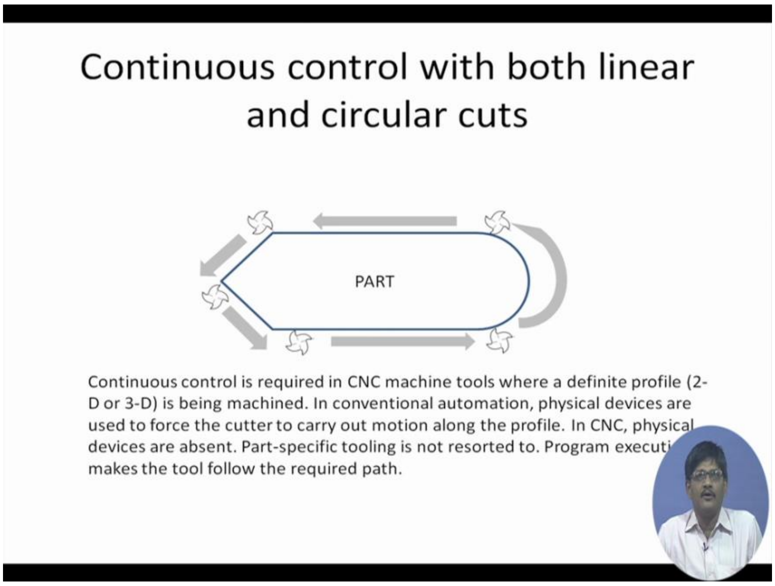

Here we have a cutter shown on the periphery of a part moving in such a manner that it may cut straight portions, it may cut an oblique portions which are straight but at an angle to both the axis, we are looking along the Z axis towards the X and y plane. And it might also have circular path I mean the path might be having circular profiles and these circular profiles will also be cut by the same cutter, so the cutter has to have the ability to move along straight line, to move along lines which are at an angle to both the X and Y axis and also along a circular path.

When we have conventional automation, if such a part has to be cut, generally physical devices will be employed in order to realize these motions of the cutter. In CNC, we will be simply programming for these motions of the cutter all around the part. Now in continuous control, what are the salient features then?

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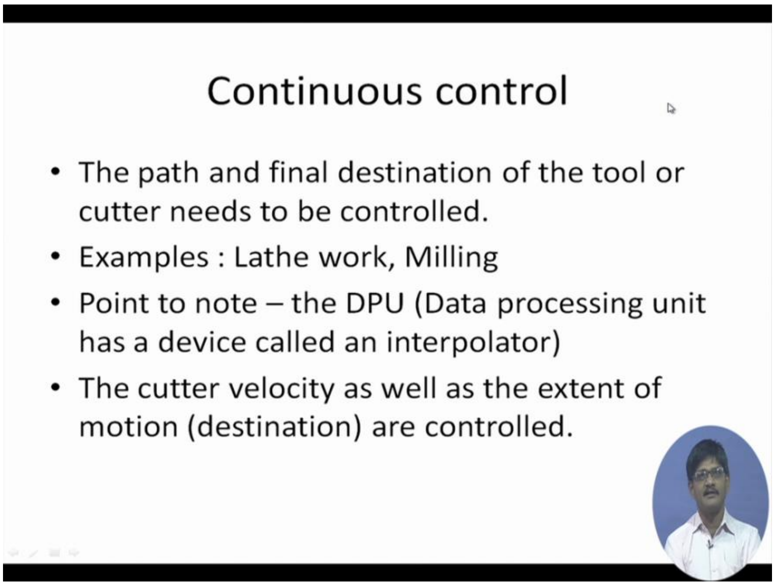

The path and the final destination of the tool or cutter need to be controlled, so we are having control over the final destination which means the extent of motion. And also, we are having to control the path of the tool, how can path of the tool be controlled? It can be controlled by controlling the ratio of the velocities along the different axis. We also have to control the rate of the motion of the cutter along its path that means the absolute velocity of the tool has to be controlled as well. Examples are typical work profiles, cut on the lathe, on the milling machine, et cetera.

And naturally, as interpolation is taking place the data processing unit has to have a device called an interpolator, so 3 things destination, cutter velocity, components along the different axis and the absolute value of the cutter velocity, these things need to be controlled in case of continuous control. This figure shows a typical example of the control loop of point-to-point control.

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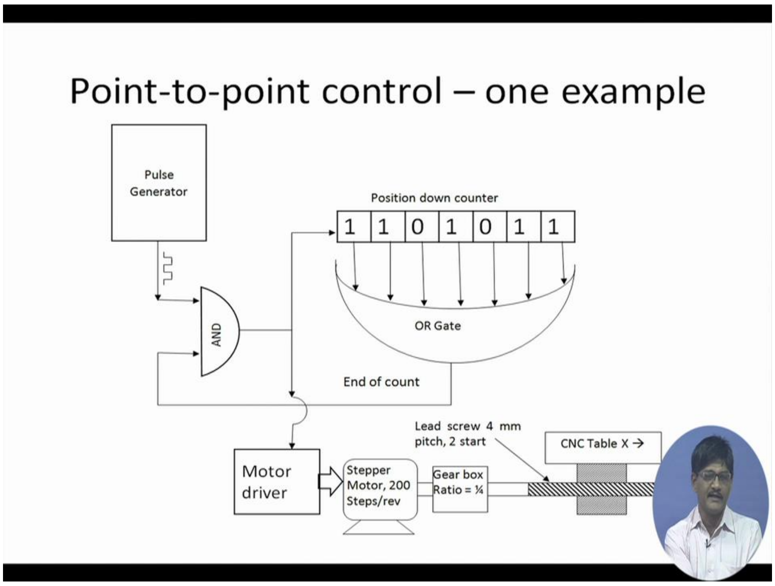

We had two different types of control one is point to point control and there is continuous control, so this is an example of point-to-point control, let us have some quick look how is it operating. 1st of all we have a pulse generator which is sending out pulses, if you remember high-voltage, low voltage, so say 5 volts, 0 volts or 12 volts, 0 volts, something like that is coming out and it is compatible with the stepper motor which is shown here. The stepper motor is a device, which response to a pulsed input, pulsed voltage input by carrying out one angular step for every pulse received; so this is the stepper motor which is shown.

The stepper motor, if it receives a train of pulses, it will execute a corresponding number of angular steps by rotating its shaft output shaft, how much? It is written here, this stepper motor rotates carries out one rotation or one evolution in 200 such angular steps, so that one step is equal to 1 points 8 degree, so these pulses are coming out on the pulse generator and they are ANDED with a signal, which is coming out from here, this is an OR gate. Now what is this?

This is called a position down counter, it is a device which can contain inside a digital say byte that means say a an 8 digit 8 bit or less or more, it can contain a binary number here okay and as the name suggests, position down counter, for example, 1101011, the content inside can be decremented that means it can be reduced for every pulse which is coming at this point which is called the clock input. So if a pulse arrives here, once it goes inside it reduces the content by one, so that after one pulse comes in it will become 1101010, so this way it will go on reducing for each and every pulse which comes inside, so ultimately it will become 0.

So when these are containing different bits, they are also input to an OR gate, the OR gate output will become 0 only if all these are 0s, which means that the OR gate is acting as a sort of detector for all these bits becoming 0s or the full content becoming 0 so that its output is given a name end of count. If it becomes 0, we can be sure that the content inside is 0 okay. So, once this becomes 0, this particular output becomes 0 and it stops further pulses from the pulse generator to go out to come here and also reach the stepper motor controls.

So this is a way in which we can design or we can make this device work in such a way that after a definite number of pulses have passed through this AND gate, this will be counted down to 0 and further pulses will not be allowed through this AND gate and the stepper motor will come to a stop. So we can plan it in this way that if I have a definite programmed motion to be carried out, I will put a corresponding calculated value of a binary number here after this gets counted down to the pulses which are coming out from the pulse generator, further pulses will be stopped when this reaches end of count and the motor will be stopping after carrying out those many angular steps of motion.

Those many angular steps of motion are converted by the gearbox to the smaller value and the CNC table moves correspondingly and it will come to a stop when this is counted down to 0. This is one way in which point-to-point controls can be made to work, let us see another example.

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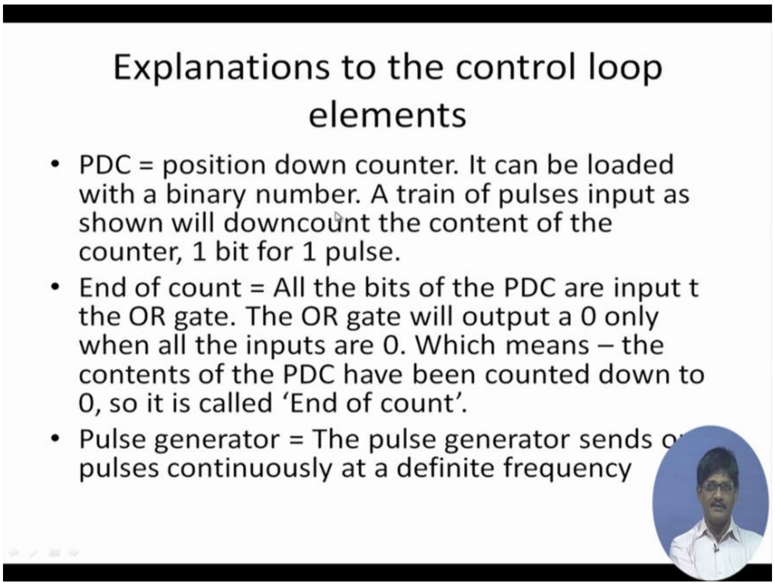

So these things we have already discussed, I will just put in summary of these explanation, position down counter as we have discussed is a counter which contains a number inside in binary and it can be counted down by pulses coming in at the clock input. End of count is output of the OR gate, when 0 it means that all the inputs to the OR gate they are individually 0. Pulse generator is a device, which sends out pulses continuously at a different frequency

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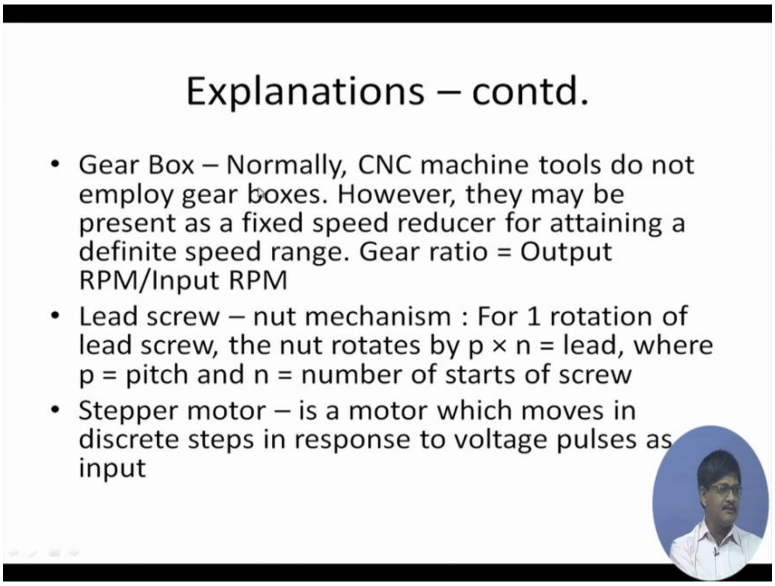

Gear box is basically in this case simply a speed reducing mechanism at a definite ratio okay. Gear ratio when expressed, in this case we will read it this way that output rpm by input rpm is equal to gear ratio. The lead screw-nut mechanism which has been shown here converts rotatory motion to straight-line motion at a definite ratio. What is this, this transfer function is 1 rotation of lead-screw produces lead amount of motion of the nut. What is lead equal to? Lead equals to pitch into number of starts okay, we will have new numerical examples of this so we will discuss it at that time. And stepper motor as we discussed is such a motor which moves in discrete angular steps in response to voltage pulses as input.

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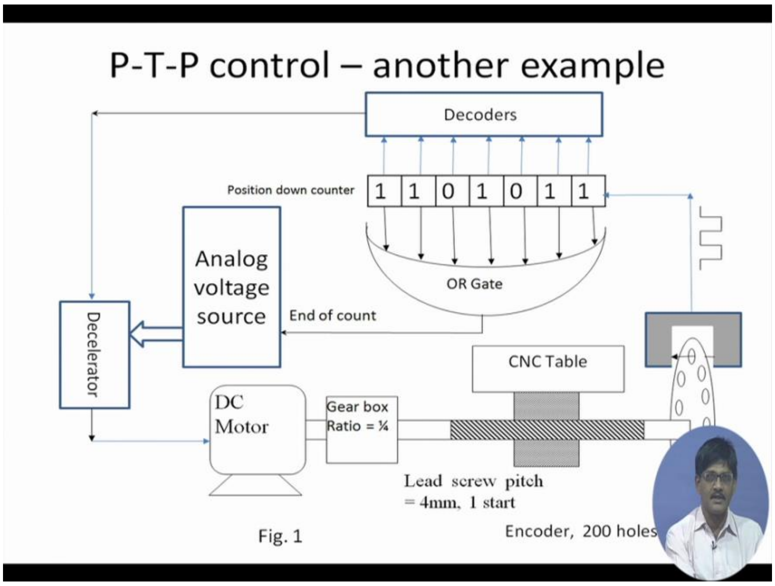

So in this figure we see the depiction of another type of point-to-point control, let us see 1st of all what is the prime mover. The prime mover is a DC motor, this DC motor connected with a gearbox as previously is also connected to a lead screw okay. This lead screw nut combination produces linear motion of the table.

And since the DC motor cannot be controlled as a stepper motor to start and stop precisely at definite point, start maybe but not stop at a definite point because it has inertia, we have to have some sort of feedback device in order to find out the extent of motion the DC motor executes, so this is a feedback device called an encoder. Whenever we are not sure of the prime movers will be to stop at a definite location, we employ such feedback devices.

So in this point-to-point device, it is having a close loop, this loop is obtained from the encoder through an LED that means light emitting device with a photoreceptor and a pulse generator ultimately give us voltage pulses here corresponding to each and every hole present on the encoder. When 1 hole is coming here, light is emitted from this side, received by the photoreceptor and a corresponding pulse is generated. So these pulses are feedback pulses which are incident on the clock input of the position down counter here.

So I put a certain number here, these numbers get down counted by these pulses coming from the feedback and until and unless this number becomes 0 by this counting down, once again the OR gate sense out a high value or value of 1, which keeps the analog voltage source on. So the analog voltage source is kept on as long as this count is not 0 and this analog voltage source feeds the DC motor, which rotates the gearbox, which rotates the lead screw and which moves the table. What is this decoder and decelerator? When the DC motor is rotating due to inertia it cannot be brought to a perfect stop while it is at its highest speed.

So when we have moved sufficiently close to the target, the decoder circuit through some binary circuits senses that it is certain distance away from the target and it reduces the voltage output of analog voltage source through a circuit called a decoder and the DC motor starts getting lower voltage and rotates at a lower rate. This way, decoder sequentially reduces the voltage to the motor from the analog source and the motor decelerates and finally comes to a halt at the required position, so this is an example of point-to-point controls with closed loop control.

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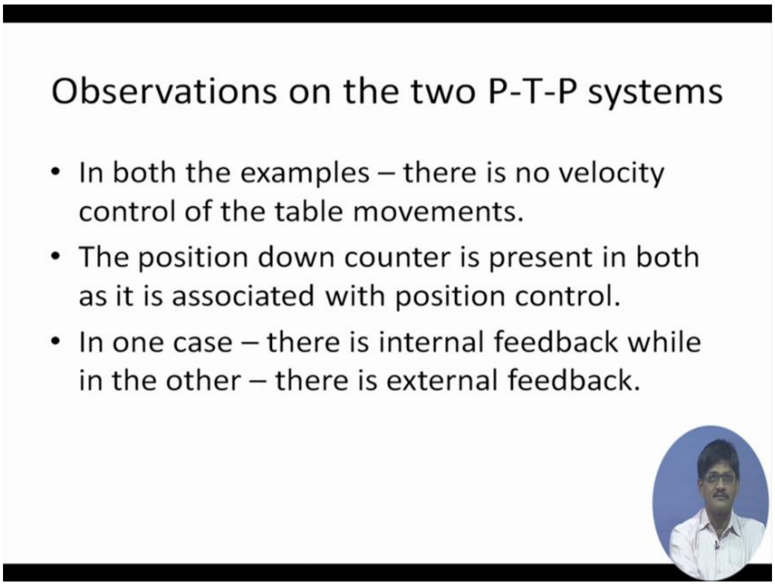

So in these two point-to-point systems as we have observed, there is no velocity control, the position down counter is present in both because it is associated with position control and there is internal feedback in one case, while there is external feedback in the second case.

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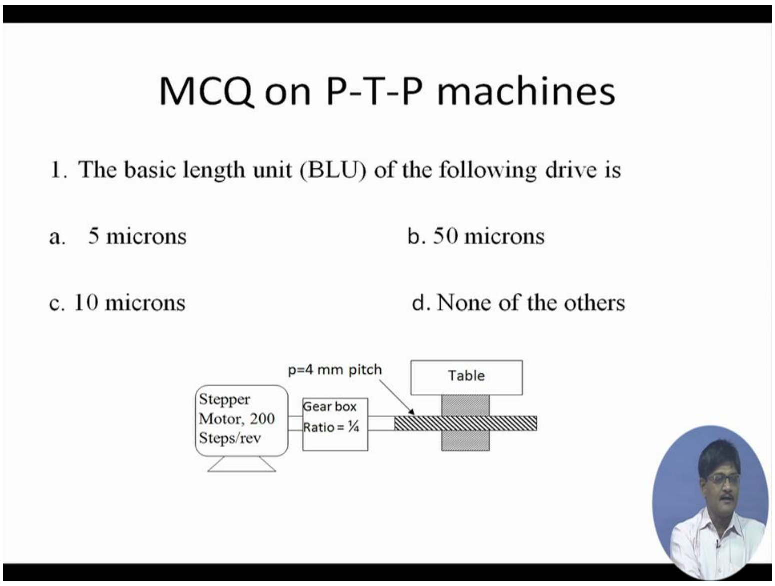

Practice problem for our work next. The basic length unit of the following drive is 5 microns, 50 microns, 10 microns, none of the others. What is basic length unit? Basic length unit is the smallest distance a system can step through accurately or it can read accurately, okay. In this case, the stepper motor receives pulses and corresponding to each pulse it will carry out the definite amount of motion, so for this system the basic length unit is that small amount of movement which the stepper motor will execute for 1 pulse voltage given to it.

Since 1 pulse results in 1 step of motion, let us find out how much this 1 step of motion will will move the table. So if 200 steps are there in 1 revolution, the gearbox receives 1 full revolution and output quarter of a revolution. So one full revolution of the gearbox will result from 4 revolutions of stepper motor shaft, so 4 revolutions of the stepper motor shaft will be 800 steps, 800 steps are rotating the lead-screw ones. And 800 steps therefore will give rise to 4 millimeters of movement assuming that lead screw has a single start.

So 4 millimeters of movement obtained from 800 steps therefore, 1 step will give rise to 4 millimeter divided by 800 equal to 5 microns of movement, so the answer is 5 microns.. Let us now have a look at an example of continuous control. We have discussed point-to-point control, two examples of it and now we are going to have a look at continuous control.

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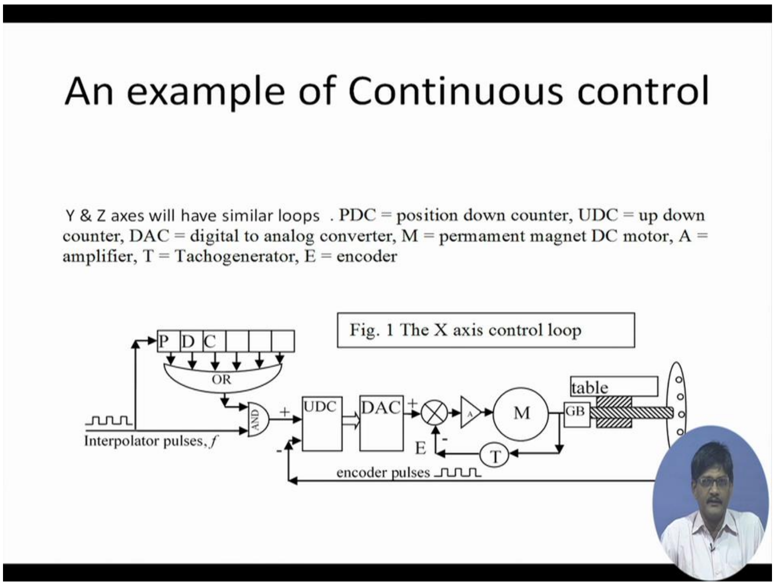

Coming back to our discussion, so here this represents the circuit for one axis of movement. If you remember, we had discussed that continuous control will always have an interpolator, so instead of a pulse generator we are having interpolator pulses coming in and these interpolator pulses are again sending pulses straight to the to the control loop and they are also sending pulses to the position down counter, we are conversant with the position down counter, it will contain some number inside which ultimately will be counted down to 0 and at that point it will stop further pulses from going through.

So that means the interpolator pulses which are coming in they are first getting counted and they are also passing through and reaching something called UDC or Up-down counter. Inside Up-down counter we have a content, which is up counted by these pulses coming in and they are also down counted by pulses which are coming from the encoder, but hopefully I think you can understand these encoder pulses which are coming back as a feedback, they are down counting the content of the Up-down counter.

So the Up-down counter is ultimately having a balance of pulses, which are 1st of all up counted by the pulses coming in from the interpolator and down counted from the encoder, it is having a balance of pulses. So this content is then converted to an analog voltage, which is ultimately given to the motor through some circuit, so if we look at it this way that how is it different from point-to-point control.

Unlike the point-to-point control machine, the motor is now going to have a voltage which varies and this varying voltage will produce different velocities of the motor and corresponding to these different velocities the motor is going to carry out different rates of motion, that cutter feed is now going to change and therefore, cuter axis velocity ratio are now going to change, so the cutter can take up different path directions and it can move at different rates of motion. Other parts like gearbox, table, et cetera, they are just the same as before but here there is another additional component that means from the motor there is an inner feedback loop shown by T or the tachogenerator.

This tachogenerator gives an inner feedback for control of velocity, it makes the time constant of the system much less that means if the system is having a sluggishness response, it makes this response faster or bigger, so we have two feedback loops in this typical continuous control loop, one is for feedback of velocity and is another is for feedback of position coming from the encoder.

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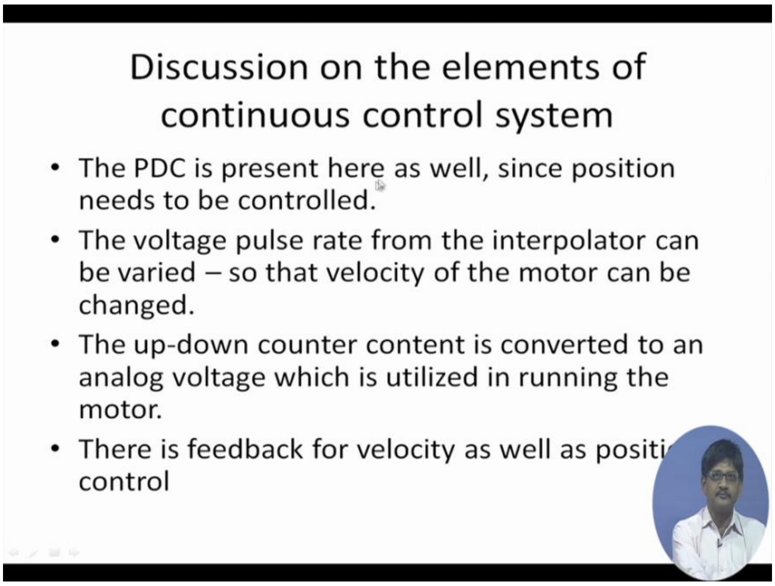

So discussion on the a continuous control system, we have already discussed and therefore I am not going to repeat it, voltage pulse rate coming from the (inter) interpolator can be varied so that velocity can be changed for the motor, et cetera, these things we have already gone through, thank you.