Computer Numerical Control of Machine Tools and Processes
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Lecture 1
Introduction to Computer Control - Role of Computers in Automation

Welcome viewers, today we are going to start the first lecture of Computer numerical control of machine tools and processes. My name is A Roy Choudhury and I am a professor in the mechanical engineering Department of IIT Kharagpur. So 1st of all computer numerical control, what does it mean?

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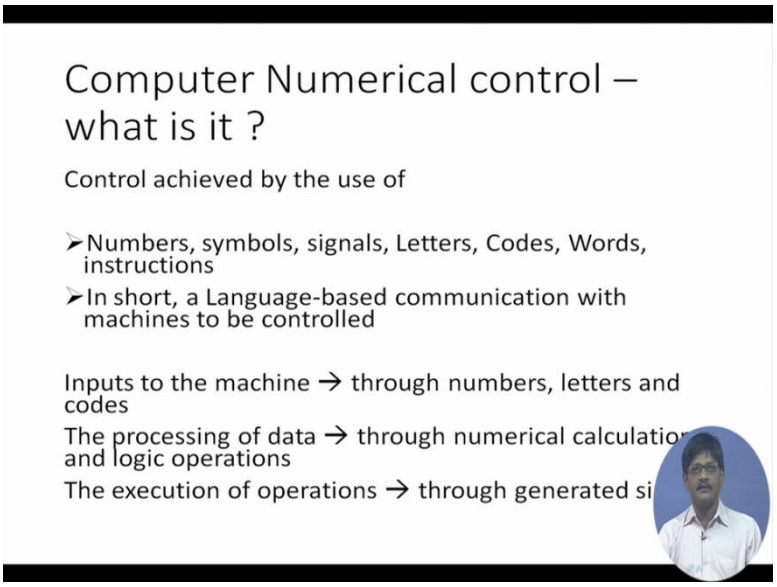

It means that control of a particular machine tool or a process is achieved by insertion of or use of number, symbols, signals, letters, codes, words, instructions. In other words in short, the communication with the machine in the form of a language. Previously, machine and human interaction used to take place through physical devices like cams, tracers, templates, so it was not very sophisticated, but now with the advent of numerical control and computer numerical control, a sort of language communication was started with machine tools and processes. So in what way can this happen?

It can happen in the form of input to the machine, data input through numbers, letters, codes, this data can be processed inside the machine through numerical calculations, logic operations and execution of operations can be carried out through generated signals from the computer or from some control circuit in the form of voltage signals, et cetera et cetera. So what is the connection between numerical control, computer numerical control, etc?

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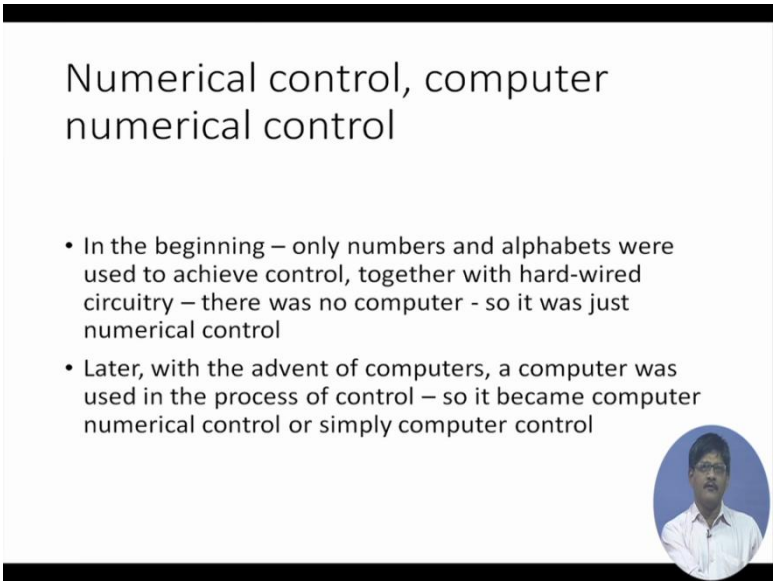

So in the beginning what happened was there was no computer to start with and we had numerical controlled machines in which numbers and alphabets were used in the form of codes to feed information into a machine. And for that, at 1st these machines were called or they were referred to as numerical controlled machines. Inside, they were primarily consisting of hard wired logic circuitry and after the advent of computers, data entry became easier through the computers, hardwired circuitry, logic circuit, et cetera sometimes were replaced by software. And control inside the control loops the computer also used to participate in order to improve the control characteristics, so it became known as computer numerical control or simply computer control.

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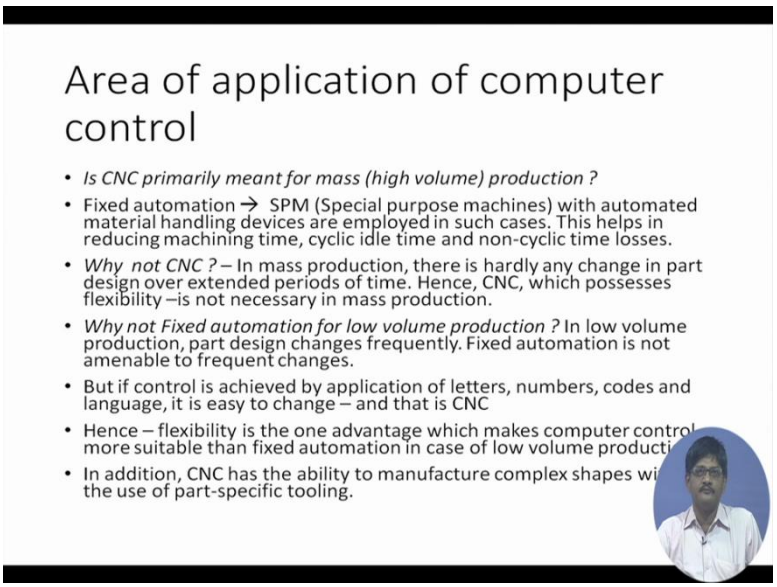

What is the area of application of computer control? Do we understand that say in mass production that is high-volume production, lots of pieces made in a particular span of times a like 1 lakh pieces in one year, so in mass production would CNC or computer numerical control be suitable? Here surprisingly it is not so, why because mass production finds the application of fixed automation that means fixed means machines which are they can only carry out certain operations and nothing else. Special-purpose machines, special purpose machines find wide applications in mass production together with automated material handling devices, why so?

This is because in case of mass production there is not much change in part design over extended periods of time. There what we find is, a huge number of pieces have to be made again and again repeatedly over long periods of time, so a computer which is primarily meant for flexible communication or changeable communication with machines, it does not find wide application in this particular area. Not much change is there with time, so we generally go for systems which are exactly dedicated for that particular purpose. Special-purpose machine for example, camshaft grinding machine, you can only grind camshafts and nothing else.

So that is why in mass production CNC is not very suitable, CNC's strong point is it can be changed very easily why because it is consisting of language instructions, it is consisting of numerical calculations and logic operations inside the machine, these things are not very difficult to change if the requirements change. And why not fixed automation for low-volume production, by low-volume production I mean small lot and batch production and even piece production.

This is because fixed automation has dedicated machines, so if you dedicate some machines, build them for very small number of pieces, after that part design becomes gets changed to a different part, you have no use for that particular fixed automation, it becomes obsolete that is why if you have low-volume production, you cannot implement fixed automation or dedicated material handling system in that case, you cannot automate it with fixed automation. In that case, CNC becomes highly applicable because if you are wanting automation, make programs on the CNC machine which can which can produce those parts and when the parts changes, part design changes because it is low-volume small amounts, small number of different jobs one after the other.

So when the parts design changes, make a separate program for the next part and start running the machine where the cost for change over will be much-much less in this case, so we understand that for low-volume productions for small lot and batch production, etc CNC would prove to be highly appropriate. Also, we should not I think I should mention here at this moment that CNC also has the ability to manufacture complex shapes okay without parts specific tooling. Parts specific tooling means say foam tools, if you if you want to make a very difficult profile, make a foam tool conjugate profile and machine that particular part, so you incur a lot of costs for the tooling.

The CNC's, it is not the tool shape that produces the conjugate shape on the part, but the tool movements properly controlled by the computer can produce very complex shapes, this is an added ability of the CNC machine. Let us see how the control is achieved in case of CNC.

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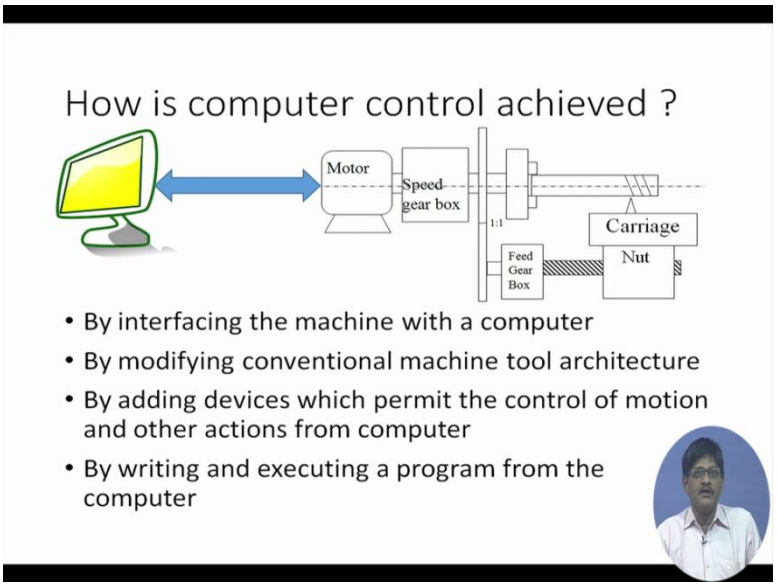

There you can find I have drawn a monitor to represent the computer and from the computer there is some signal, which can directly control a motor, but is this a CNC machine? It is not, I have intentionally drawn a conventionally control lead okay operator run lead on which you will see some equipments like speed gearbox, feed gearbox, carriage, nuts, et cetera, it is not a CNC machine. So in order to achieve control over a machine 1st of all a computer has to be there, it has to be interfaced with the machine and the conventional machine tool architecture has to be changed.

So we will find some changes taking place in this particular architecture and apart from that there should be the addition or incorporation of some devices which can control the motion

and the extent of motion, I mean rate of motion and the extent of motion. And also, we have to ultimately write a program on the computer and execute it so that it develops proper signals to the motor and other devices of the machine in order to control it; this is how computer control is achieved. So comes a question actually what is a CNC program.

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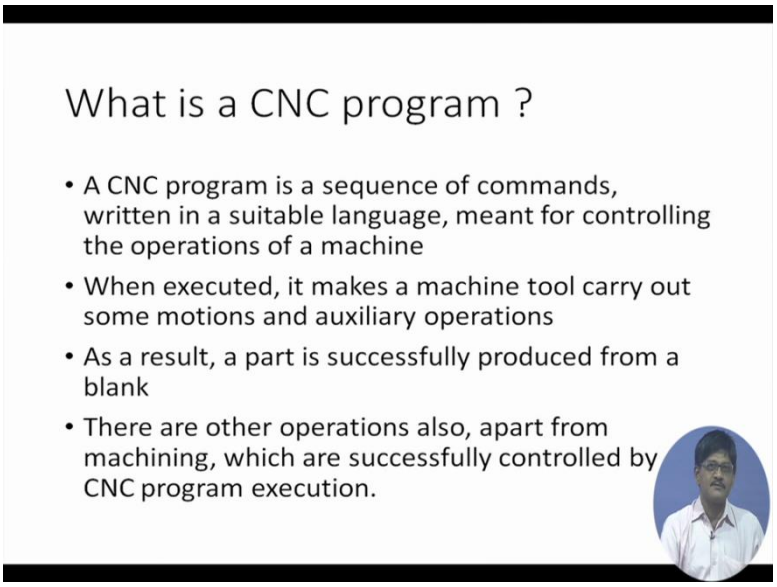

A CNC program is a sequence of commands just like we give a sequence of commands to someone to carry out some operation, it is just a sequence of commands, it is written in suitable language and it is meant for controlling the operations of a machine. When executed, it makes a machine to carry out some motions and auxiliary operations. Generally by motion I have meant here say fast motion to approach a particular point and then say starting a linear cut at a controlled rate, then taking circular cuts either clockwise or counter clockwise at a definite feed rate.

And also there can be auxiliary operations for tool changing for changing a job and bringing in another palette containing another blank like that. And this way, when a computer program is executed it will ultimately lead to a part being successfully produced from a black. And CNC program ultimately does not necessarily mean that it is only for controlling the operations of a machine tool, but it can be used employed for controlling other general-purpose machines, other general machines as well.

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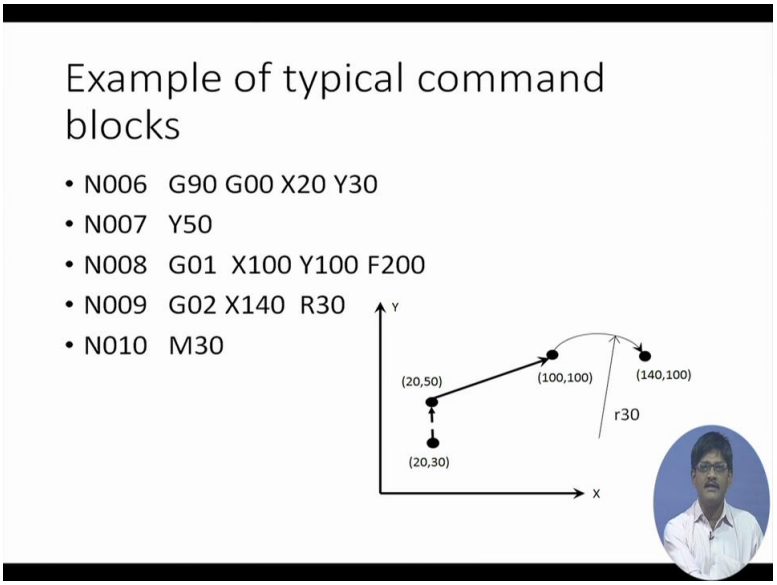

This is an example of a typical some command blocks taken from a CNC machine, what does it show? The 1st column shows the line number N006, N007, et cetera. After that we have a number of codes placed one after the other, what are these codes? For example, G90, G90 means whenever there is a coordinate system existing, on that coordinate system we are supposed to refer to the absolute X and Y coordinate values of a particular point. So we have a coordinate system in front of us and we can see that X and Y is written there and in that X-Y coordinate space, G00 means that we are supposed to reach a target coordinate position given by X20 Y30.

So it basically means move fast, G00 means rapid travel to the target point, no velocity is mentioned because generally the machine moves at the highest possible velocity. So move fast to the point X20 Y30. After that we are supposed to move in the next command we are supposed to move to the point Y50, why is X not mentioned because it is not changed, so X remains the same and we and we change the Y coordinate to 50 from 30, which means we are now at the point 20, 50 and we have executed a vertical motion. After this vertical motion at 20 50, after that it is written G01 X100 Y 100 F200, what does this mean?

G01 is a code for linear motion that means straight-line motion at a particular feed rate that means at a particular rate of motion, the rate of motion is mentioned as F feed, it is called the feed word, 200 means if not otherwise defined 200 millimetres per minute, so the target point is mentioned as X100 Y100, so we reach the target point 100, 100 from the point 20, 50 at the rate of 200 millimetres per minute. Next line is G02, G02 means circular interpolation

clockwise, so we move from the present position of 100, 100 to the point X140 okay and as Y is not, Y remains the same and the radius with which we move is 30 millimetres okay.

So we reach this particular point at the same speed defined in the previous line to the point 140, 100 from the point 100, 100 with a circular radius of 30 millimetres in the clockwise direction. Is there any other possibility of reaching this particular point? There is, but unless otherwise mentioned it will take this particular what you call it minor arc, there is a major arc possible also with 30 millimetres clockwise that is not taken. M30 means end of program, so this is a typical example of command block of a CNC machine.

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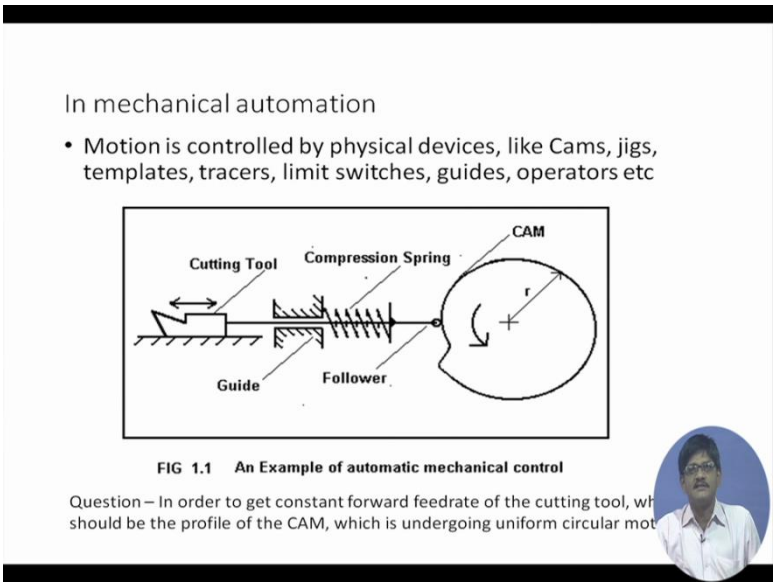

Now that we have started discussing on CNC machines, computers were not there throughout the ages and we did not have NC machines also beyond in the past say 70 years back or even more than that. So at that time how were automatic operations executed on machine tools? This is one example of mechanical automation, it means some sort of clockwork mechanised motions were carried out without the help of computers, without the help of numerical instructions, codes, language, et cetera, simply physical devices were used. It means something like if you want to command someone, you can tell him or her or you can push him or push her to do that particular task.

Physical devices, so here we see a cam, cam is a device, in which we have shown a disk like cam, which has a profile on its Perry ferry which deviates from a circle so that if it is rotating, it will move anything in connection with it readily outward. So here we have something called as follower which is pressed against the cam with the help of a compression spring and

then that cam move in a uniform circular motion in a counter clockwise direction it will tend to push the follower, and then suddenly the follower will fall back when the fall of the cam of the or drop of the cam along the radius takes place.

So it will push the cutting tool also towards the left side continuously and then suddenly it will retract, so this is the scheme of motion of the cutting tool which has been planned with the help of this particular cam. Is there a computer controlling it? No. Is there automatic motion getting repeated again and again and again? Yes. What is the purpose of this motion? Maybe it is moving forward parting some parting some job and then again retracting very fast, the job is getting fed again, so this continues unless something wears out, either the tool wears out or power goes off or the cam undergoes wear and tear, so this is a perfect example of an automatic machine by mechanical control okay.

So this also exists without computers automation. And it is a question given that is what should be the profile of the cam in order that we will have a constant forward feed of the cutting tool, what should be the profile of a cam, the answer is Archimedean spiral, you can try this out yourself. So coming back to computer-controlled machines now, we have seen the example of mechanical controls being achieved in case of automation. So how do computer-controlled machines carry out this particular control?

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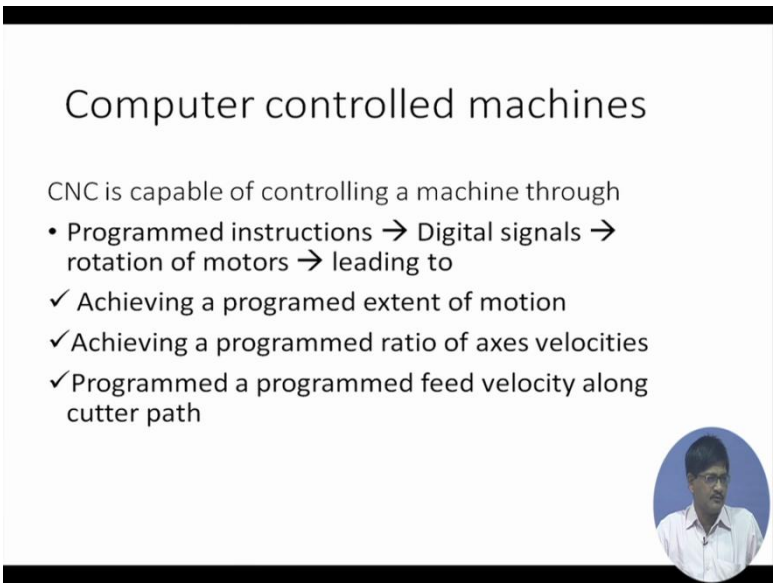

In computer-controlled machines, instead of devices like cam, et cetera, there are programmed instructions which go inside the machine and I mean when they are executed the program instructions, they develop digital signals which might be ultimately rotating motors

at a definite rate and this leads to achieving a definite extent of motion and achieving a particular ratio of the of the axes velocities okay. And also it results in attainment of programmed feed velocity along a cutter path.

Why be so much concerned about the program ratio of axes velocities, because that is ultimately the particular parameter which determines the path taken by the tool, which ultimately defines the profile of the path being machined. Here there are no physical devices but the path of the tool defines the profile of the job. So we have been talking about digital signals, binary logic, logic gates, digital circuitry, quite a lot, what do we exactly mean? Many of you might be conversant with digital circuitry, digital logic.

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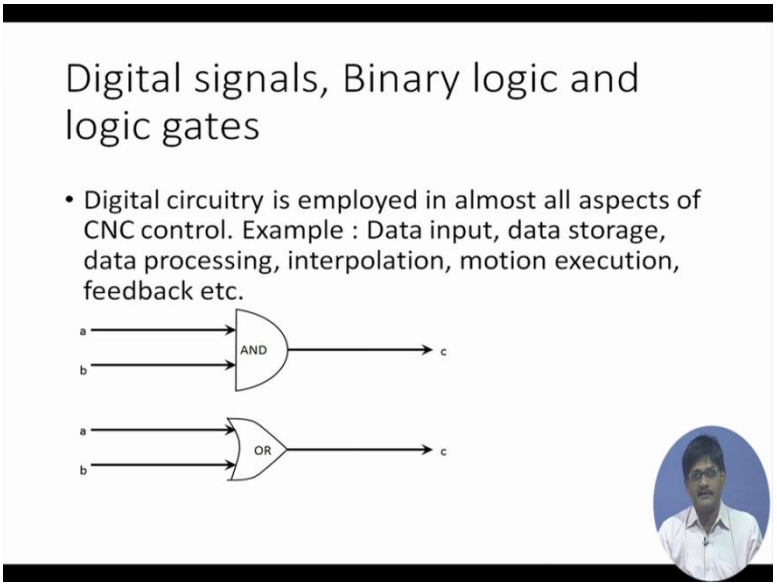

In case you do not have an introduction formal introduction to this particular subject, we will be taking up in the next lecture some aspects of digital logic and hopefully you will be able to follow the later part of the other lectures which involves some discussion on logic circuitry. What we have shown here is this that digital circuitry will be employed in many aspects of CNC control like data input, data storage, data processing, interpolation, motion execution, et cetera. in the figure we have shown 2 typical logic gates and how do we read them?

Like a and b if there are 2 inputs which can only take up 2 values like say high value and low value, AND gate is a gate which controls the relation mainly in such a way that c is going to get a high value only if both a and b are some ultimately high, this is called AND gate, that means say x and y if both are high, then only z is high, z is the output. In the same way OR gate is a little more lenient, it says that if a is high and b is high or any of anyone of them is

high, then the output is high. In 3 cases, a and b both are high, a is high, b is high, in these 3 cases the output will be high, when both are low then the output will be low, so we will have some more discussions on logic gates, they are not exactly mathematical operations but logic operations.

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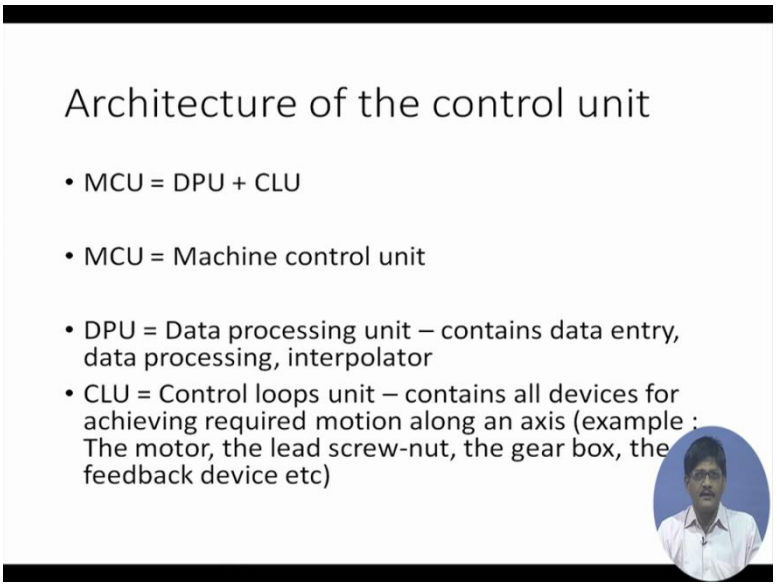

Now that we are a little we have gone into the discussions of CNC machine, let us see what is the architecture of the control unit that is what is there inside which has all the controls. The control unit is frequently referred to as machine control unit, which contains 2 different what modules; one is the Data processing unit and another is the Control loops unit, what does the Data processing unit do? It is concerned with data entry, data processing that means all sorts of calculations involving the data and also interpolation.

Interpolation means that you are instructing a machine to move on a say circular path or a linear path from one point to another, but you are not instructing it about what sorts of velocities and positions it is supposed to attain in between, so somebody has to do the calculation and there is a device called interpolator inside the data processing unit, which does all this calculation and finds out the intermediate positions and velocities of the tool okay, in order to cover the intermediate path between 2 program points. The Control loops unit, it contains all the devices for achieving required motion along an axis for example, it might involve the actual motor, the prime mover, the lead screw nut, the gearbox, all these things are together referred to as a Control loops unit.

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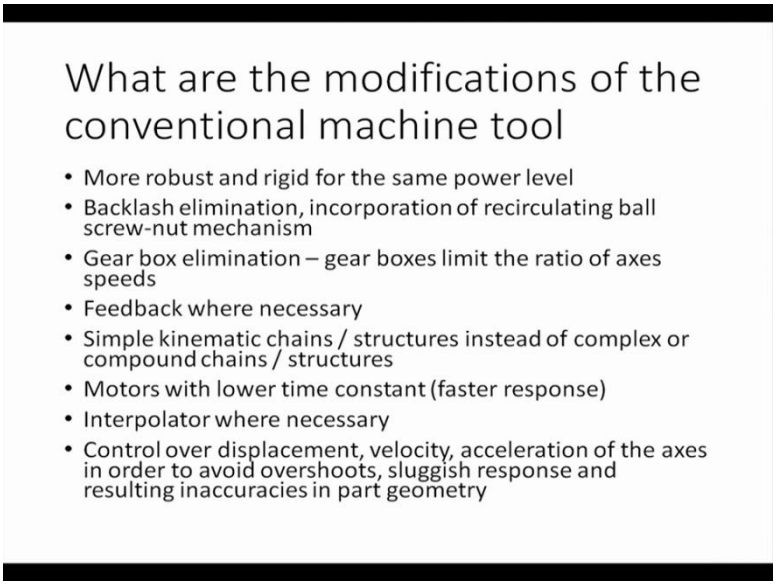

And now that we are talking of, we had referred to the modifications of the conventional machine tools in order to achieve CNC machining, so let us have a look at that water these? For example, the machine has to be more robust and rigid for the same power level why because deflections et cetera should be less so that errors are less. Are deflections there in other machines? There is but there are physical devices to ensure that the movement et cetera are exactly carried out. Here we are depending upon; in CNC we are depending upon the accuracy of the movement, et cetera in order to achieve a particular accuracy on the job.

Backlash elimination has to be there, motions here have to be completely free of backlash and for that a number of devices need to be incorporated for example, the recirculation ball screw-nut mechanism. Gearboxes which establish definite ratios of motion between axis of motion in a particular machine, these gear boxes limit the ratios of between axes speed and therefore, they are generally eliminated, but gearboxes for attainment of a particular range of speeds that has to be there. Feedback is sometimes necessary where the prime mover is not capable of carrying out exact motions as required by the program. And generally from a complex or compound chains or structures, we generally go for simple kinematic chains, which mean we will be discussing these things in more detail.

And motors with lower time constants are preferred referred which have faster response, interpolator is our necessary in case of continuous control. And we need to have machines which have more where overshoots and sluggish response can be avoided that means that means the dynamic constant of the machine have to be so designed so that overshoots are less and sluggish response is avoided, et cetera.

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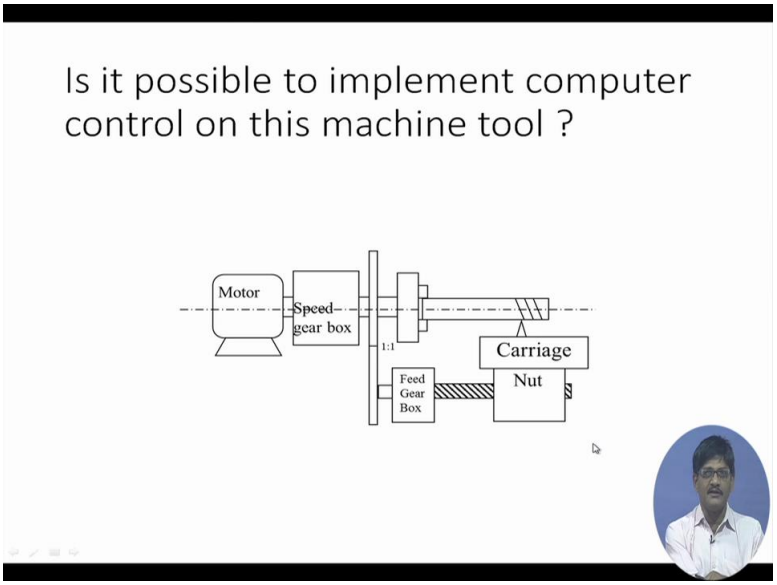

So in this machine is we want to implement computer control, we can see that there is a chain moving from the top up to the spindle and there is also power flowing this way so that the same motor through gearboxes is controlling 2 motions, this has to be removed and a separate motor has to be put for the feed motion, so one motor for the feed motion, one motor for the speed motion and yet another motor would be required for a cross feed, one for Cross field, one for longitudinally feed okay.

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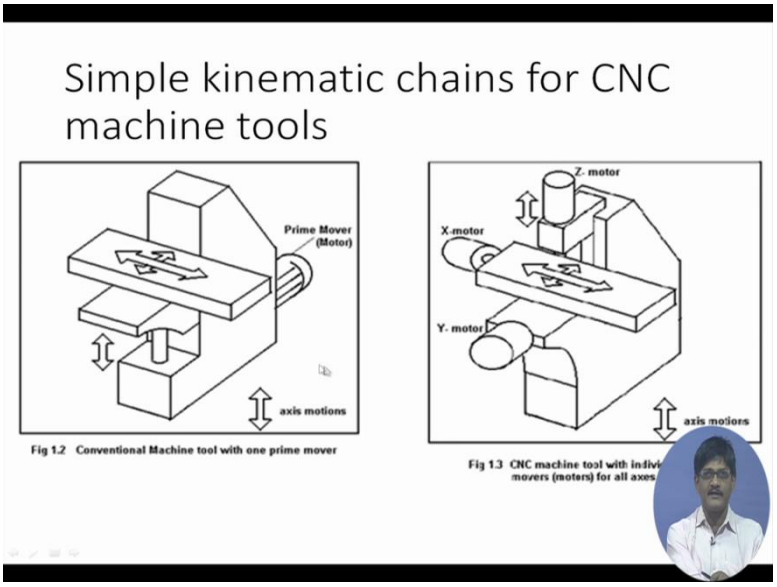

For example, you would see a milling machine in which we have 3 motions X, Y and Z and there is a motor which is also providing the cutting speed. Instead of this, on the CNC

machine we will find one motor for X, one motor for Y, one motor for Z and also separate motor for a rotation of the cutter.

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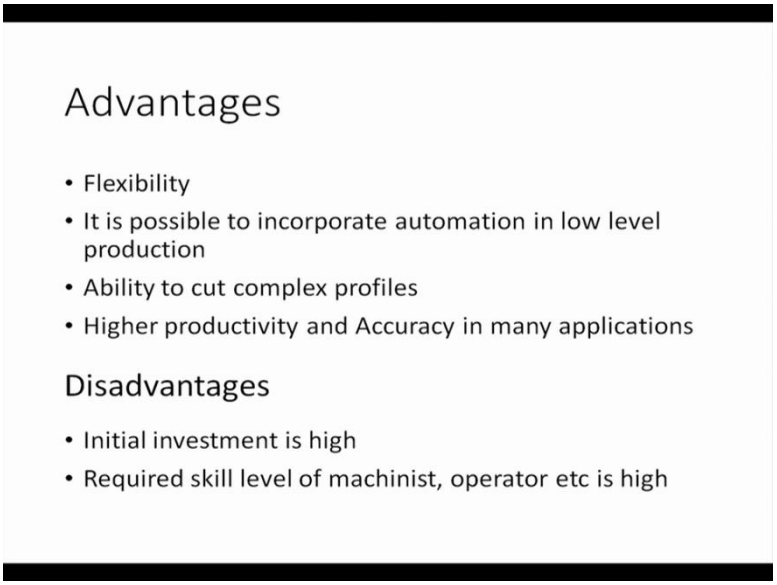

So finally let us look at the advantages of the CNC machine. It is more flexible, it is possible to incorporate automation in low-level production, we have the ability to cut complex profile and in many applications we can attain higher productivity and accuracy. The disadvantage is that the initial investment is very high and required skill level of machinist, operator, et cetera is high.

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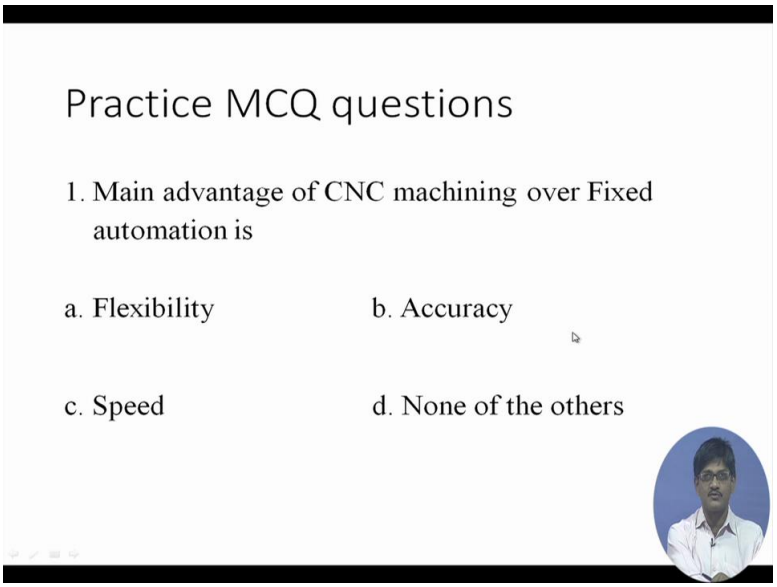

There is one practice question, main advantage of CNC machining over fixed automation is flexibility, accuracy, speed, none of the other, and the answer is flexibility, thank you very much.