Computer Integrated Manufacturing
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Lecture 14
Computer Numerical Control (part 3 of 4)

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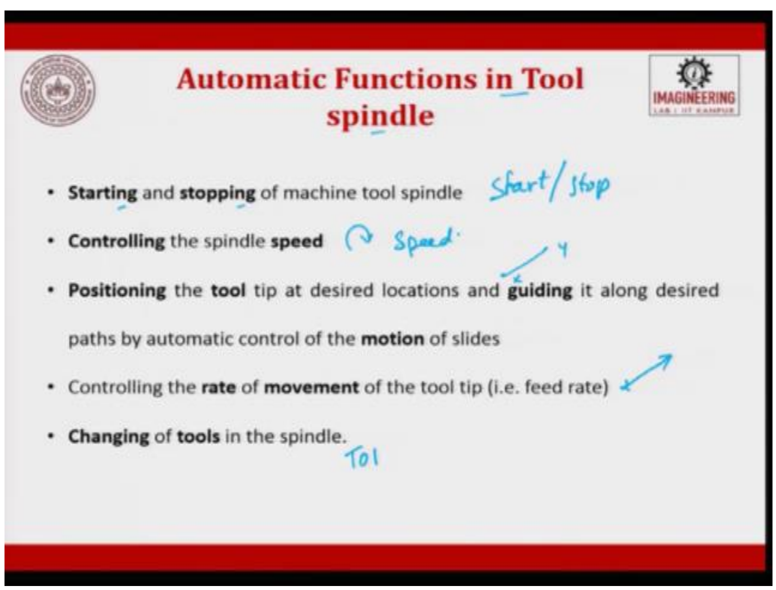

So, welcome to the next lecture on Computer Numerical Control. So, let us look little bit more on functions, so the automatic functions in tools spindle which is there in a CNC machine are, it has a starting, stopping of the machine tools spindle by a, by call of a command or press of a button, then controlling the spindle speed, positioning the tool tip at the desired location and guiding it along desired path by automatic control of the motion of slides. Then controlling the rate of movement of the tool tip then changing the tool in the spindle.

So, these are the automatic functions in a tool spindle. So, it can start, stop, control the speed. This is start, stop, this is speed, then it is position X and Y data, then it will try to do the feed rate, and then finally change of tool. So, these are the 5 automatic functions which happens with respect to a tool spindle, start, stop, controlling, positioning, control rates and change of tools.

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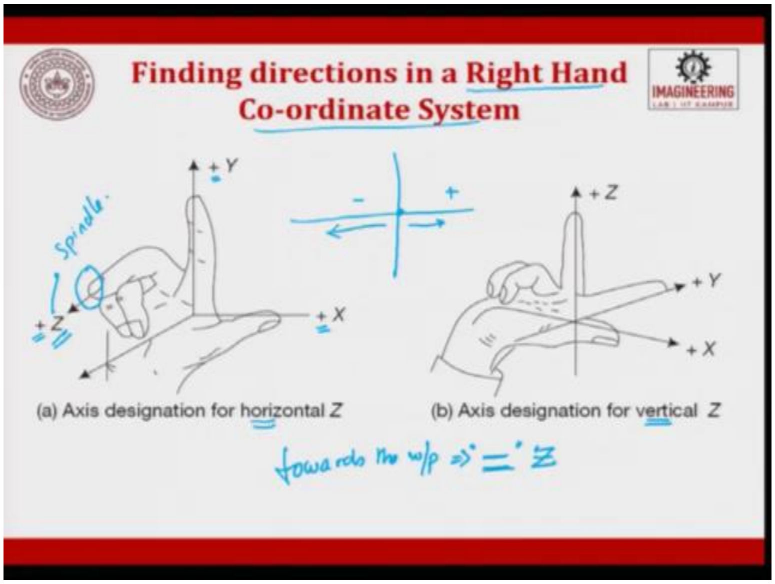

Now, let us get into little bit of how are these axis is fixed in a CNC machine. So, they follow right hand co-ordinate system, so right hand co-ordinate system is followed and you make sure that the perpendicular to the plane will always be Z and this Z will be focused towards the spindle. So, the perpendicular to the plane will be focused towards the spindle so now you can easily fix the X and Y.

And again the next point comes. What is this plus signal which is given? So, the plus can be, if you take it moving towards your right can be plus and moving towards your left can be minus. I am talking in terms of as a viewer. So, as a person who is drawing so plus and minus, when you view it, it will be inverse.

So, it is just like your graph co-ordinate system, if you are at the center, this become plus and the opposite side becomes minus or if you are trying to go towards the work piece, then towards the work piece, then it is always a negative sign, it can be Z axis, X axis, Y axis, right and as far as the machines are concerned, they will have two types, one is called as horizontal, the next one is called vertical.

So, looking into the orientation of the spindle axis, now you try to put your perpendicular finger to the plane as the Z axis, the other two axes are fixed. So, by this way they try to fix the axis and give the plus and minus signal to the coordinates. This is very important, you should know this, if you do not know this, then you will try to randomly fix your X and Y coordinates for a CNC program and you will start writing.

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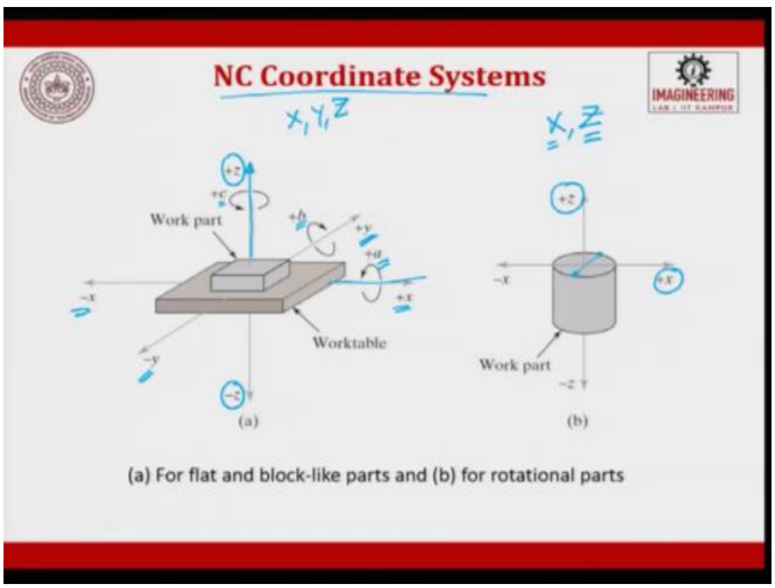

When you take a flat work piece the coordinate system for your flat work piece, when it is resting on your work table, I told you this direction perpendicular to the plane will be Z, when it is away from the work piece it is positive, when it is towards the work piece it is negative right and then once you fix this you will quickly go fix your X axis positive, X axis negative, then Y axis positive, Y axis negative.

Now, when we have to fix a object which is freely floating in air. So, you need to also fix the rotation axis, rotation about X becomes A axis, rotation about Y become B axis, rotation about Z becomes C axis. So, you will now have 6 axes for the nomenclature X, Y, Z and then A, B and C and again you can have plus A and minus A, depending upon the clockwise motion and anticlockwise motion. This is for a prismatic job, when you go for a cylindrical job you will not have Y axis, because it is diametrically it is the same.

So, you will have the Y axis overlaps with the X axis so you will have X axis and Z axis only. So, for your lathe component you will have X and Z axes only, Z axis become the spindle axis, and X axis becomes a diametrical, you give a depth of cut, and then plus and minus is when we move along the direction of the work piece, you will try to have. So, here when you talk about prismatic X, Y and Z we will try to have.

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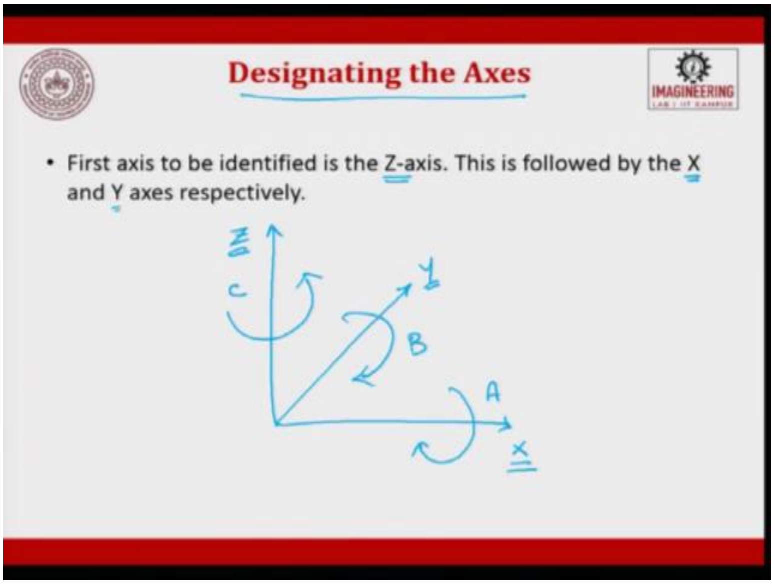

So, the designation of the axis is very important, so first what, first axis to be identified in a CNC machine is going to be Z, the followed by X axis you will try to find and then Y axis. So, if we try to put back into the coordinates form, so this is your Z axis, this is your X axis and this is your Y axis, this is your C axis, this is your B axis and this is your A axis. So, first you will start with Z, then you will go with X and then you will go with Y, and then you will try to go for rotational axis whatever it is.

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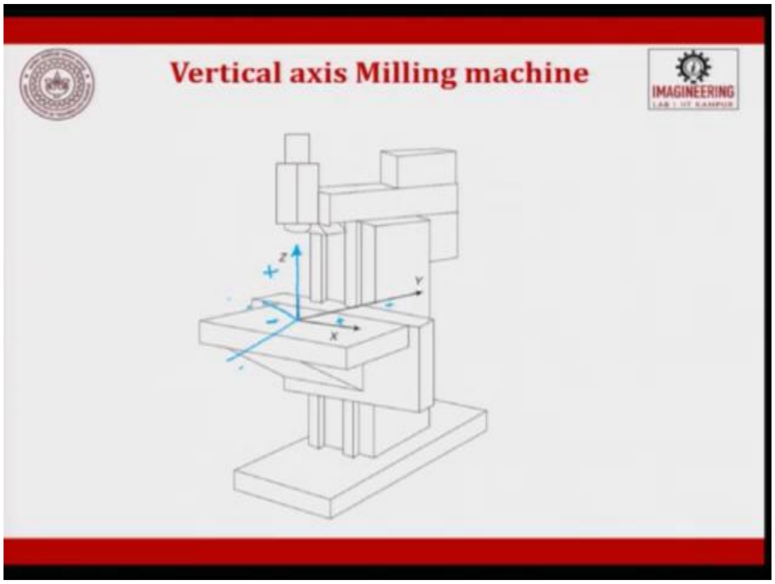

So, for a vertical milling machine so you will see this is your spindle axis, suppose you want, okay this is your spindle axis, so spindle axis I have said plus and this is minus, assuming towards the work piece, away from the work piece. Now, if you try to fix this as an origin so when you move this side it is minus and this side it is plus and it is plus here and minus this side, for Y axis. So, by this way you will be able to fix the axes vertical CNC machine.

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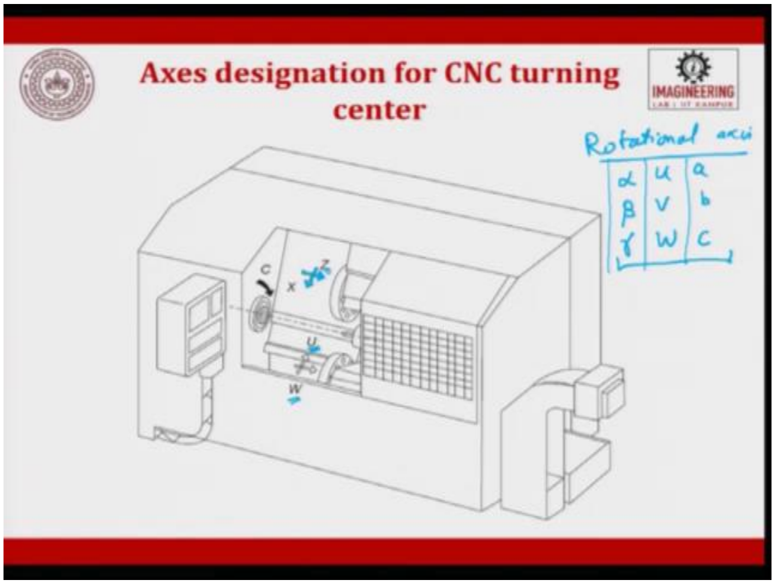

When we move towards a turning center, a lathe machine you will try to have, see you will try to have I told you two axes, X which is the depth and Z along the feed, X and Z will be the two directions, you will give and rotation about Z is the C axis and rotation about X is the U axis, rotation about Z is a W axis.

So, you can see the rotational axis depending upon the controller, you can call it as alpha, beta, gamma, u, v, w, a, b, c. So, these are different-different types of rotational axes, which are used in a CNC machine. So, depending upon your controller, you have to decide a look at the controller, or the manual and then decide whether to use a b c, u v w or alpha, beta, gamma, all are the same.

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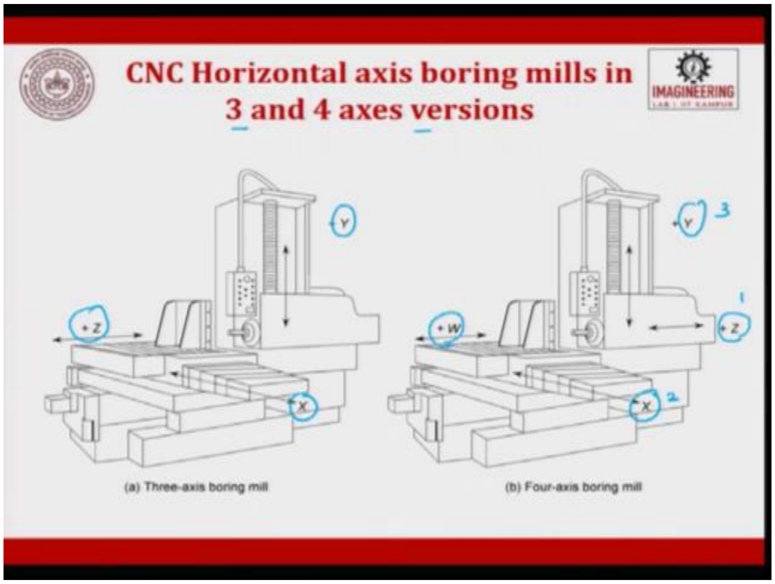

So, the CNC horizontal axis boring mill in 3 and 4 axis version so this is the boring mill, so this is the spindle axis first you fix Z, then you will fix up X, then you will fix up Y, when we try to make a rotation, a rotation axis first in a 4 Axis. What will happen? This is the spindle axis you will fix first, then you will go second, then you will fix the third and rotation I said u, v, w. So, about Z axis whatever rotation happens is W axis.

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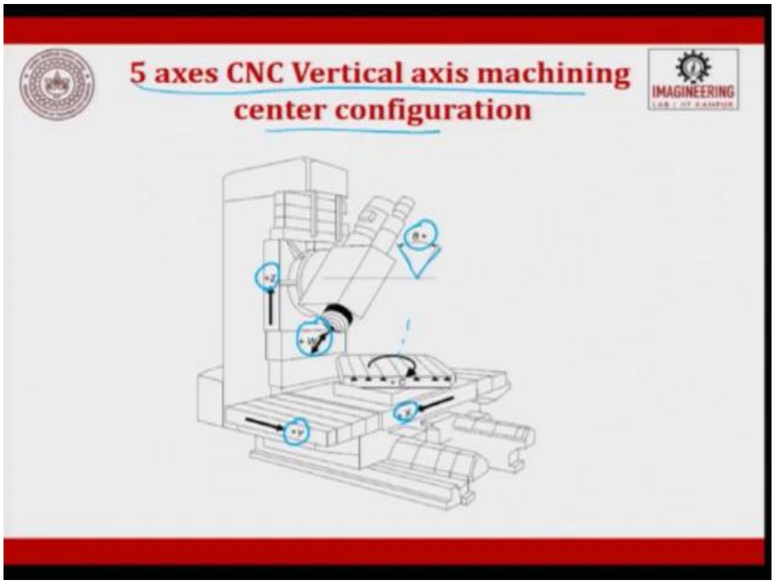

So, when we talk about a 5 axes CNC machine vertical which can machine any configuration, the most complex parts are machined in a 5 axes machine. So, if you want to make a complex part to me the most complex part is your face, a human face has so many points, so many facets, which keeps changing along the x y z direction. So, this if you have a 5 axes machine, then to a large extent you can try to develop very close to a realistic human face, okay.

So, now let us fix the axes, Z axis, is the spindle axes, then we will try to fix the X axis and then Y axis right, and then now what you have to fix is, you have to fix two more axes. So, what is it? Rotation about X, rotation about Z, so u v w and here they have used w is about this axis, you will have rotation.

So, this is nothing but a spindle control, then you will have a table control, which is nothing but a C axes and then you will also have a angle with which you can change that is B axis. So, you can have B, C and w please see that the controller and the machine what is the axes names they have used and you should use that in your program.

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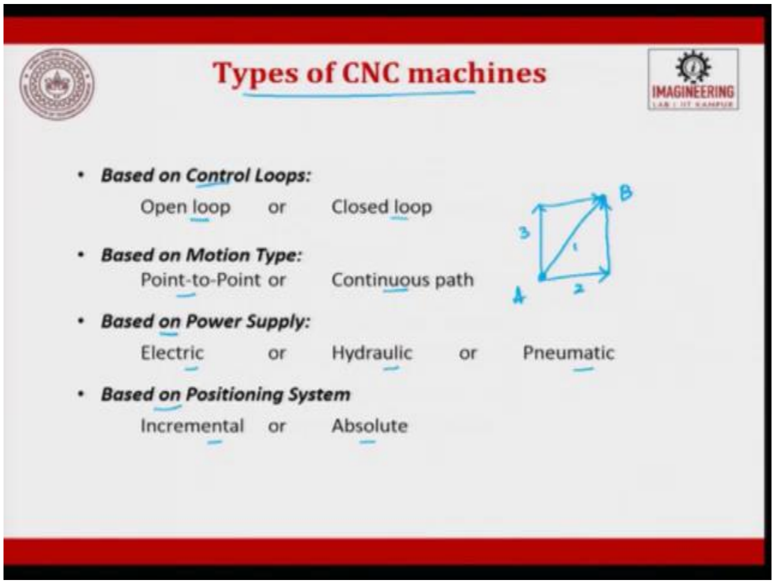

When we talk about different types of CNC machines, they are classified into 4 types based upon the controller loop, when we talk about the control loop there are 2 types, one is called as a open loop system, the other one is called as a closed loop system. If we do not get a feedback on our system, then that is called as open loop system, when we get a feedback from the machine tool to the MCU we process that data it is called as closed loop.

Today wherever you need to have very high accuracies, and resolutions we use a closed loop system. And I told you in a nano domain, whatever measurements we do we will try to have a closed loop system, open loop system we just give the data from the controller MCU to the machine tool we assume that it is perfectly alright and we go ahead. So, here the accuracies which are talked today are 10 micron and 5 micron.

The next is based upon the motion type, there are two types of classification based upon the motion type, one is called as point to point, the other one is called as control path, continuous path. So, point to point is from A point to B point you go and in between you are least bothered which, how did you go to the B point. For example, if you have A here, B here, you can directly go to B, you can go like this to B, you can go like this to B.

So, first in this direction, then you can go so you can see this is 1, this is 2, this is 3, three possible ways are there. So, this is point to point, anyhow reach the destination that what is point to point.

When you do continuous, we are worried about which path to take, so those things are called as continuous path.

The next one is based upon the power supply, whether it is electrical based, or hydraulic based, or pneumatic based. Electric is more of motor, which is very precise and control, which occupies less power and it does not need other systems. Hydraulic and pneumatic needs a pack and then other system to support.

The last one is based upon the positioning, it can be incremental, it can be absolute. Incremental mean always with respect to the previous point, absolute means always with respect to a universal point, a standard reference. So, these are the 4 different types of classifications in CNC machines we have, so now let us see them in detail.

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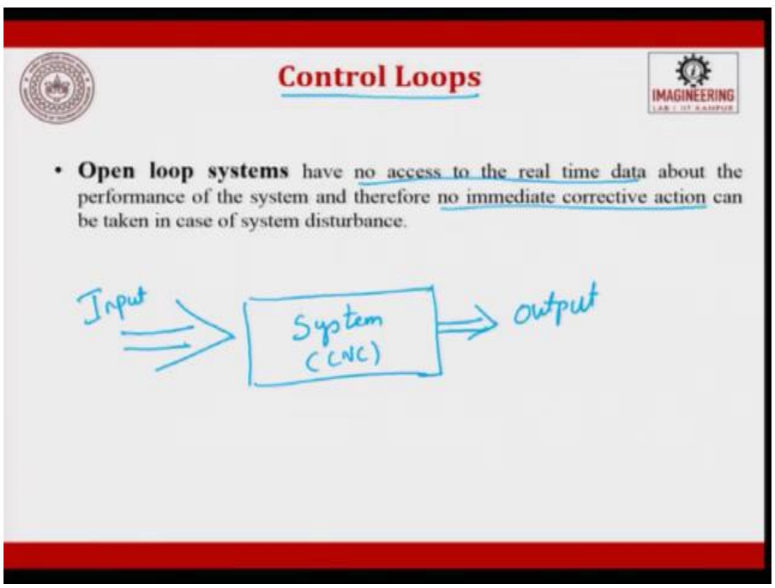

So, let us talk about the control loop, open loop system have no access to the real time data about the performance of the system and therefore no immediate corrective action can be taken in the case of the system disturbance. So, what happens here? You will have an input, you will have a system here, a system is a CNC machine here then you will have an output.

So, this is a block diagram for open loop system, there is no access to the real time data about the performance of the machine. Therefore, no immediate correction actions can be taken in a open loop system.

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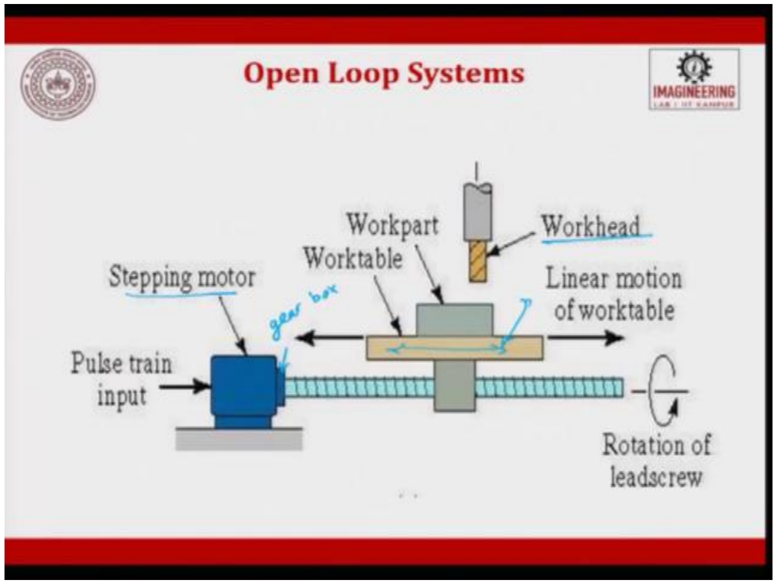

So, when we will look at the figure for a open loop system, you will see that there is a motor which I have already explained to you it is a stepper motor or a stepping motor, this is attached. So, you will have a gearbox here, or you can directly couple also gearbox, this is attached to a lead screw. So, this motor rotates the lead screw, this when it rotates it moves the table.

So, on the table you will have a work piece, or a part, this is machined by a work-head. So, here when the screw moves, lead screw rotates it is going to move the table left side or right side, towards and then a machining can happen. So, here there is no closed loop. So, whatever disturbance, or corrective measures have to be done, it will be done only after measuring the work piece some correction steps can be done.

So, this is the problem of open, or the limitation of open loop system, but it is very economical, the maintenance is very less.

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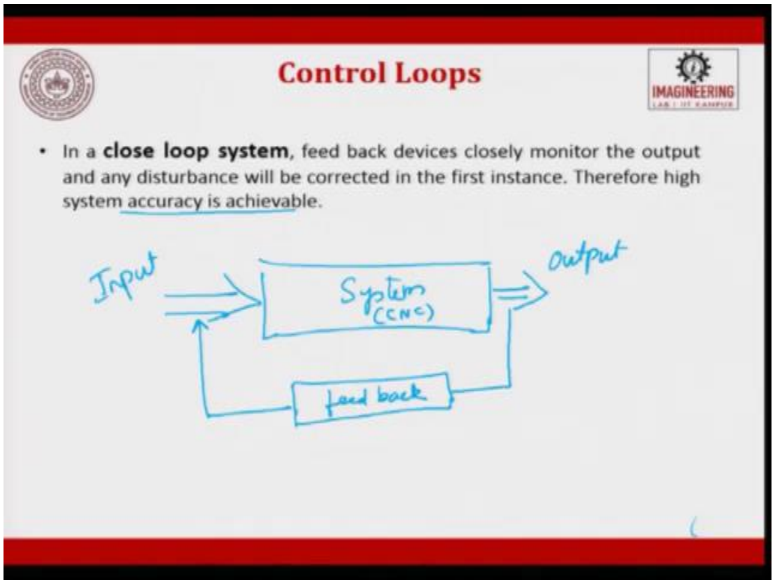

Now, let us look at a close loop system. In a closed loop system the feedback device closely monitors the output and any disturbance will be corrected in the first instant, during the process itself we have a self-correcting mechanism. So, that on process quality assurance is done and not after machining the part, if you look into the block diagram, it will be input, you will have a system, you will have an output.

So, from here we will have a feedback okay, and this is attached to the input. So, here what happens is the feedback device closely monitors the output and any disturbance will be corrected in the first instance, therefore high system accuracy is achieved. So, this is what everybody would feel and everybody would like to have a closed loop system. It is expensive, it is very accurate, it and there is quality check done on the system. So, you would like to get even the first part the best part.

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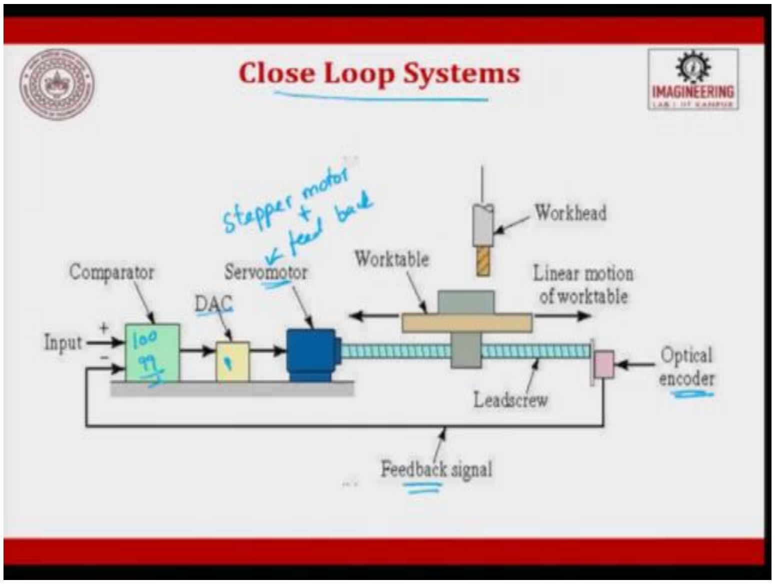

So, when we look at the complete block diagram of a closed loop system, you will see that you have a motor as a servomotor, a stepper motor is converted into a servomotor, it is attached to a lead screw, this lead screw is attached to a table, the table has the work piece, the machining relative motion can happen and at the end of the lead screw, you have an optical encoder which suppose you hear you give 100 turns, it will check whether hundred turns are done.

If it is slipping by 1 turn, 99, why does it slip? Because that torque which is involved for cutting if the resistance is given by the tool towards the work piece then it might stall the rotation you might slip one. So, it this will try to count and next time what happens this fellow will give you a feedback single only 99. So, this is compared 100 has to go, 99 has gone, so it will try to see whether what is that it, it should be give one signal more or less.

So, then that one is converted digital to analog converter is used and that signal is given here, one and then that is in turn given to the servomotor. A stepper motor with a feedback, a stepper motor plus a feedback makes it into a servomotor. So, this is what is the block diagram for a closed loop system.

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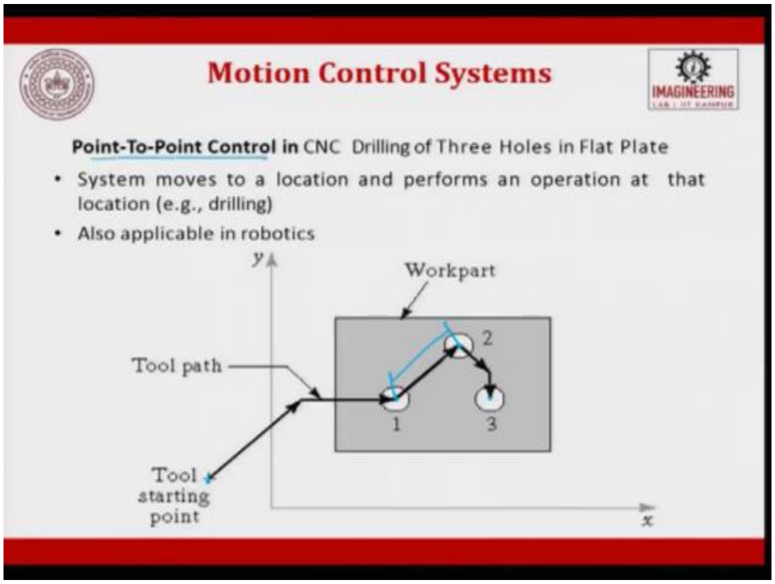

Now, let us see the next one is point to point control system based on that. As I told you the tool, the drill will come here, do the first drilling operation it will go to 2, it will do the operation, it will come to 3 and drill the operation, in between what path it takes does not matter for us. So, it will start here, and then it will accelerate till here, it will stop here.

So, here point to point control in CNC drilling of 3 holes in flat plate, the system moves to the location and performs an operation at that location. It does not bother about the path. So, when we are talking about robo-welding, it needs point to point, when it is punching, point to point, when it is spot welding, point to point. So, drilling, point to point, so here this is the starting point, the starting point, it goes along this and then does this machining. So, machine control point to point control, motion system is this.

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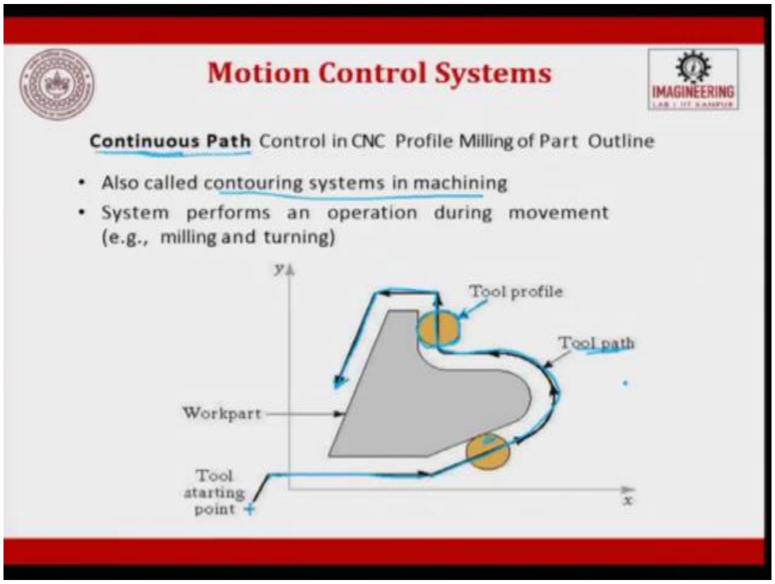

When we talk about continuous path system, so in continuous path system, the control in CNC profile milling of the part geometry. So, it is very clearly said that if you want to machine the part, the cutter has to start from here, go along this line then make the stepper, then take a radius, then go along this line, make a straight line and then come back.

So, here if you see this is the tool path, which is getting generated and this is the tool, which moves along the given profile. So, this is the tool path, you can see and this is the tool and this is the profile of the tool. So, this is called as a tool profile. So, here it is continuously monitored in which direction to go and what happens to generate the part.

So, continuous path control in CNC profile milling of the path outline are called as contouring system in machining. System performs an operation during movement. So, there it was the movement was done and then an operation was done, but here the movement and the operation will be done simultaneously to generate, that is why it is called as continuous path motion control system.

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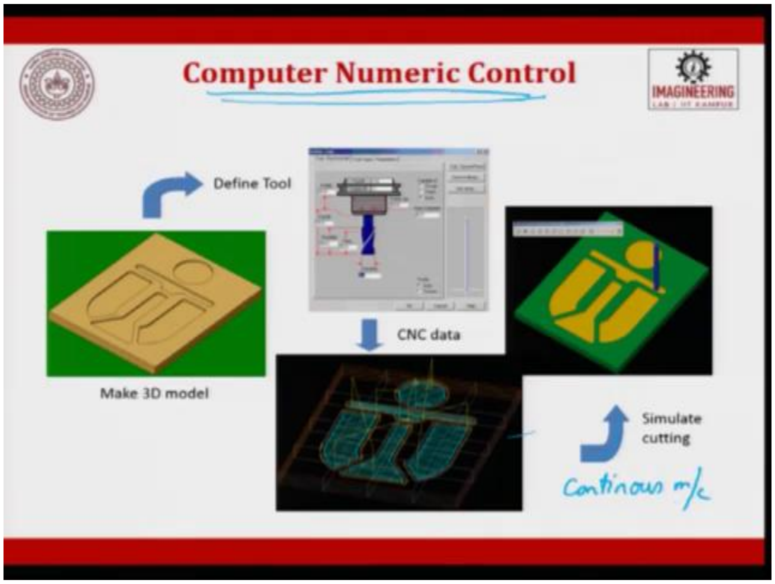

So, when we use a CNC machine what will happen is, you want to make a mold so then you make, you want to make a mold so the tool is define the tool, we define all the length, diameter, flute length, everything and then this data is given to a CNC and here you see that there are so many simulations, the cutter path is done and then finally after the simulation you will try to generate this part.

So, now what you can do is, you can compare your model making with the continuous. So, why I am saying this is this is very important as far as continuous machining is concerned, continuous machining.

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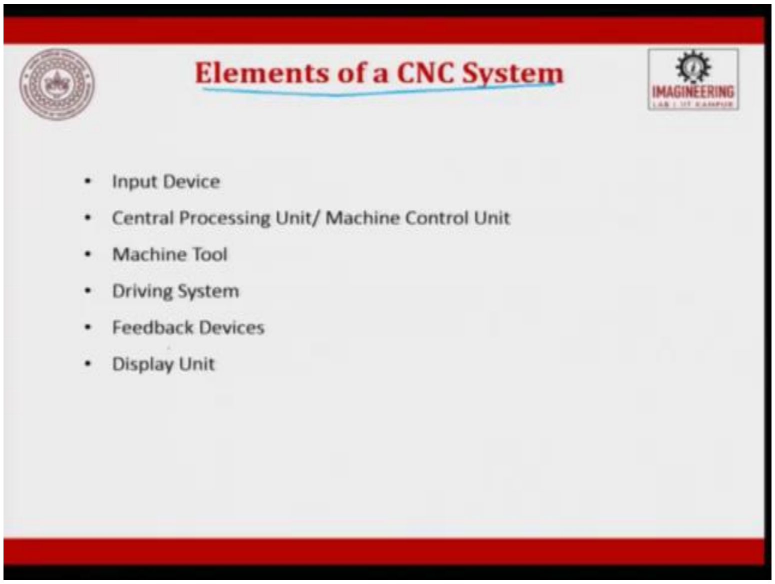

So, let us now look into the elements of a CNC system, you will have a input drive, you will have a central processing unit, or a machine control unit, you will have a machine tool, you will have drive systems, you will have feedback devices, and you will have display units, these are all the elements of a CNC machine.

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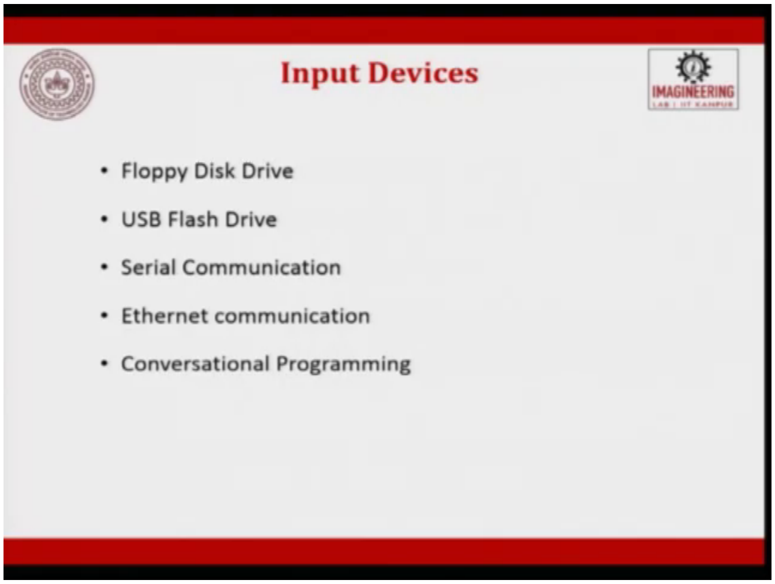

So, what are all the inputs? You can have a floppy disk, floppy disks are nothing but see from the tape it went to a disc magnetic tapes and disks. So, floppy disks are large disks, where in which is used to store the data, floppy disk drives.

Then you have USB flash input drives. You have serial communication that is what is RS-232-C which we saw serial communication. You will have Ethernet communication and you can also have conversational programming as inputs to the CNC machines, these are all five this is outdated. So, you will have the rest four used exhaustively today.

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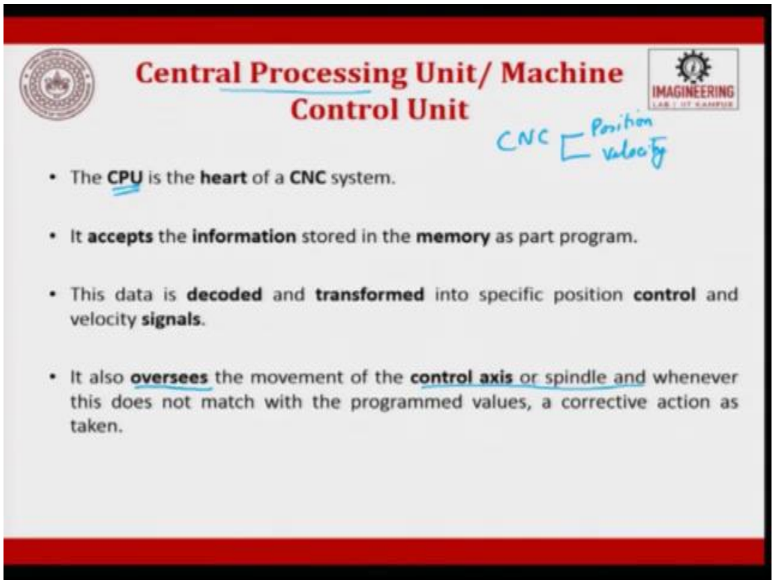

When we talk about the machine control unit or the CPU, CPU is the heart of a CNC machine, it accepts the information stored in the memory as a part program, this data is decoded and transformed into specific position controls and velocity controls. I told you in a CNC machine two data are important, one is position, the other one is velocity, these two are very important.

So, based on this you will try to do data, it also oversees the movement of the control axis or the spindle and whenever this does not match with the program value a corrective actions are taken. So, it also oversees the control axis, or the spindle movement. So, these are the four tasks of a central processing unit, or a machine control unit.

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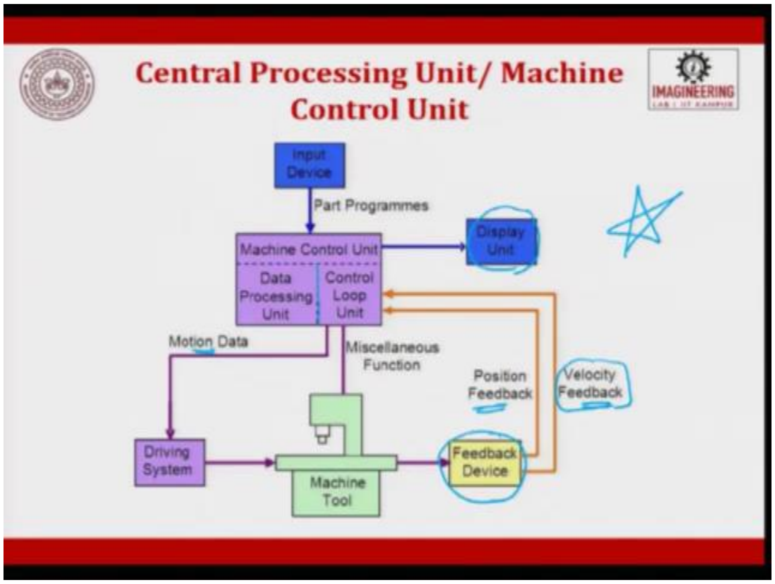

So, when you look at the block diagram for the machine control unit, you have a input device in the machine control unit, you have two parts, one is data processing unit, another one is control unit, control unit is basically for the movement, data processing is to convert the data such that the machine can understand.

So, now the control is more towards motion data, so this motion data in turn gives you to the drive systems. So, X drive, Y drive, Z drive, spindle rotation all these things are given, this in drives are attached to the machine tool and whatever happens in the machine tool there is a feedback which is collected and which is given to the control unit.

So, now the control unit after the feedback is given, it tries to check and give you further signals for the machine tool to happen. So, the two types of data which are taken for the feedback is position feedback data and velocity feedback data and then finally from the mission control, you have a display unit which is there.

This diagram is very-very important for you to understand the complete CNC machine. You will have a input device, you will have a machine control device, from a machine control, you have data processing, control loop this control loop gives it to a drive, drive system, the drive system takes over to the machine tool, machine tool gives a feedback position, as well as velocity.

It is further processed in the control unit and again that is given to the machine tool this loop keeps continuing until you get the required output. So, this is a very-very important block diagram which you should know.

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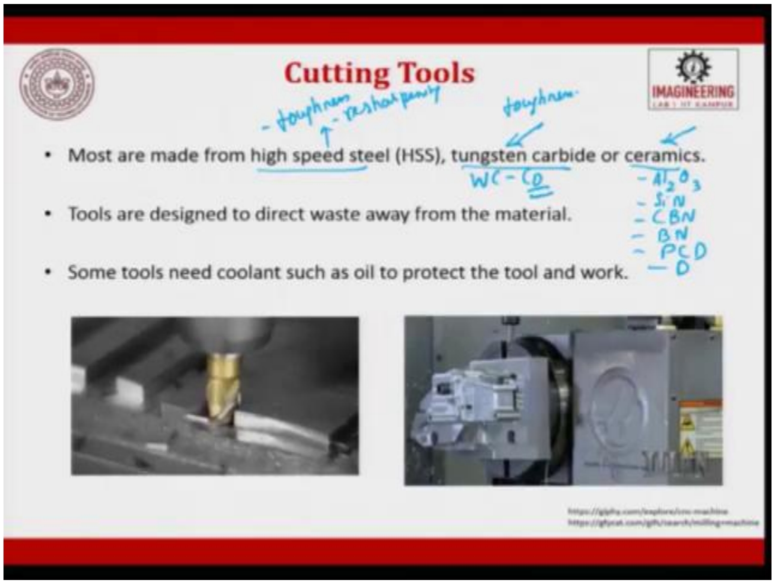

When we talk about cutting tools, as I told you earlier also, cutting tools are different from machine tools, we have never talked about the cutting tools, the cutting tools are tools where they are harder than the work piece and they have the geometry which gets superimposed to the work piece to generate a profile.

So, it is superimposed and then it also has a relative motion so the features are generated because of the superimposition and the feed movement, or the relative movement of the tool with respect to the work piece, you get the desired output. The most are made from high speed steel and tungsten carbide steel and ceramics.

So, high speed steel even today is used because of toughness and re-sharpening, but however in CNC we try to avoid this, we try to go for tungsten carbide, or we try to go for ceramic, tungsten carbide has still a property of toughness. So, if you try to take tungsten carbide cobalt, the toughness property to the cutting tool is given by the cobalt, right.

And here if you see this when machining happens, you see it is rotating, and now the tool when it comes in contact to the work piece, it is an impact load. So, toughness has to be very high, so wherever there is a lot of impact load we go for tungsten carbide cobalt, wherever there is going to be a continuous cut and heat is going to be generated, we go for ceramic tools. You have alumina tools, you have silicon nitride, beside silicon nitride we have CBN, we have Boron nitride, we have poly-crystal diamond, we have diamond.

So, all these things fall under ceramics, we used it for machining, the tools are designed to direct waste away from the material. Some tools need coolant, such as oil to protect the tool and the work piece. So, that it tries to remove the heat and give reduce the friction. So, that it can come for a longer time.

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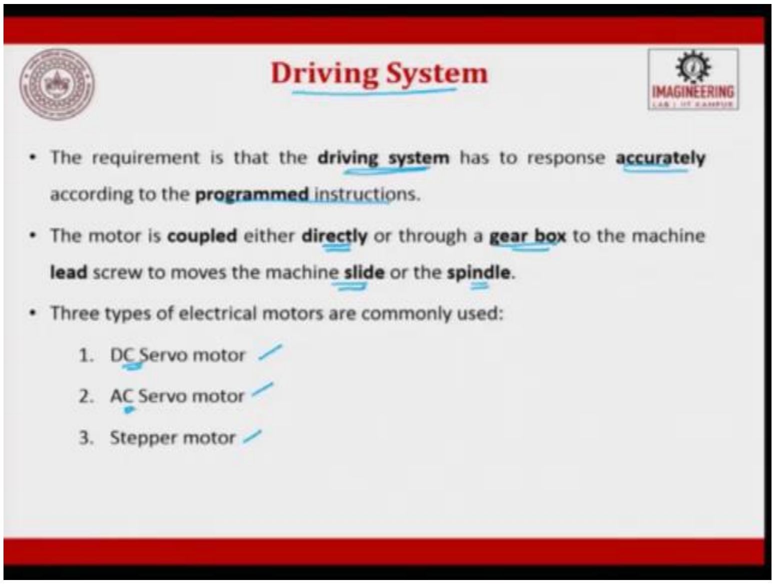

When we talk about drives, which is very-very important the heart of a CNC machine, when we talk about drives, it the requirement is that the driving system has to respond accurately according to the programmed instruction, the drive systems takes care of the accuracy part of it. The motor is coupled either directly or through a gearbox this is what I was discussing when I talked in the previous slides, directly through a gearbox to the machine a lead screw to move the machines slide or the spindle.

There are three types of motors, which are generally used in a CNC machine, they are DC servo, AC servo and stepper motor. So, servo feedback, DC servo, AC Servo so when we have a AC power supply converting into DC and then using it. It is called as DC servo, directly using the AC we call it is AC servo, today almost all the machines work on AC servomotors, because AC-DC conversion there is a huge loss. So, people are more and more focused towards AC servomotors.

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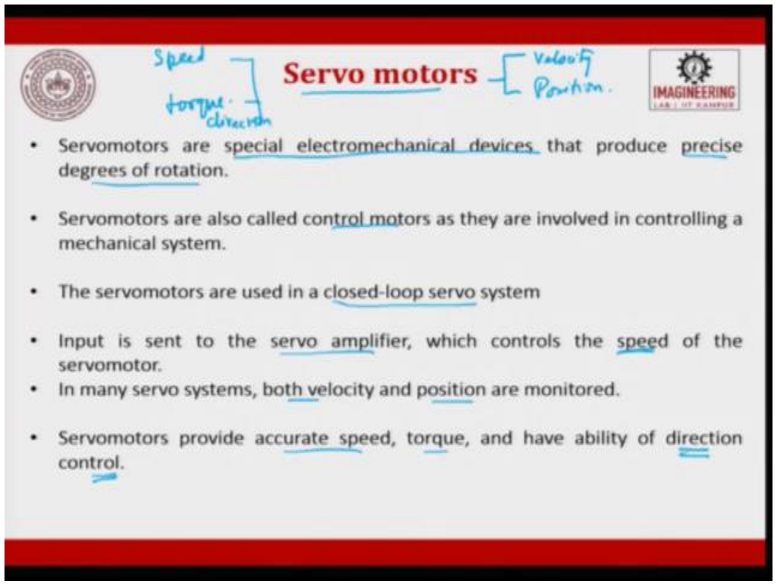

So, let us look at a servomotor more in detail. Servomotors are especially electromechanical devices that produce precise degree of rotation, it is a special electromechanical device, which produces precise degree of rotation. Servomotors are also called as control motors as they are involved in controlling a mechanical system. What is a mechanical system? The entire machine tool is attached to a motor.

The servomotors are used in a closed loop servo system, the input is send to the servo amplifier, which controls the speed of the servo, position, velocity, amplifies signal amplification. So, that it controls the speed. In many servo systems both velocity and positions are to be monitored, servomotors provide accurate speed, accurate torque and have the ability of direction control, whether to go in the clockwise direction or in the anticlockwise direction.

So, the important take home points are two things, velocity and position, here it is speed and torque control apart from direction, this is what is very important take home message of this slide.

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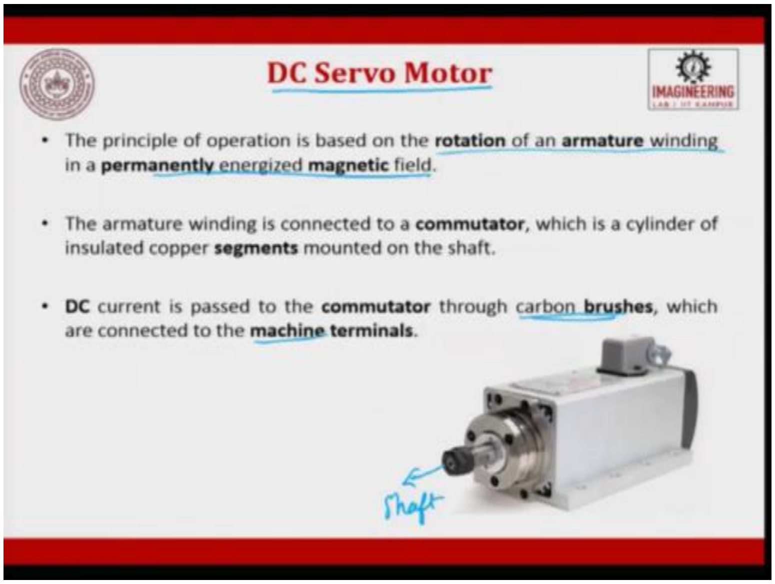

So, this is how a typical DC servomotor rotates, or looks like, the principle of operation is based on rotation of an armature winding in a permanently energized magnetic field, please understand the principle of operation is based on the rotation of an armature winding in a permanently energized magnetic field DC motor. So, that is what is a DC servomotor works.

The armature winding is connected to your commutator, which is a cylinder of insulated copper segmented mounted on the shaft. So, this is the shaft, so the armature winding is connected to the commutator, which is a cylinder of insulated copper segments mounted on a shaft, the DC current is passed to the commutator through carbon brushes. So, that is why DC the motor always has a wear and tear is carbon brush. Today we have brushless carbon DC motors also, which is connected to the machine terminal.

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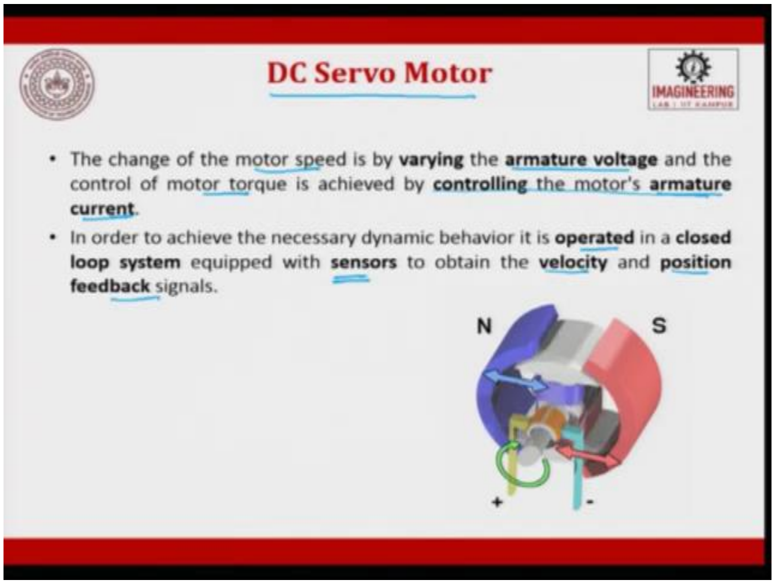

So, this is how is the simulation, or the animation sorry it is the animation of how does a DC servomotor work. The change of the motor speed is by varying the armature voltage and the control of motor torque is achieved by controlling the motor armature current. So, the change of motor speed is by varying the voltage and the motor torque is achieved by changing the armature current.

In order to achieve the necessary dynamic behavior, it is operated in a closed loop system, equipped with sensor to obtain the velocity and the position feedback signal. So, here in order to achieve the necessary dynamic behavior it changes with respect to time, it is operated in a closed loop system, equipped with sensors, we will see what are sensors, encoders, will sensors to obtain the velocity and the position of the feedback system.

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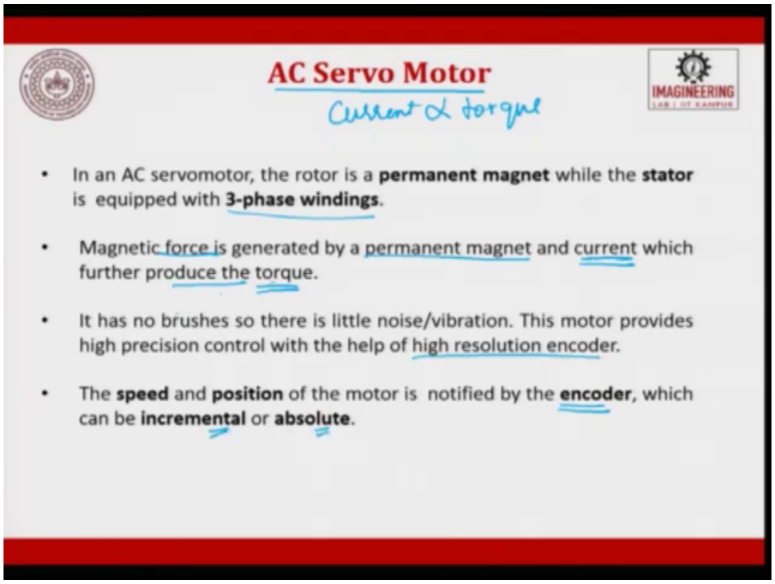

So, let us see next the AC servomotor, in a AC servomotor, the rotor is a permanent magnet, same like AC and DC motor. So, I am just talking about AC servomotor, the rotor is a permanent magnet, which the stator is equipped with the three phase winding. The magnetic force is generated by a permanent magnet and the current which further produces the torque.

So, magnetic force is generated by permanent magnet and the current always controls the torque, in the previous case also, in this case also current is proportional to torque and voltage is always with respect to magnetic field. So, it has no brushes so there is little noise and vibration, AC servo is very much used today. This motor provide high precision control with the help of high resolution encoders. The speed and position of the motor is notified by encoders we will see what are these encoders, which can be both incremental or absolute.

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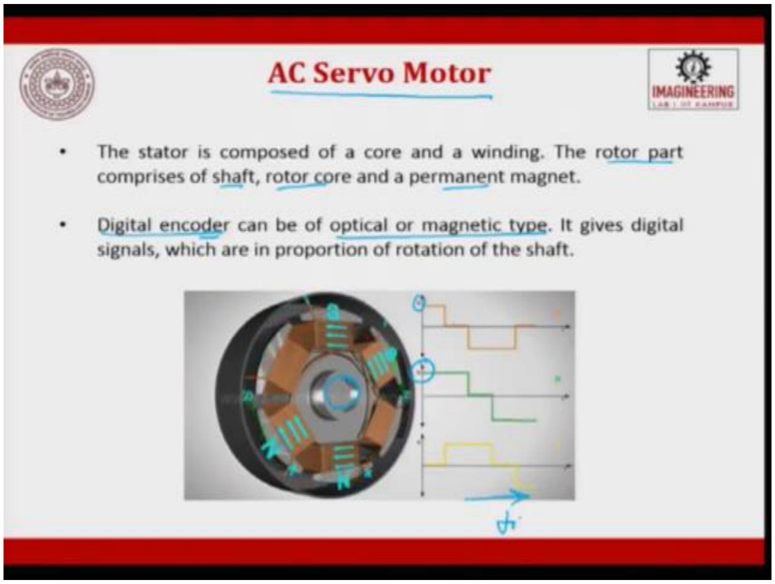

So, this is the animation for AC servomotor, the stator is composed of a core right, stator is composed of a core and a winding. The rotor parts comprises of shaft, torque, rotor core and a permanent magnet, the rotor part comprises of a shaft, rotor core and a permanent magnet.

A digital encoder can be of optical or magnetic type. It gives digital signals, which are in proportion to the rotation of the shaft. So, digital encoders are optical and magnetic in type. So, you can see here the voltage signal, what happens to the voltage signal this brown, green and red how does it respond please see, this is with respect to time.

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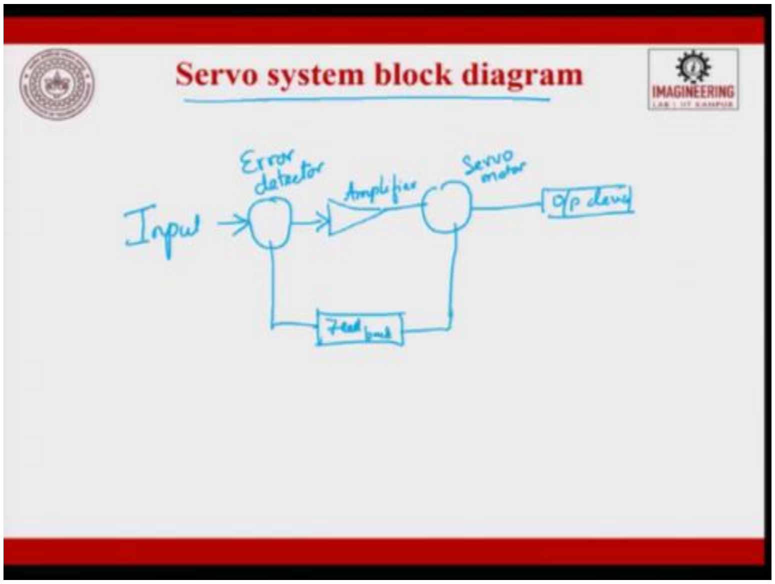

So, let us see the block diagram for a servo system so servo system is input, then you have a error detector, then you will have an amplifier, then you will have a servomotor, then you will have a output device, and from a servomotor we try to give a feedback.

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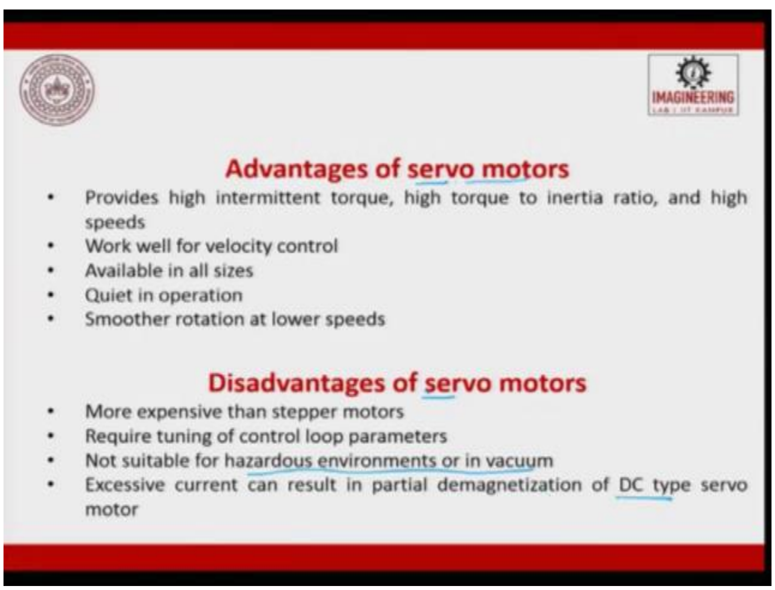

So, an advantages of servomotor is it provides high intermittent torque, high torque to inertia ratio and high speeds. So, that is why servomotors are more used, works very well for velocity control, available in all sizes, quiet in operation, smoother rotation at lower speed, these are the advantages of servomotor.

What are the disadvantages of servomotor? It is more expensive, it requires tuning of control loop parameters, not suitable for hazardous environment or in vacuum, excess current can result in partial demagnetization of DC type servomotor. So, these are the disadvantages.

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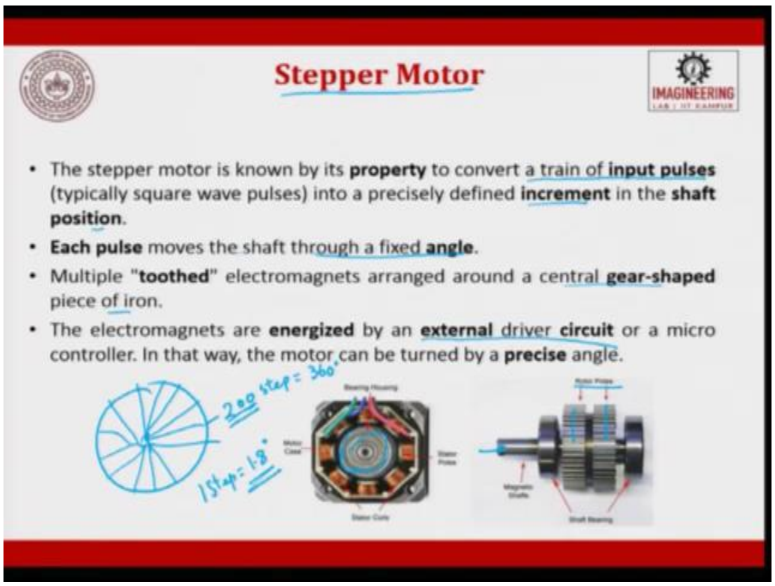

Now, the last motor we will see is the stepper motor, the stepper motor is known by its property to convert a train of input pulses, square pulses, into a precisely define incremental in the shaft position. So, what it does is? You have a 1 RPM, now you divide that 1 RPM into several small segments and these segments are called as steps.

So, generally what happens is, for one rotation 200 steps we give for 360 degrees. So, now 1 step tries to control 1.8 degrees, so you can have a quarter of it, you can have a four times of it, half of it by playing with the hardware. So, your step size can be reduced or increased depending upon your requirement.

So, this is what is a train of input pulses, each pulse moves the shaft through a fixed amount, so that is 1.8 depending upon the step. Multiple toothed, electromagnets arrange around a central gear-shaped piece of iron, this is what is told here, multiple toothed electromagnets arrange around the central gearbox, a gear shaped piece of iron. The electromagnets are energized by the external driving circuit, or microcontroller.

So, external drive circuits, drive circuits, drive systems or a microcontroller in that way the motor can be turned by a precise angle. So, if you look at it here is a magnetic shaft, you have shaft bearings, two sides and you will have rotary poles which are there. So, that will try to count the number of pulses and get the required output.

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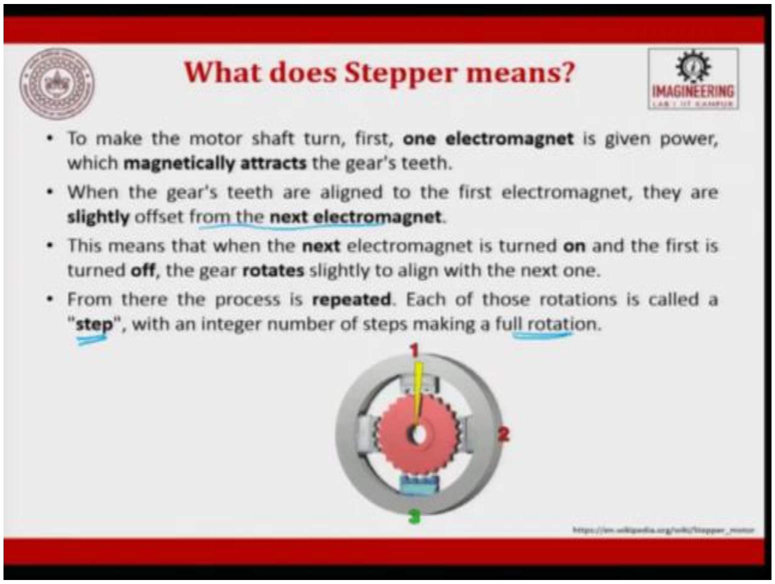

How does a stepper motor work? So to make the motor shaft turn, first, one electromagnet is given power which magnetically attracts the gear teeth. So, you can see the animation here, when the gears teeth are aligned to the first electromagnet, they are slightly offset from the next electromagnet.

So, slightly offset, this means that when the next electromagnet is turned on and the first is turned off, the gear slightly rotates by a small angle, this process is repeated. So, each of these rotations is called a step, with an integer number of steps making a full rotation. So, number of steps leads to a full rotation, so you can see here 1, 2, 3, 4, how does it energize and how does it pull and how does this angle happens.

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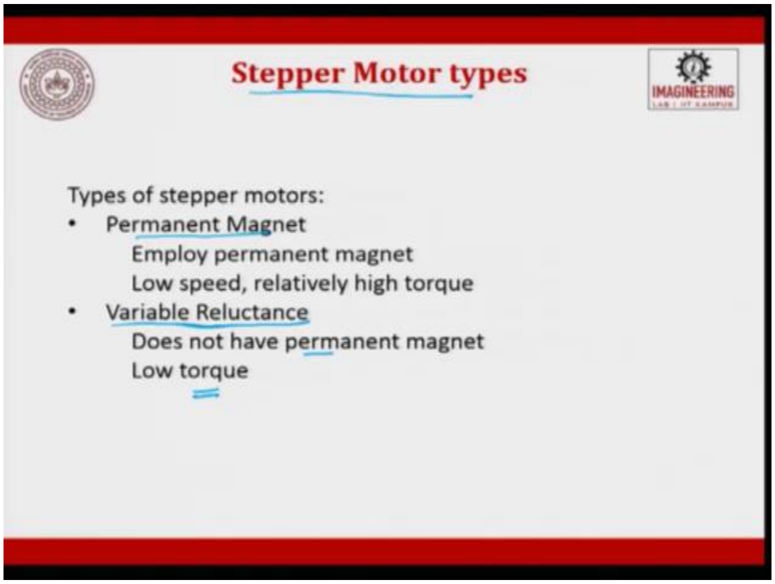

So, stepper motor types, you have two types of stepper motors which are available today, one is called as permanent magnet type, the other one is called as variable reluctance type. In the permanent magnet, we employ a permanent magnet, which is used for slow speeds and relatively lower torques, wherever we would like to have variable reluctant does not have a permanent magnet and it is used to for low torques, only we use variable reluctant type stepper motor for operation.

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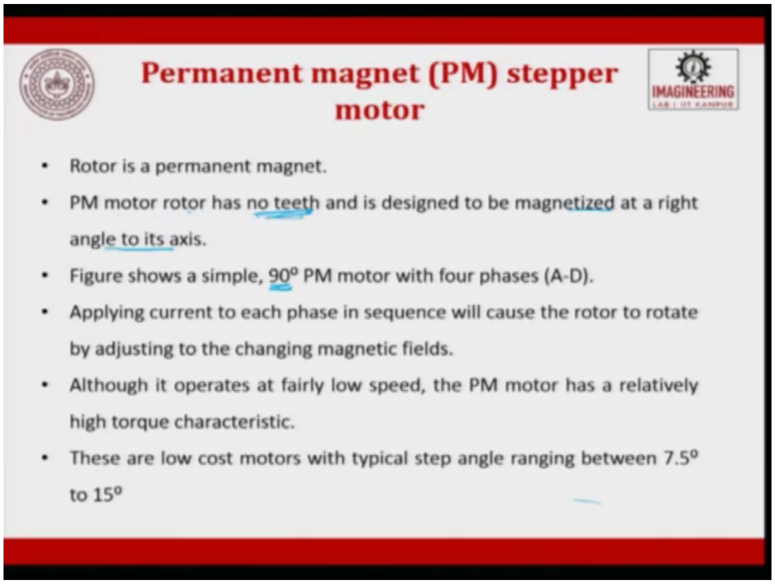

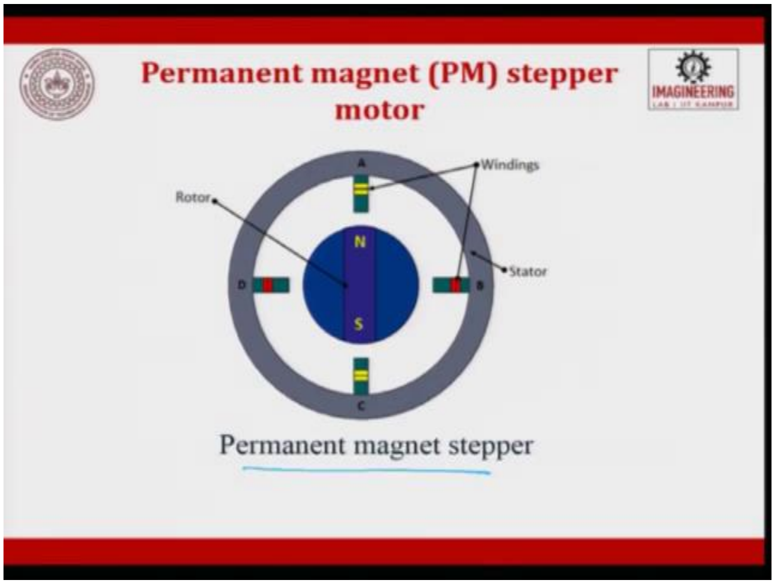

Today the stepper motor technology is very much understood and it has become very competitive. So, you get stepper motors at very low costs today. So, the permanent magnet stepper motor, which was the classification, first classification of the stepper motor, the rotor is a permanent magnet, the permanent magnet motor rotor has no teeth and is designed to be magnetized at right angles to its axis, there is no teeth in the gear.

So, figure shows a simple 90 degrees permanent magnet motor with 4 faces A B C D, we will see that in the next slide. Applying current to each phase in sequence will cause the rotor to rotate by adjusting to the changing magnetic field, very important to the changing magnetic field. Although it operates at fairly low speeds, the permanent magnet motor has a relatively higher torque characteristics, these are low cost motors with a typical step angle varying from 7.5 to 15. I told you, 1.8 into 5 times and 15 is 1.8 into 10 times so 15 degrees.

So, this is what we were trying to talk about A, B, C, D you will have windings, this is the stator and you will have polls, North and South. So, every time when you try to energize one, it rotates by one quarter and tries to move. So, here it is not a teeth. So, that is what I said so the PM has motor, rotor has no teeth, which was there in your servomotors.

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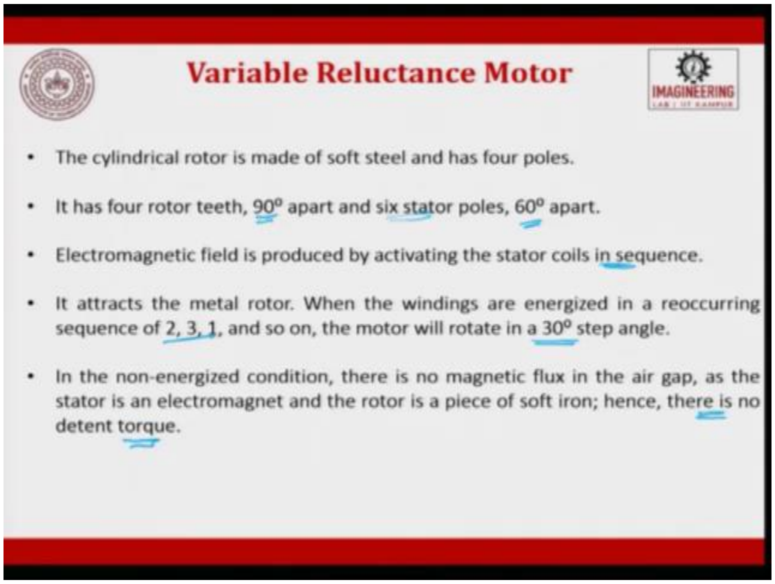

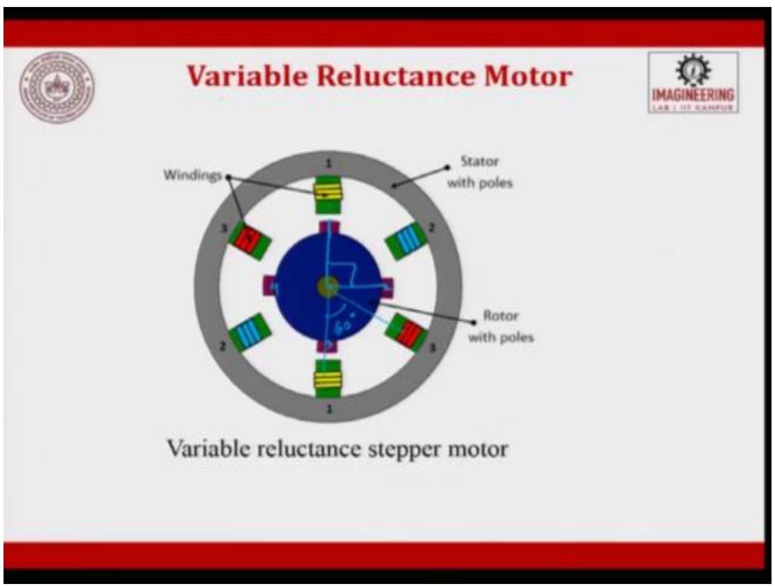

So, the variable reluctant type motor, the variable reluctant type motor, we have a cylindrical rotor is made of a soft steel and 4 poles. It is made of soft steel and 4 poles. It has 4 rotor teeths, 90 degrees apart and six stator poles of 60 degrees apart, these are 90 degrees and these are 60 degrees. So, these, this is a router with pole and these are stator with poles and these are the windings which you have.

So, the electromagnetic field is produced by activating the stator coil in sequence. So, sequence can be 1 2 3 4, or 1 whatever it is. It attracts the metal rotor, when the winding are energized in a reoccurring sequence of 2 3 1 and so on, the motor will rotate 30 degrees in step angle. In the non-energized condition, there is no magnetic flux in the air gap, as the stator is an electromagnet the router is a piece of soft iron, hence there is no decent torque in the given by the motor. So, this is how a variable reluctance torque motor looks like.

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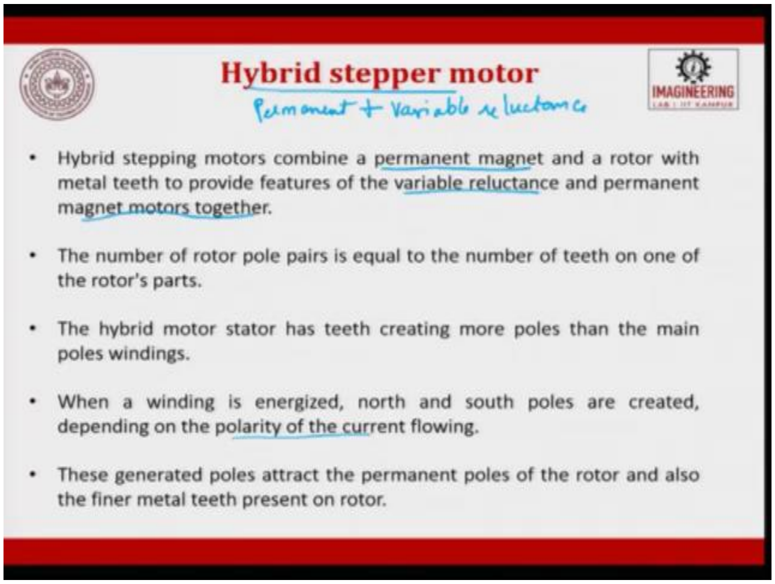

So, you have a Hybrid stepper motor, today which is available hybrid stepper motor is a combination of a permanent magnet and a rotor with a metal teeth to provide features of a variable reluctant and a permanent magnet motor together. So, today hybrid is permanent plus variable reluctance and a permanent magnet. The number of rotor poles paired is equal to the number of teeth on one of the rotor parts.

The hybrid motor stator has teeth creating more poles than the main pole winding, when the winding is energized, north and south poles are created, depending on the polarity of the current flow these generated poles attract the permanent magnet poles of the stator and also finer metal teeth present on the rotor.

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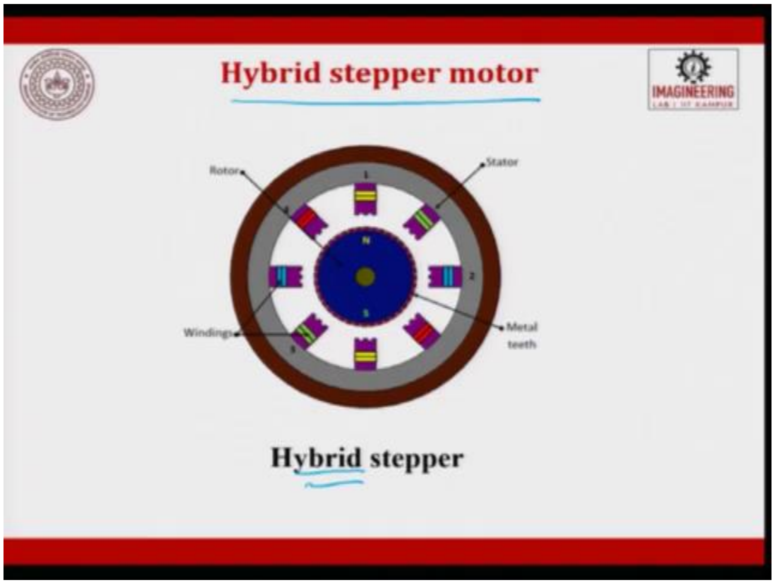

So, this is what it looks like in a Hybrid stepper motor, you will have a mix of permanent and variable reluctance. So, you can see here windings, which are there like permanent and you will have rotor, which has north and south, we will have metal teeths, which gives the combination of both. So, that you try to get the better performance of these two.

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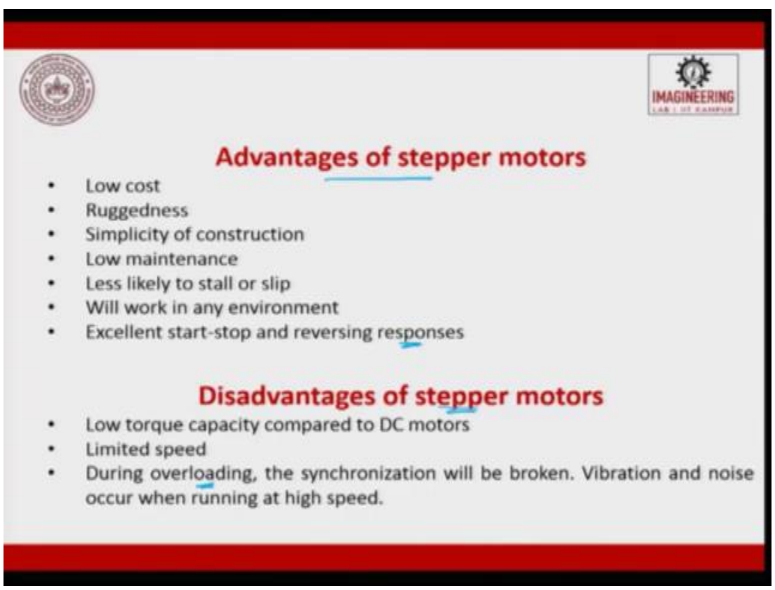

So, what are the advantages of stepper motor? A stepper motor are low cost, they are ruggedness, they are simple in construction, they have low maintenance, less likely to stall or slip will work in any environment, excellent start-stop and reverse responses are available in stepper motor, which is not there in servomotor.

Disadvantages, it is used to for low torque capacity only, it has limited speeds, and overload the synchronization will be broken, vibration and noise occurs when we do a overload. So, stepper motors for lighter loads, stepper motors for quick stop and stop, which is rugged and low cost, as compared to that of a servomotor.

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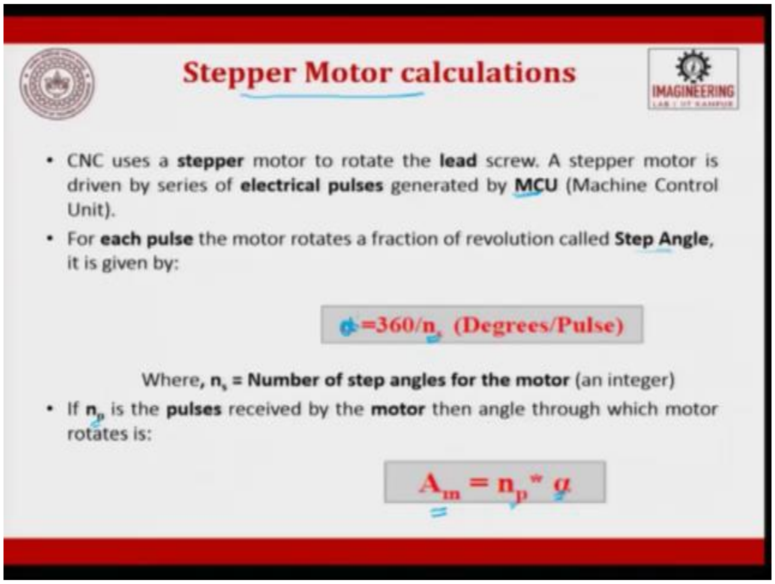

So, stepper motor calculations, we will try to see a small calculation, CNC uses a stepper motor to rotate the lead screw, a stepper motor is driven by a series of electrical pulses generated by MCU, for each pulse the motor rotates a fraction of revolution called a stepping angle. So, stepping angle,

$$\propto = 360/n_s$$

So, that will try to dictate my alpha, the rotation, the angular rotation, if np is the pulse received by the motor, then angle through which the motor rotates is Am is nothing but,

$$A_m = n_p * \propto$$

So, you multiply this you will try to figure out the Am. So, received by the motor, then the angle through which the motor rotates is Am.

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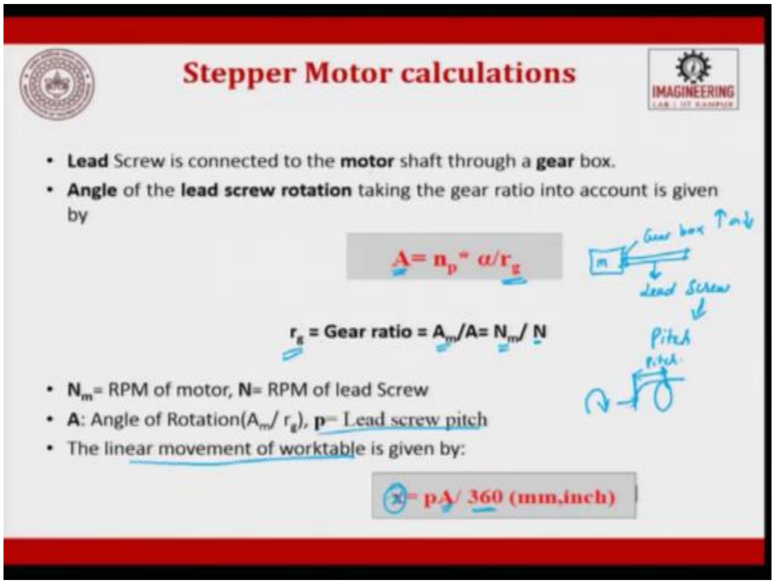

So, the lead screw is connected to the motor shaft so this is the motor, then this is the lead screw. So, the lead screw is connected to the motor shaft through a gearbox, so here I said there is gear box. So, what is a function of a gearbox? The gearbox can increase or decrease, decrease the speed.

So, the angle of the lead screw rotation, taking the gearbox ratio into account is given by,

$$A = n_p * \propto / r_g$$

What is rg? rg is the gear ratio,

$$r_g = Gear\ Ratio = \frac{A_m}{A} = \frac{N_m}{N}$$

What is Nm? Nm is the number, is RPM of the motor, N is the RPM of the lead screw. So, you can try to get the gear ratio, A is the angle of rotation, which is nothing but Am by rg, rg is the gear ratio, Am is the pulses which is given which we saw in the previous slight and p is the pitch.

So, if the linear movement of a work table is to be given, it is nothing but X,

$$x = pA/360$$

,that is what is to be done to find out the linear movement of the work table. So, when we talk about a screw, there is a pitch. What is a pitch? Pitch is nothing but you start from here, you rotate it and then it comes here. So, this distance what it advances is called the pitch. So, I rotate and then there is an advancement, it can be 5 millimeter, it can be 8 millimeter, or whatever it is.

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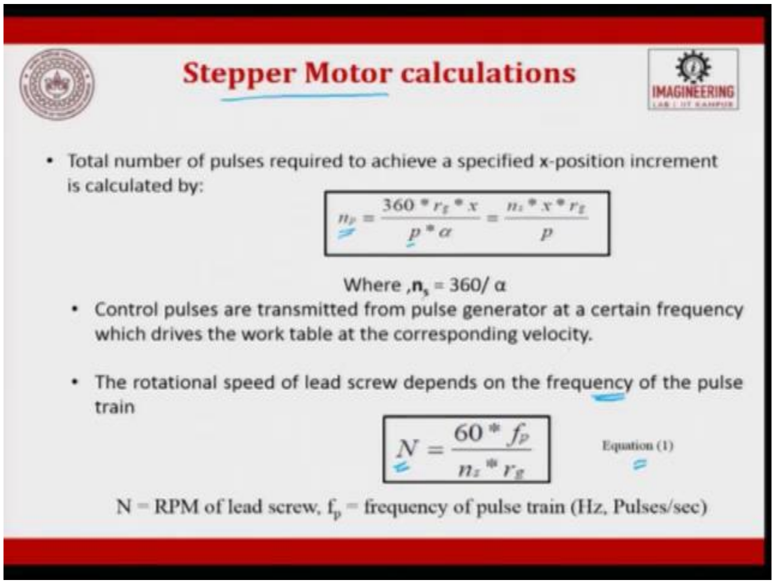

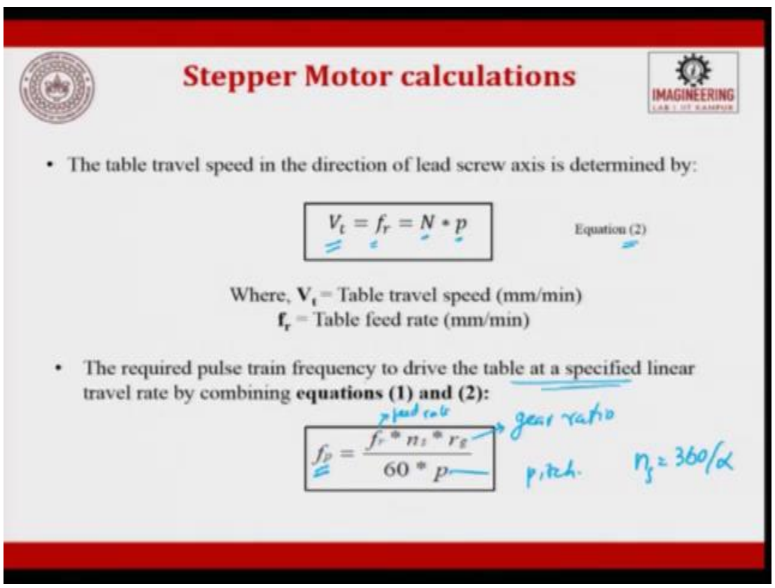

So, the stepper motor calculations, the total number of pulses required to achieve a specified X position increment is calculated by,

$$n_p = \frac{360 * r_g * x}{p * \ \alpha} = \frac{n_s * r_g * x}{p}$$

So, the control pulse are transmitted from pulse generator at a certain frequency, which drives the work table at a corresponding velocity.

So, the rotation speed of a lead screw depends on the frequency of the pulse, given by,

$$N = \frac{60 * f_p}{n_s * r_g}$$

So, with this we can try to find out the RPM of the lead screw. The table travel speed in the direction of the lead screw can be found out, Vt is nothing but,

$$V_t = f_r = N * p$$

The required pulse train to derive the table at a specified linear travel by combining equation 1 and 2 this is equation 1 and 2 we try to get,

$$f_p = \frac{f_r * \ n_s * r_g}{60 * p}$$

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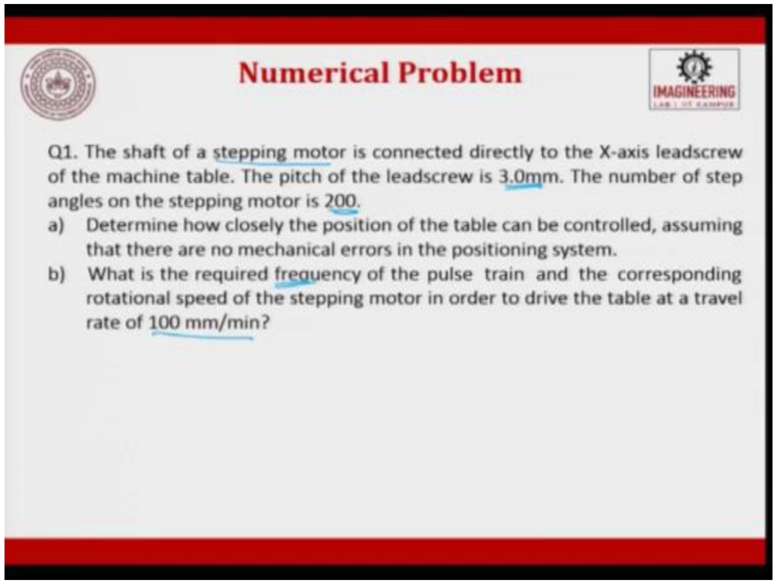

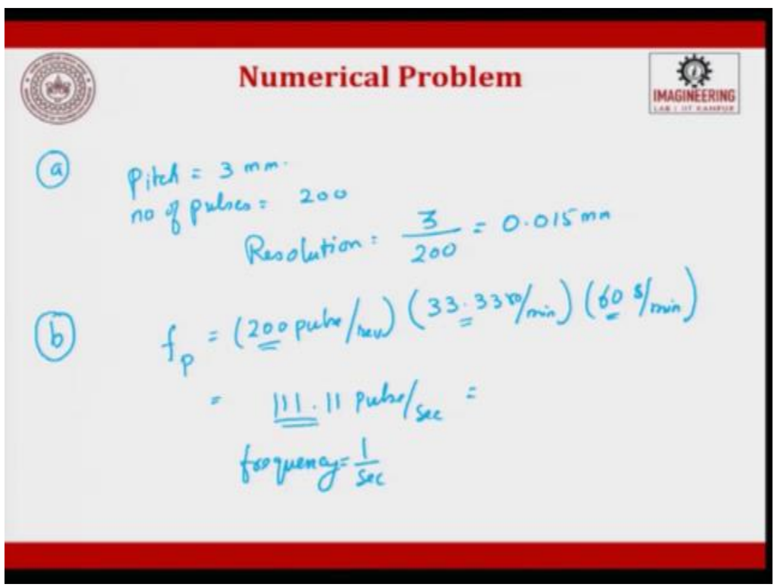

So, let us try to solve a problem so that we have a better understanding about this CNC and in reality you will have these specifications either given by the costumer or by the manufacturer. So, the problem goes like this, the shaft of a stepping motor, or a stepper motor is connected directly to the X axis lead screw of a machine table.

So, I have not specified any gear box is there in between, when there is a gearbox specified, gearbox should be taken as a waiting factor you will multiply that and you will get the result, but if it is not specified you take it as gear ratio 1 and start solving the problem. The pitch of the lead screw is 3 millimeter that means to say I rotate one time the motor my advancement will happen 3 millimeter. The number of step angle on the stepping motor is 200.

So, that means to say for 1 rotation, there you have to give 200 pulses to rotate 360 degrees. So, determined how closely the position of the table can be control, assuming there are no mechanical errors in the positioning system, this is an ideal case that is problem number 1. The problem number 2 is what is the required frequency of the pulsed train and the corresponding rotational speed of the stepping motor in order to drive the table at a traverse rate of 100 millimeter per minute, what is the frequency number of pulses required?

So, let us try to solve it so what was question number (a), question number (a) was to determine how closely the position of the table can be controlled. So, now for that what we have to do is, we know that pitch is 3 millimeter and the number of pulses is 200, so the resolution or the increment,

Resolution = 3/200 = 0.015 mm

How do you solve problem (b), what is problem (b)? You have to find out what is the required frequency.

So, you have to find out the frequency what is there. So, frequency can be defined as number of pulses per revolution into rotation per minute into 60 seconds per minute. So, you are just converting this is the pulse which is given, this is the rotation, rotation per minute which is given, and 60 is the rate with which it is given. So, it is seconds by minute.

So, frequency,

$$f_p = 200 * 33.33 * 60 = 111.11\, pulse/sec$$

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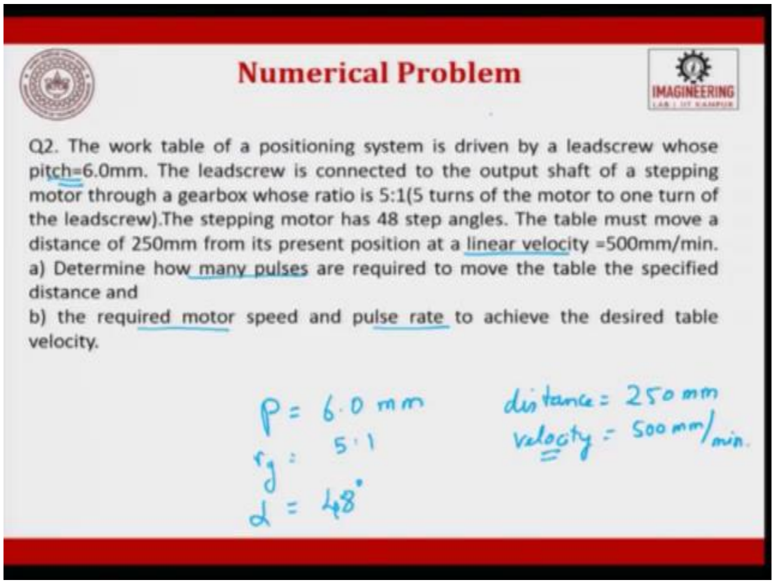

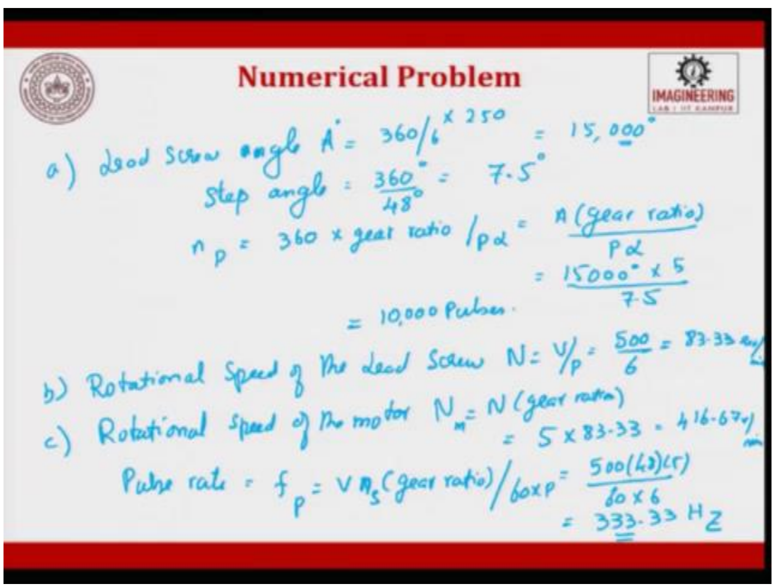

Let us try one more problem, the work table of a positioning system is driven by a lead screw whose pitch is equal to 6, pitch is 6, P is equal to 6 millimeter. The lead screw is connected to a output shaft of a stepping motor through a gearbox, gearbox ratio which is given as 5 is to 1. So, 5 turns of motor to 1 turn of lead screw.

So, it is trying to reduce, so will get a better resolution. The stepping motor has 48 step angle. So, angle, alpha is equal to 48 degrees, the table must move at a distance, the distance to be moved is equal to 250 millimeter from its present position at a velocity, linear velocity. Linear velocity is

500 millimeters per minute. So, now what are you supposed to do, you have to determine how many pluses are required to move the table, then and the required motors speed and plus rate to achieve the desired velocity. So, two problems have to be solved.

So, let us solve the problem. So, case number 1 is you have a lead screw, angle is nothing but,

$$A = \left(\frac{360}{6}\right) * 250 = 15000\ degrees$$

The stepping angle,

$$Step\ Angle = 360/48 = 7.5\ degrees$$

So, much of angle has to be rotated for 1 pulse you will go this much angle. So, the number of pulses n_p,

$$n_p = (360 * gear\ ratio)/p\alpha = 10000\ pulses$$

Let us try to solve (b), rotational speed of the lead screw, which is nothing but,

$$N = \frac{V}{p} = 83.33\ rev/min$$

So, when we have to do the (c) case, where in which we have to find out the pulse rate. So, rotational speed of the motor is,

$$N_m = N * (gear\ ratio) = 416.67\ rev/min$$

So, pulse rate,

$$f_p = \frac{500 * 48 * 5}{60 * 6} = 333.33\ Hz$$

So, we have found out the pulse and here 83, which is nothing but 416.67 revolutions per minute. So, this is how we try to solve the problem, in the examination you can expect some small trivial problems, where in which you can try to find out either the pulse rate or the velocity, or the gear ratio conversion, pitch, resolution, these are the some other possibilities you can expect during the examination.

So, it is, it will be good if you start looking at the problems and you also try to look at the formula and try to use your logic to solve it. I have solved it in one manner, you can, you have n number of ways to solve but the answer will be one, the answer will be one, unique that means to say unique. Thank you very much.