**Computer Numerical Control of Machine Tools and Processes**
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**Lecture 04**
**Classification: Open Loop and Closed Loop**

Welcome viewers to the 4th lecture of the open online course Computer numerical control of machine tools and processes. To continue with our lecture on classification, we will be discussing today closed loop and open loop control.

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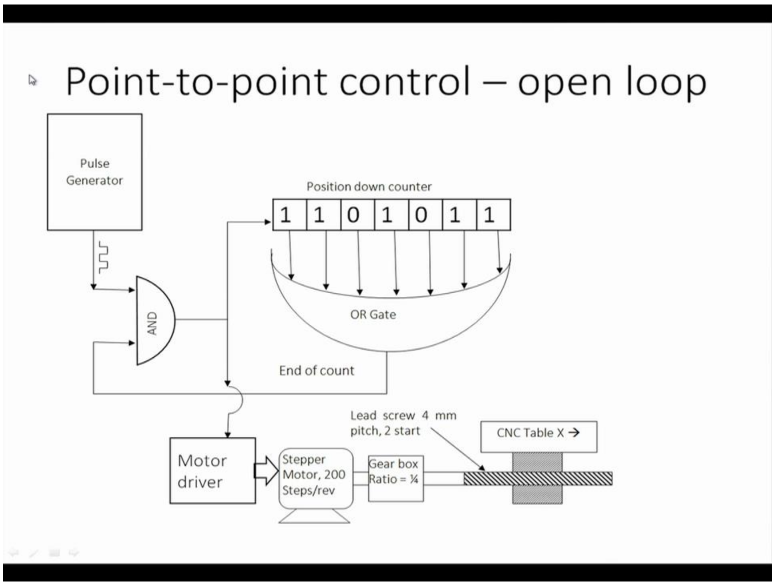


To come back to one of our previous figures we had seen this particular control loop with respect to point-to-point control. Now it can also be classified as an example of open loop control. Open loop Control essentially means that there is no feedback because we are confident on the prime movers capability reaching of particular point and I mean attaining a particular target position. If the prime mover cannot reach a particular target position, in that case we have to employ something called feedback. Stepper motor moves in discrete steps and it can be electromagnetically locked into a particular angular position after it has been decelerated.

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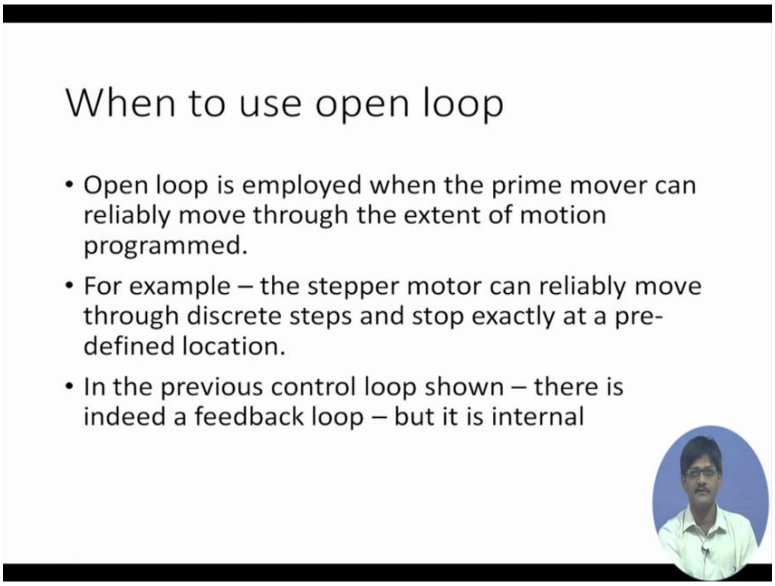


So we do not really need a feedback in this case in order to insure that it has reached a particular location. Hence, there is definitely an internal feedback through this position down counter to ensure that it executes the required number of angular steps, but externally on the machine itself on the CNC table there is no check or verification that it is actually executed required number of steps to reach the particular position or not. We are relying on the prime mover and its ability to reach a particular position, so this is an example of open loop control. So we use open loop control for as we have discussed and we are sure of the prime mover.

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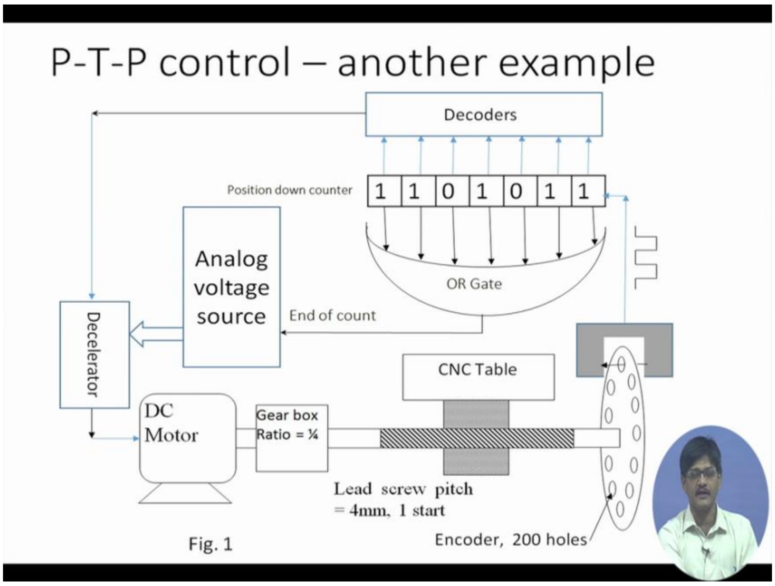


This is another example of point-to-point control however; we are using closed loop control here. What is the difference? The primary difference is there in the prime mover, here they are using a DC motor and the DC motor is connected up through a gearbox and via the lead screws to the CNC table. When the DC motor is running at its full RPM, it has to be decelerated when it has approached the target position and finally the voltage supply has to be put to 0 and mechanical brakes have to be applied to bring it to a definite stop. However, as the DC motor has sufficient inertia it is extremely difficult to ensure without feedback that it has actually reached the target position.

So only when we ensure through feedback that it has reached a definite target location, then only voltage supply is fully put to 0 and mechanical brakes are applied, so here we have provision for external feedback through this device called an Encoder. It is simply is a disk mounted axially on the lead screws and it is aided by a light emitting device, a photoreceptor and pulse emitter, pulses corresponding to each hole passing in between the light emitting device and the photoreceptor, these pulses counting the angular displacement of the encoder and thus keeping a count of the location of the CNC table.

So this way we are taking the help of external feedback to ensure the exact current position of the table and depending upon that we are deciding whether the motor has to be decelerated and ultimately the voltage has to be put completely to 0 and then mechanical brakes have to be applied, so this is an example of closed loop control employed in point-to-point system.

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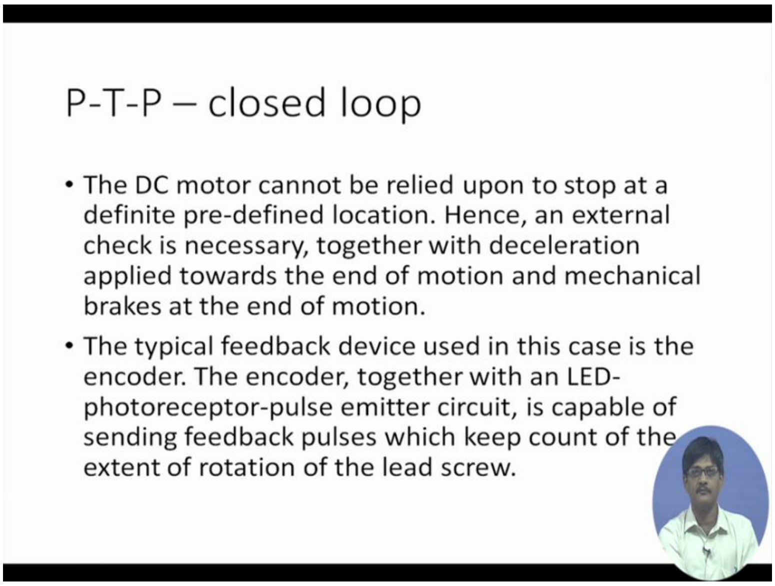


So when do we do this, as we discussed the DC motor as it cannot be fully relied upon to stop at a definite predefined location, we are using this sort of feedback. There is definitely internal feedback here as well.

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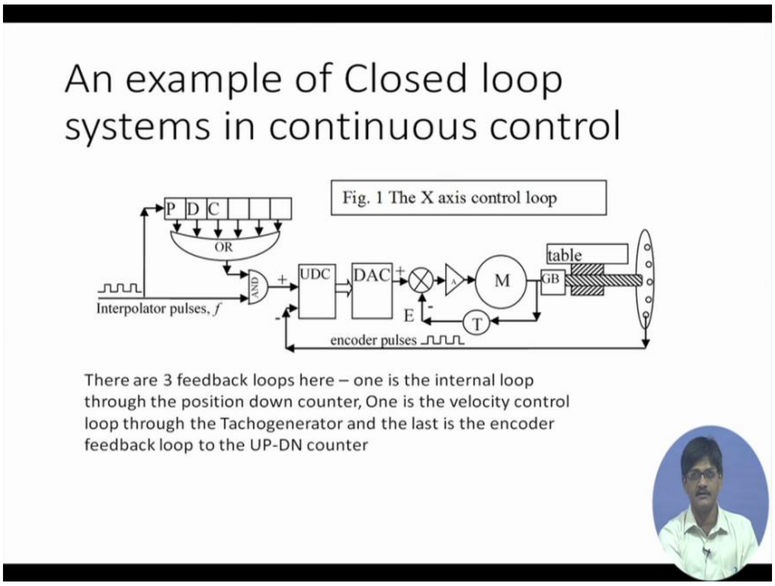


This is an example of closed loop system in continuous control. Continuous control as we have discussed, it is another type of classification in which a system which is capable of moving the table in straight line we nearly that is along a straight line at a predetermined rate and also it is able to coordinate the motions of 2 axis so as to produce circular motion that is these are the examples of continuous control.

So in this example of continuous control, as we have discussed previously one axis of motion has been shown where pulses are coming from the interpolator passing through the position down counter entering the up down counter, getting accumulated and developing a corresponding voltage another voltage through the digital to analog converter and that is feeding the motor, motor is rotating and through external feedback pulses are being sent from the encoder to the decrement the content inside the down counter, why?

Because if we are intending to move along a straight line at a steady rate, the voltage ultimately supplied to the motor should be constant. When the required velocity of the motor has been attained, the rate of pulses from the interpolator should be equal to the rate of pulses coming from the encoder and these 2 will balance each other so that the content inside the down counter should be constant, leading to a constant analog voltage by the converter and ultimately leading to a constant speed of the motor, this is how the interpolator can ensure by sending in a constant pulse rate, constant speed of the motor along one axis of motion.

So but what about closed loop control applied here? There are 2 loops here externally; one is for velocity control to quicken the response of the motor to an external stimulus like a step voltage. If a step voltage is applied to the stalled motor, the quickness or the speed with which it response to that particular stimulus by attaining a definite speed that gives us a measure of the time constant of the motor. So this inner velocity loop reduces the time constant, makes the motor respond faster. What about this outer loop?

This outer loop ensures that deceleration is attained when the motor is towards its has almost reached its target point and it also ensures that position control is achieved so the external loop is proposition, the internal loop is for velocity, so these are the 2 examples of closed loop control employed in continuous control systems. And this is once again the internal loop for position control, so how do we have the external loop for position control, because we can never be sure that the prime mover has actually moved the table to the required position or not.

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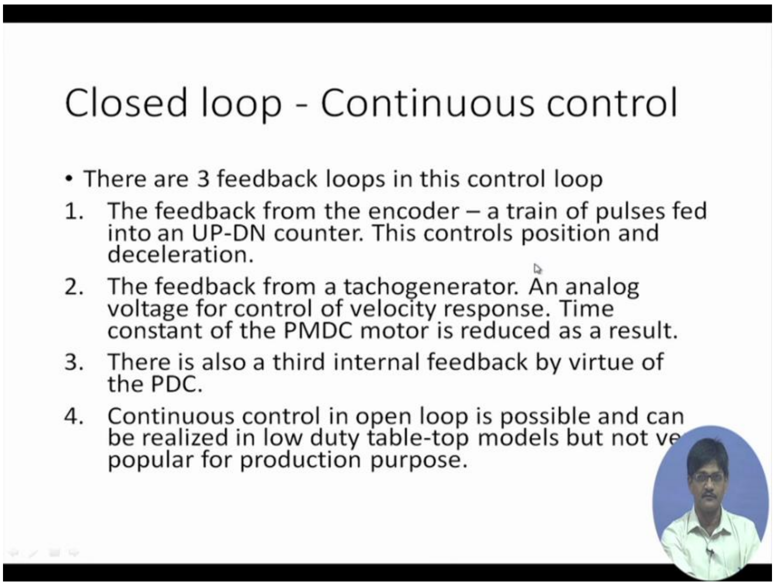


So these points we have already discussed that is what are the 3 types of feedback and how they are implemented

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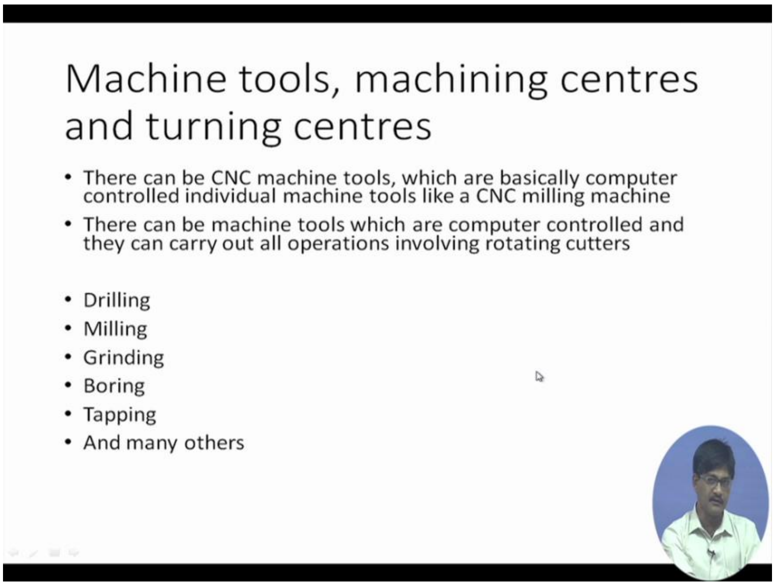


Now, classification can be done by other means as well for example, we can classify CNC machines as conventionally controlled machines or rather CNC leads, CNC milling machine, CNC drilling machine, these comprise one group of CNC machines tools. There can be other types of CNC machine tools, which are referred to as machining and turning centers. What is the idea of the machining centre? On the machining centre, instead of the job going from machine-tool to machine-tool to get different operations carried out on itself, all the machining operation can be can be made available at a particular location, so that the transfer time of the part from one machine to another, the setup time of the machines or the part in several machines, this can be drastically reduced.

So instead of part going to different machines, all the machines come to the part at a definite location and this is the basic concept of the machining centre. For example, there can be machining centre in which all operations involving rotating cutters can be made available for example, drilling, milling, grinding, boring, tapping and so many others. But for this, the basic structure of the machine, requirements that we have from the machine, they become different from ordinary machine-tools.

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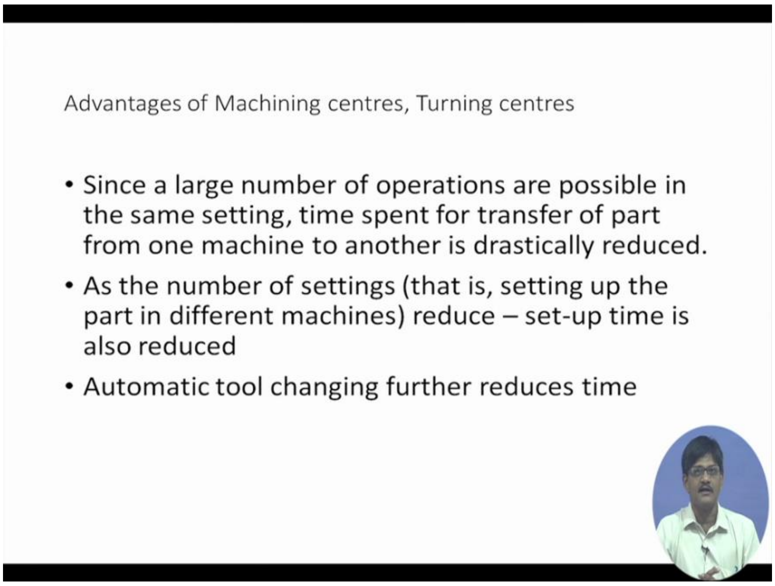


For example, since a large number of operations… by the way these are the advantages, advantages we have already discussed. Large numbers of operations are possible in the same setting, time spent for transfer is less, number of settings becomes reduced and tool changing is automatic that further reduces time. Just a moment, we need to just have a look at the previous slide.

Yeah, so let me just discuss it verbally that is the way in which the structure of the machine is changing is this, the spindle has to have a large wide range of rotations per minute that means it has to have an infinitely variable drive for the spindle say starting from 0 to 6000 RPM, why? Because it should be able to do milling, drilling with very small tools, asking for very high RPM, then grinding and also tapping. So while very small values of RPM should be available, very large values of RPM should also be available and it should be available in at infinitely variable form, this is one requirement for machining centres.

So and apart from the spindle, we also need to have an automatic tool changer because since a number of operations are becoming possible, so number of tools will have to be available and if number of tools are to be available, they have to be stored in a magazine or a storage device and tool changing should be made automatic, so these are the requirements of machining centre.

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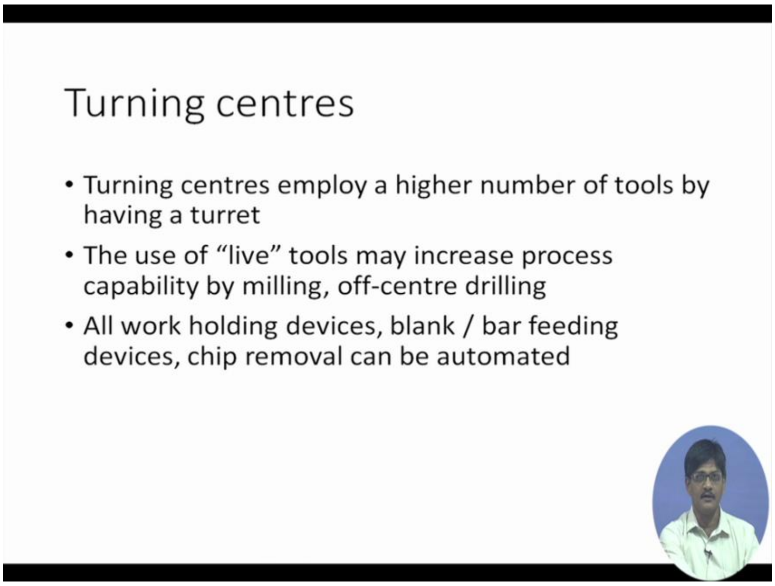


Turning centers also employ a higher number of tools by having a turret and if "live" tools can be used that means tools which have their own motors for making them rotate, then milling, off-centre drilling, these operations would also be possible. Apart from that, work holding devices, blank or bar feeding devices, chip removal, all these things can be automated, which makes the turning centres much more versatile than ordinary CNC lathes.

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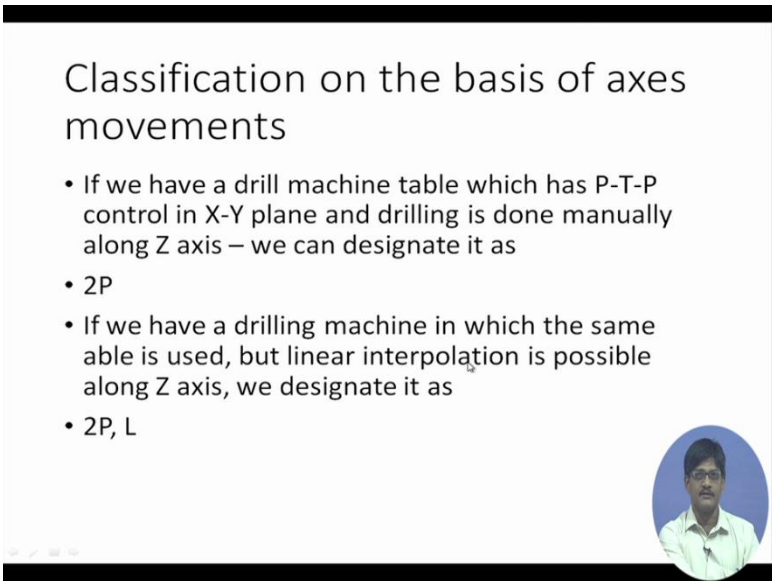


There can also be type of classification depending upon the type of axes movements available, let me give you some examples. If we have a drilling machine table which has point-to-point control in X-Y plane and drilling is done manually along Z axis, we can designate it as 2P. As the name suggests that there are 2 axes which are moving and they are moving in the point-to-point mode, so the drilling table would be called 2P. On the other hand, if we have a drilling machine in which the same table is used, but linear interpolation is possible along Z axis that means the tool is now available automatically and it comes with linear interpolation, which means that its speed can be controlled along Z axis. So 2P remains there, L designates that there is yet another axis and linear interpolation is possible along that axis.

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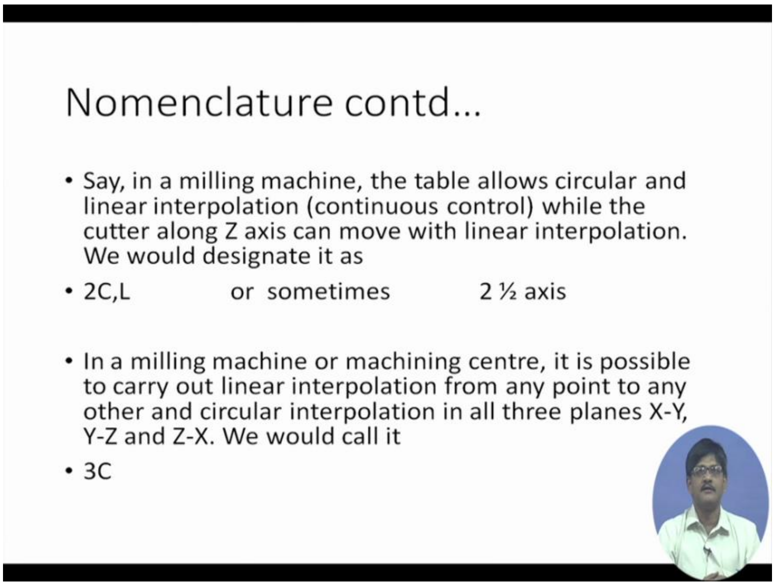


Let us take a milling machine, in the milling machine say the table is able to move in a in circular and linear interpolation mode that means continuous control, while the cutter along Z axis can move with linear interpolation, so it is designated as 2C, L that means in 2 axis I have continuous control and in the remaining axis in the 3 axis machine, I have linear interpolation along Z. It is sometimes referred to as 2 and a half axis as well, but it might be misleading in some cases, this is designation of half axis.

Another example, say in a milling machine or a machining centre, it is possible to carry out linear interpolation from any point to any other point in circular interpolation in all 3 planes X-Y, Y-Z, Z-X, what would we call it? We would call it a 3C machine that means 3-axis continuous control.

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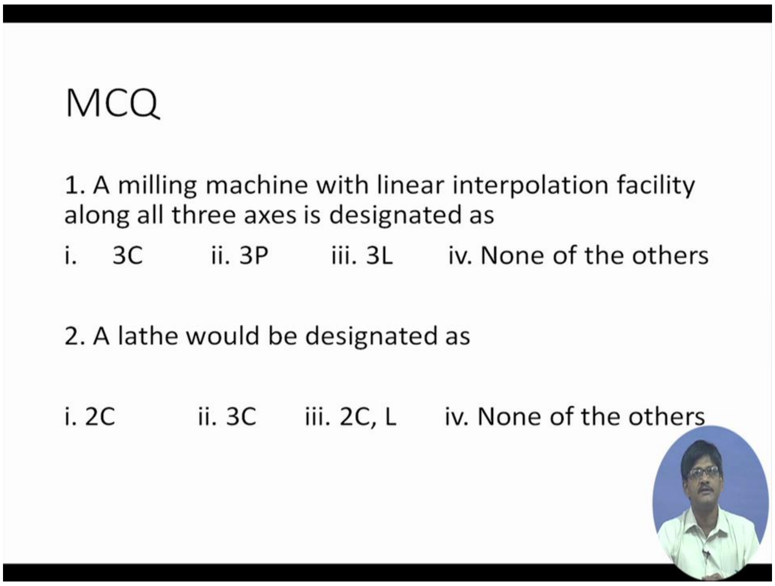


MCQ, a milling machine with linear interpolation facility along all 3 axes is designated as 3C, 3P, 3L, none of the others. In this case, since linear interpolation facilities available all 3-axis, we will call it 3L so the correct answer here is 3L. A lathe would be designated as… 2C, 3C, 2C L, none of the other. Let us look at the lathe, how many axes of motion does it has? It can move along X axis and it can move along Z axis, so combining these 2 we can have circular interpolation, linear interpolation, so we would be calling it 2C, a lathe would be designated as 2C.

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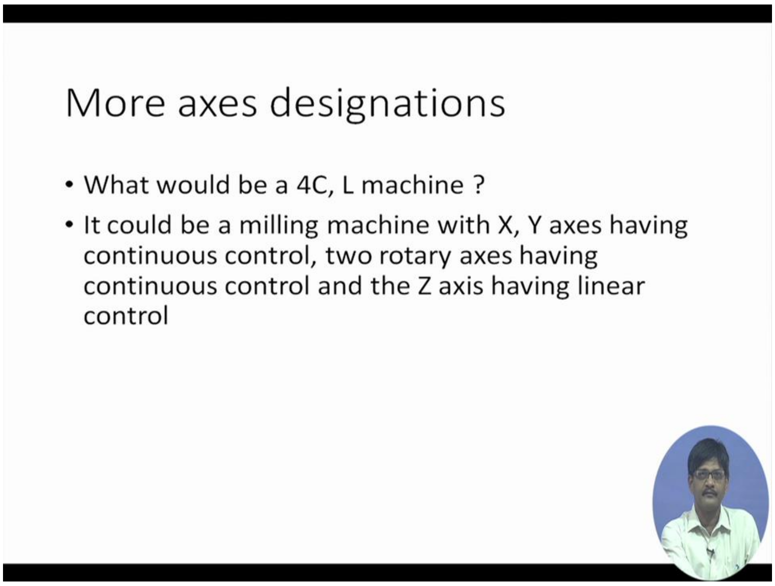

What would be a 4C, L machine? It could be a milling machine with X and Y axes having continuous control, two rotary axes having continuous control and the Z axis having linear control, so X and Y, two rotary axis 4C, L for the Z axis having linear control.

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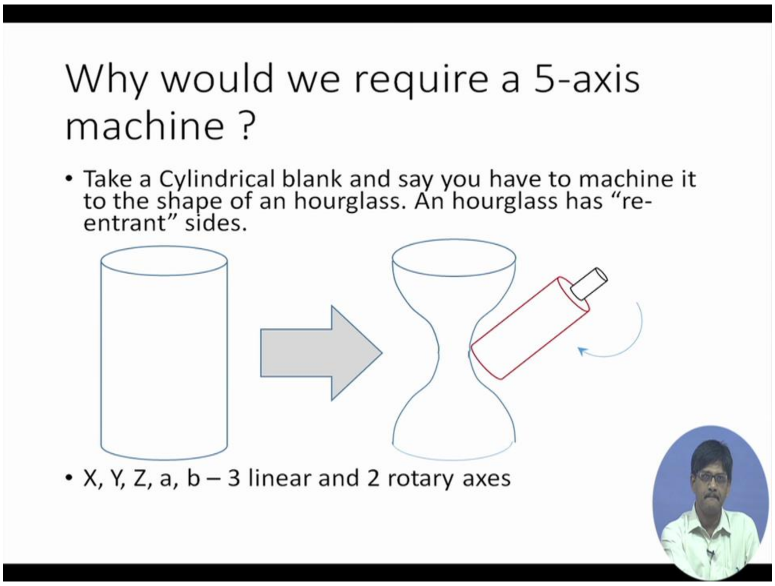


So, when we are talking of rotary axis, why do we at all need rotary axes, when we know that our 3 dimensional world is basically made of 3 axis okay. And we have also heard of 5-axis machine being sort of ultimate, so let us take this example. Suppose, from the cylindrical job you have to make an hourglass shape, if we have 3 axis of motion available and if the tool is residing with a vertical axis initially, it can never come to this part of the job okay because it it can only go down. If it has to reach this part in a 3 axis machine, it will have to move along this particular vertical line and therefore, the upper part of the body will be damaged.

In these cases, these portions of the body they are known as "re-entrant" sides in the body sometimes is called is said to be having folded surfaces okay, the surface folds over itself. So in order to access these seemingly inaccessible portions, that pole has the ability to rotate from a vertical axis configuration to an inclined axes configuration, so naturally we have provide facility for rotating the tool to attain this sort of configuration. So this requires one axis and if you move 90 degrees and come here, here again you will need another axis of rotation so 3 Linear axes plus 2 rotational axes would mean 5 axes would be necessary to completely machine this sort of work pieces and therefore, we require a 5-axis machine to be fully versatile.

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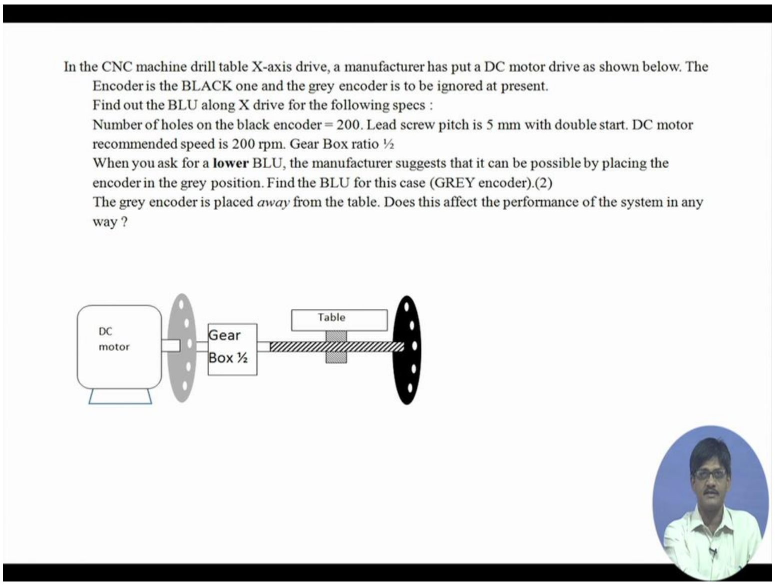


Let us take this problem, I am afraid the size of font is not very large; I hope you can read it. Let us have a quick look what it says. In the CNC drill table X axis drive, the manufacturer has put a DC motor drive as shown below, the encoder is the black one and the grey encoder is to be ignored at present. Find the basic length unit along X-drive for the following specifications: number of holes on the encoder is 200, lead screw pitch is 5 millimeters with double start, DC motor recommended speed is 200 rpm and the gearbox ratio is half, so let us try to find out how much is the basic length unit.

Basic length unit is either the smallest distance through which the table can be made to move to by us or it is the smallest distance which is readable when the machine is moving. In this case, it is the smallest distance information which can be returned by the encoder to the machine control. So let us see what the smallest distance which the encoder can read is. The encoder can read distances which are covered in between two pulses which it is sending back, so let us have a quick look how much is the distance covered by the table when the encoder has moved from one hole to another that means from one pulse to another.

The table basically moves lead amount of distance for one rotation of the lead screw, which means 5 millimeters into 2 since it is double start, so 10 millimeters of movement is carried out by the table when it is moving, when the lead crew has rotated once. By the time the lead screw has rotated ones, 200 of those encoder holes have passed in between the light emitting diode and the photoreceptor hence, per hole the distance covered by the table is simply 10 millimeters divided by 200 okay, let us make a note of that.

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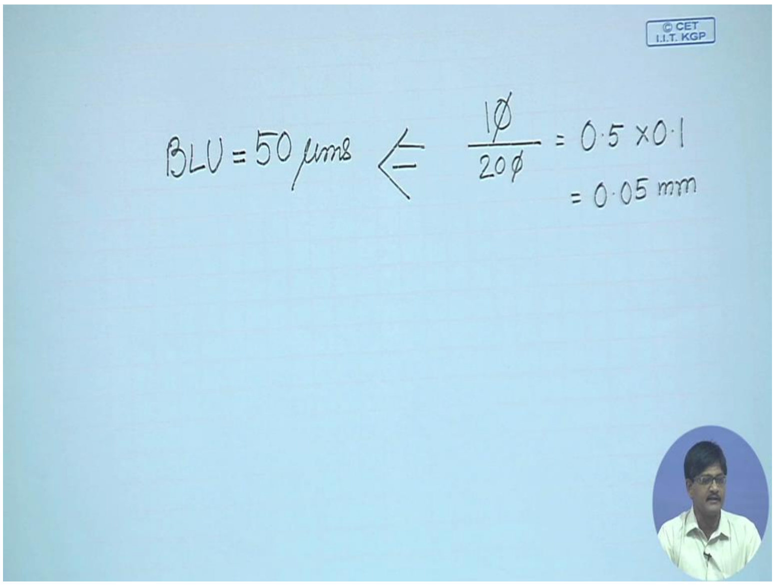


So we have 0.5 into 0.1, which means 0.05 millimetres, 50 microns. I am writing from this side to that side, but English is generally written from this side so sorry if I have confused you. So coming back, 50 microns basic length unit, what do we do with that? Now when you ask for a lower basic length unit, the manufacturer suggests that it can be made possible by placing the encoder in the grey position, same encoder, just mount it on the motor shaft instead of the lead screw shaft, this is what the manufacturer suggests. So let us find out the basic length unit for the grey position I am mean for the grey encoder position.

So that means this encoder is now out and this encoder is now in, so let us see how much is the how much is the basic length unit at this moment. So, if the gearbox is having ratio of half, by the time the DC motor shaft rotates once, the lead screw will rotate only half a time. So this means that 200 steps would keep a count of half the rotation equal to 5 millimeters, so 5 millimeters of movement divided by 200 is the present basic length unit, let us write it down 5 millimetres by 200.

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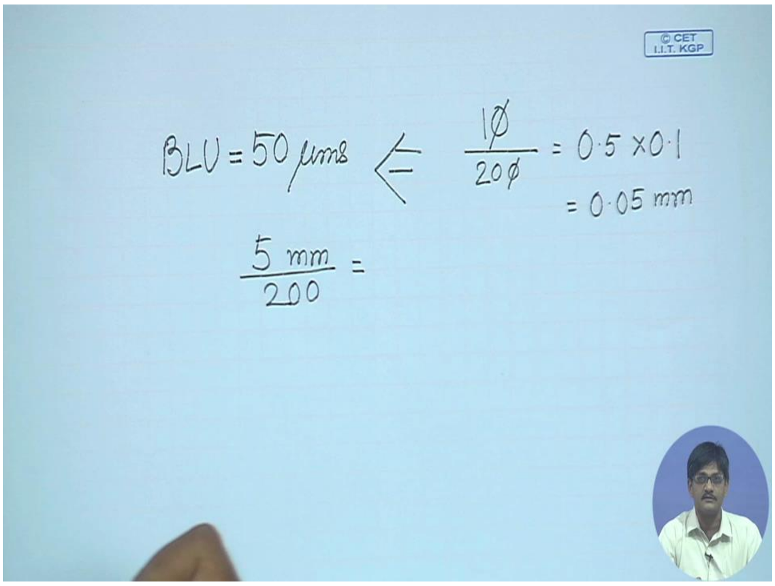


Obviously, it is half of the previous value which means 25 microns that is good. I mean if you can simply change the position of the encoder and get a reduction, but a good reduction 25 microns, why not, but it is not done in real practice. The question is the grey encoder is placed away from the table, does this affect the performance of the system? Yes it does. Further you are away from the actual point of interest; more will be the errors that you will be accumulating on your way. What can be the errors? Backlash to start with, okay.

There can be so many clearances between gear teeth and backlash is just everywhere in mechanisms, et cetera, so all these errors will not be taken into account in the feedback signal which is set by the encoder now. Even when you have the lead screw mounted encoder, there also you will still suffer from any backlash which is occurring in the lead screw nut mechanism okay, in this position. Backlash may be existing here and it does affect the lead, the encoder mounted on the lead screw. And if it is further away beyond the gearbox, you will be accumulating even higher amount of errors on your way, so that is why this practice is not recommended even though it gives you lower basic length unit.

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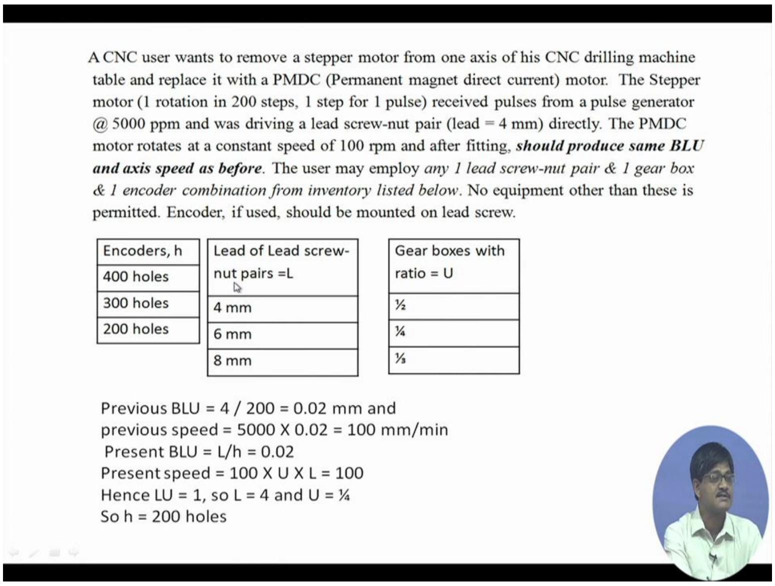


The last problem that we are going to deal with if we have the time, this says, a CNC user wants remote a stepper motor from one axis of a CNC drilling machine table and replace it with a permanent magnet DC motor, so this is his drilling machine table so it must be point-to-point. The stepper motor, 1 rotation in 200 steps and 1 step for every pulse, receives pulses from a pulse generator at 5000 pulses per minute and was driving a lead screw nut pair of lead 4 millimeters. The permanent magnet DC motor rotates at a constant speed of 100 rpm and after fitting, should produce the same basic length unit and axes speed as before.

This is the requirement; you are going for a permanent magnet motor from instead of a stepper motors, but we want to retain the values of basic length unit and axes speed. The user may employ any lead screw nut pair and 1 gearbox and 1 encoder combination from the inventory listed below, no equipments other than these is permitted, encoder is used should be mounted on the lead screw as we have learned from the previous example. So what do we have here? We have 3 encoders with different number of wholes and we have a lead screw nut pair with different lead values and gear boxes with ratios half, one fourth and one third, so how do we solve this problem?

We say that the previous basic length unit must have been 4 by 200 why, because there was no gearbox, so 4 by 200 0.02 millimetres that means 20 microns. The previous speed was 5000 multiply that means frequency of pulses multiplied by the basic length unit equal to 100 millimetres per minute. The present basic length unit will be equal to the lead which we want to use divided by the encoder number of hole, it should be 0.02. So we do not know the values of L and h that we are ultimately going to choose at this moment. Present speed should be 100 and by multiplication we have 100 RPM multiplied by gear ratio that we choose multiplied by the lead that we chose.

From here we get, LU must be equal to 1 from this particular expression, LU must be equal to 1. So L must be 4 and U must be one fourth that is the only possibility that we can get from L and U combination, L is 4 and U is one fourth hence, coming back to this expression h must be 200 holes, so we choose L equal to 4, U equal to one fourth and h equal to 200, thank you very much.