


**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 3<sup>rd</sup> 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 us see in what is the spread of CNC technology in a manufacturing scenario.

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### The Spread of CNC technology

- CNC machine tools find wide application in low level and medium level production.
- CNC technology supports the realization of unconventional concepts in manufacturing – like Rapid Prototyping (RP)
- It is possible to manufacture complex shapes by CNC




CNC machine tools find wide application in low-level and medium level production that means volume, low volume and medium volume 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.

(Refer Slide Time: 01:31)

## Types of Classification

- Type of cutter movement (or motion control)  
Point - to - point (P-T-P) and Continuous
- Type of control - Open loop and Closed loop
- Type of 'organization of machine operations' - Machine tool, machining centre and turning centre
- Type and number of axis movements



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 1<sup>st</sup> of all let us take up the discussion of point-to-point control.

(Refer Slide Time: 02:15)

## PTP – Point-to-point control


The tool or cutter has to move from one point to another, the path of the cutter between these points is not critical

Examples

- Drilling, EDM die sinking, spot welding, brazing, soldering

Salient features

- The control system does NOT require an interpolator
- The cutter moves from one point to another and carries out machining / required operation at these points.
- It generally covers the distances between the points at highest attainable velocity.
- Cutter radius compensation is generally not required



What is point-to-point control, we find that whenever we are talking of machine tools, there are some machine tools in which the operation, 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 in

between taken by the cutter between these points is not critical that means it is not very important; it need 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.


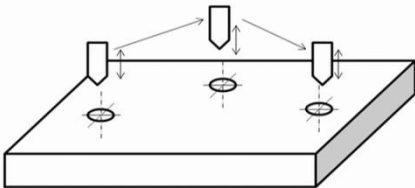
In all these cases the particular operation is to be carried out at definite locations, so there are some salient features associated with this type of control. The control system 1<sup>st</sup> of all does not require an interpolator, the interpolator calculates and implements the definite velocity relations between axes at a 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?

(Refer Slide Time: 05:04)

### How do the PTP machines operate

- There is (generally) no control of axial speeds. The axes may move at highest possible speeds
- There is no cutting action while the tool is moving from one position to another.



The diagram illustrates a point-to-point (PTP) machine operation. It shows a 3D perspective of a rectangular workpiece with three circular holes. A vertical tool is positioned above the workpiece. Arrows indicate the tool's movement: it moves down to drill the first hole, moves horizontally to the second hole, moves down to drill it, moves horizontally to the third hole, and finally moves down to drill it. This sequence demonstrates the discrete nature of PTP control, where the tool only moves when it is at a specific location to perform a task.

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 3<sup>rd</sup> 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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The slide is titled "Continuous control – straight cut". It contains the following text:

- The cutter moves along straight lines at controlled rates between points
- As the cutter moves, it removes material by cutting
- Linear interpolation is carried out
- Circular interpolation is not done

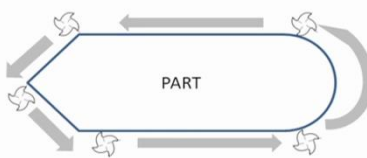
The diagram shows a 3D perspective of a rectangular workpiece with a cylindrical cutter moving along a straight line on its top surface. A grey arrow indicates the direction of movement from right to left. The cutter is shown in a hatched style. In the bottom right corner of the slide, there is a circular inset image of a man with glasses and a white shirt.

Compared to this, when we are talking of different types of machines, there is continuous control machine as well, which are continuously controlled. It is 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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### Continuous control with both linear and circular cuts



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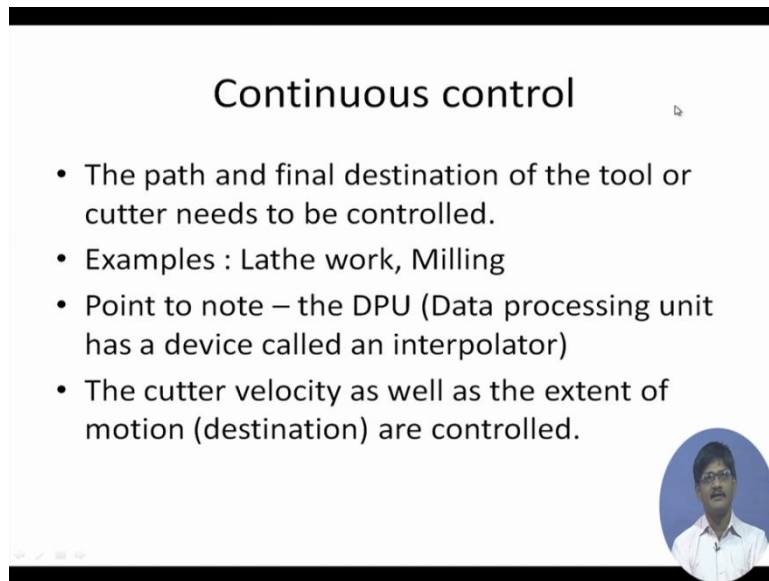
Continuous control is required in CNC machine tools where a definite profile (2-D or 3-D) is being machined. In conventional automation, physical devices are used to force the cutter to carry out motion along the profile. In CNC, physical devices are absent. Part-specific tooling is not resorted to. Program execution makes the tool follow the required path.



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 (7:45) 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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## Continuous control

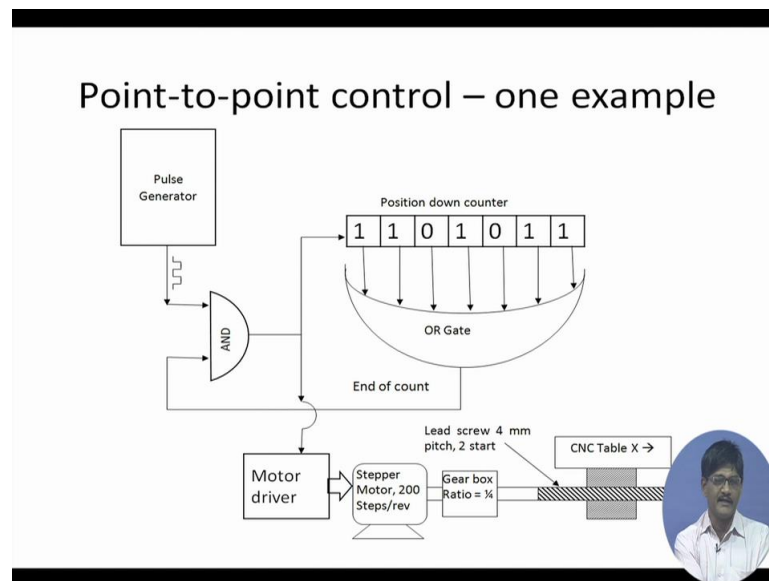
- The path and final destination of the tool or cutter needs to be controlled.
- Examples : Lathe work, Milling
- Point to note – the DPU (Data processing unit has a device called an interpolator)
- The cutter velocity as well as the extent of motion (destination) are controlled.



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. 1<sup>st</sup> 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; 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?

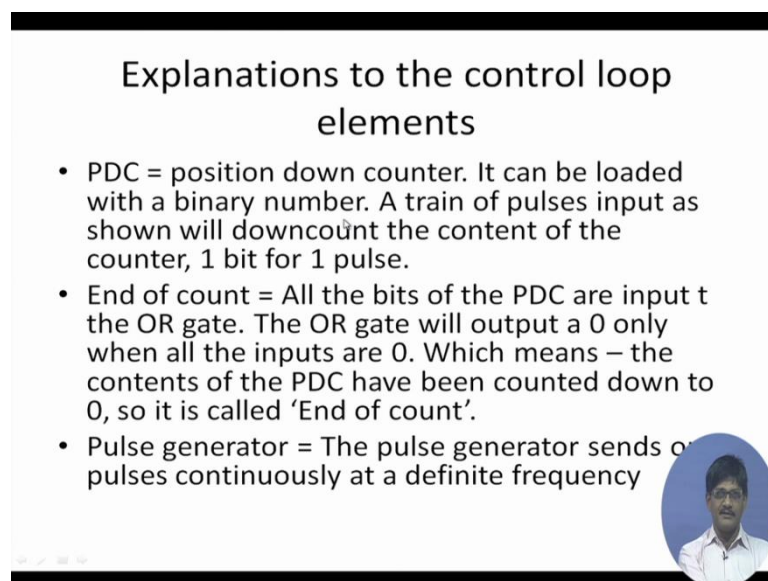
This is called a position down counter, it is a device which can contain inside a digital say byte that means say a an 8 digit 8 bit or less or more, it can contain a binary number here okay and as the name suggests, position down counter, the content inside for example, 1101011, the content inside can 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.

(Refer Slide Time: 15:22)



**Explanations to the control loop elements**

- PDC = position down counter. It can be loaded with a binary number. A train of pulses input as shown will downcount the content of the counter, 1 bit for 1 pulse.
- End of count = All the bits of the PDC are input to the OR gate. The OR gate will output a 0 only when all the inputs are 0. Which means – the contents of the PDC have been counted down to 0, so it is called 'End of count'.
- Pulse generator = The pulse generator sends out pulses continuously at a definite frequency



So these things we have already discussed, I will just put in summary of these explanation, position down counter as we 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 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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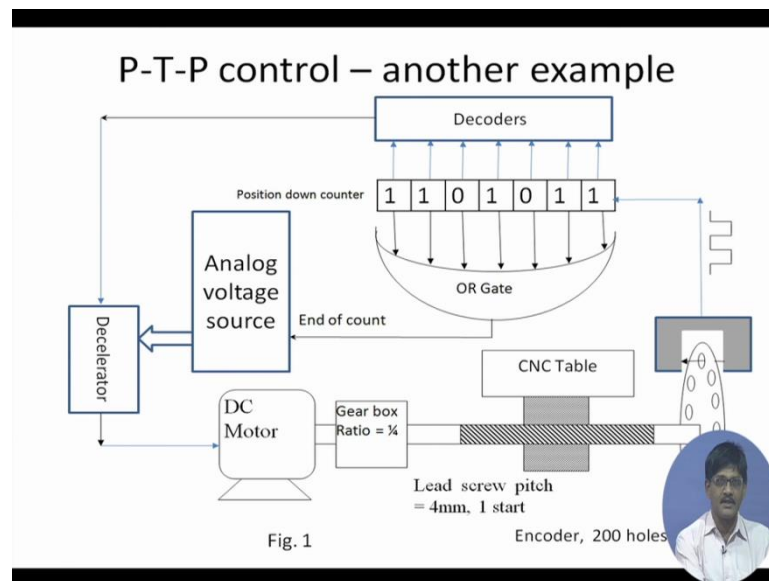
### Explanations – contd.

- Gear Box – Normally, CNC machine tools do not employ gear boxes. However, they may be present as a fixed speed reducer for attaining a definite speed range. Gear ratio = Output RPM/Input RPM
- Lead screw – nut mechanism : For 1 rotation of lead screw, the nut rotates by  $p \times n = \text{lead}$ , where  $p = \text{pitch}$  and  $n = \text{number of starts of screw}$
- Stepper motor – is a motor which moves in discrete steps in response to voltage pulses as input



Gear box is basically in this case simply a speed reducing mechanism at a definite ratio okay. Gear ratio when expressed, in this 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 equal 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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We will take a quick look I am sorry my face is obstructing part of the figure, but hopefully you will understand. So in this figure we see the depiction of another type of point-to-point control, let us see 1<sup>st</sup> 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, and this is the lead screw. This lead screw nut combination produces linear motion of the table.

And since the DC motor cannot be controlled at a stepper motor to start and stop precisely at definite point, start maybe yes 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.

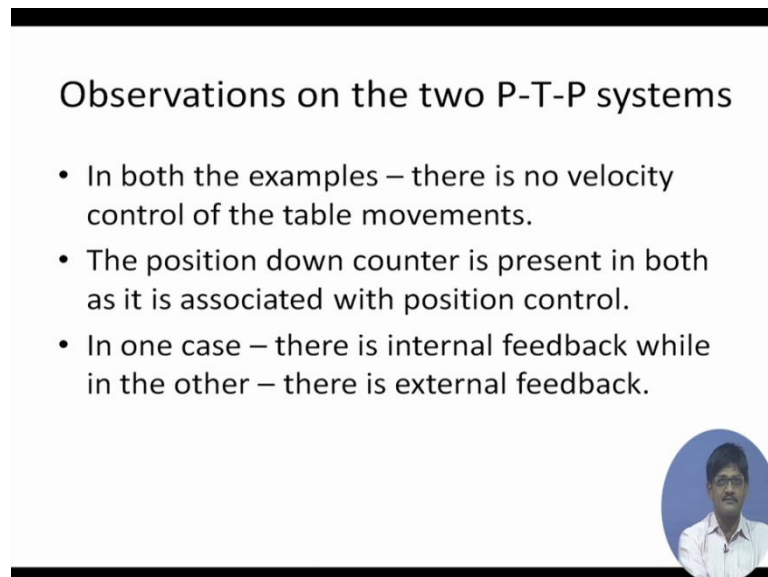
So in this point-to-point device, it is having a close loop, this loop is obtained from the encoder through an LED that means light emitting device with a photoreceptor and a pulse generator ultimately give us voltage pulses here corresponding to each and every hole present on the encoder. When 1 hole 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, it 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 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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**Observations on the two P-T-P systems**

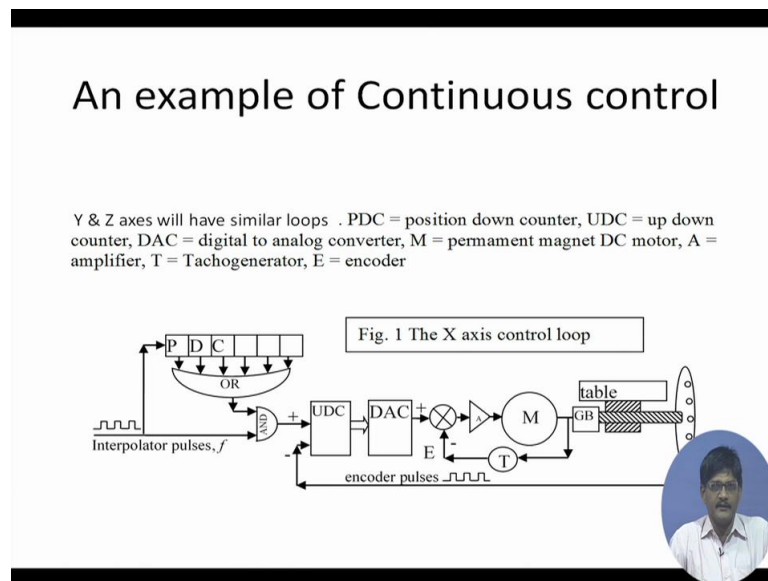
- In both the examples – there is no velocity control of the table movements.
- The position down counter is present in both as it is associated with position control.
- In one case – there is internal feedback while in the other – there is external feedback.



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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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 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 1<sup>st</sup> 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, it is partly obstructed 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 1<sup>st</sup> of all up counted by the pulses coming in from the encoder and down counted by the pulses coming from the sorry from the interpolator they are up counted and from the encoder they are down counted, it is having a balance of pulses. So these 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, cutter 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 techno-generator.

This tacho generator 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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### Discussion on the elements of continuous control system

- The PDC is present here as well, since position needs to be controlled.
- The voltage pulse rate from the interpolator can be varied – so that velocity of the motor can be changed.
- The up-down counter content is converted to an analog voltage which is utilized in running the motor.
- There is feedback for velocity as well as position control



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.